PACIFIC
LOCOMOTIVE COMMITTEE
REPORT

1939

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PACIFIC LOCOMOTIVE COMMITTEE.

CHAPTER I.

INTRODUCTORY.

London, the 31st March 1939.

To

HIS EXCELLENCY THE MOST HONOURABLE THE
GOVERNOR-GENERAL OF INDIA IN COUNCIL,
NEW DELHI.

SIR,

We have the honour to present the report of the Pacific Locomotive Committee.

2. *Appointment and Terms of Reference.*—The appointment of our Committee was intimated in the Government of India Press Communiqué, which was published simultaneously by the Secretary of State for India in London and by the Government of India in India on 26th July, 1938.

The Committee was constituted as follows:—

Lt.-Colonel A. H. L. Mount, C.B., C.B.E., R.E. (Retd.), M.Inst.C.E., M.Inst.T., Chief Inspecting Officer of Railways, Ministry of Transport, *Chairman.*

Mr. R. Carpmael, O.B.E., M.Inst.C.E., M.I.Mech.E., M.Inst.T., Chief Engineer (Civil), Great Western Railway.

Rai Bahadur P. L. Dhawan, C.I.E., M.A., M.I.E. (India), former Chief Engineer (Civil), North Western Railway, now Member, Federal Public Service Commission.

Monsieur Robert Léguille, Regional Chief Mechanical Engineer, French National Railways.

Mr. W. A. Stanier, M.I.Mech.E., M.I.Loco.E., Chief Mechanical Engineer, London Midland & Scottish Railway.

The Committee was assisted by Mr. E. S. Cox, A.M.I.Mech.E., M.I.Loco.E., Technical Assistant to the Chief Mechanical Engineer, London Midland & Scottish Railway.

Mr. K. C. Bakhle, B.Sc. (Lond.), M.I.E. (India), Divisional Engineer, Great Indian Peninsula Railway, was appointed Secretary to the Committee.

Messrs. Carpmael, Léguille and Cox had not previously visited India.

Our terms of reference were:—

"*To consider the design and operation of three classes of engines, viz. XA, XB and XC types, and to advise on:—*

(*1*) *the suitability of the designs, as originally framed and as subsequently modified, for the type of work for which the engines were intended;*

(*2*) *the suitability of the procedure followed in preparing and approving the designs for these engines;*

(*3*) *the circumstances attending, and the justification for, the initial and subsequent purchases of these engines;*

(*4*) *the conditions subject to which these engines can be used with safety, with particular reference to their suitability for the track on which they are required to run, and, conversely, the suitability of the track for these types of engine;*

(5) *any modifications which would have the effect of increasing their scope without any sacrifice of safety; and*

(6) *any modifications that should be made in the procedure hitherto followed for the trial and purchase of engines.*"

3. *Activities and Tour of the Committee.*—During the months of July and August, 7 meetings were held in London, and 10 persons in all were interviewed, including representatives of Consulting Engineers and certain serving and retired officers of Indian Railways. In accordance with the suggestion of the Government of India, we assembled in Bombay on 1st September, and our tour lasted for six weeks from 2nd September till 14th October inclusive; it thus coincided with the latter part of the monsoon, which gave us the benefit of observing the effect of the rains on the permanent way in various parts of the country.

The following was our itinerary :—

Bombay—Madras	Over the G. I. P. R. and M. & S. M. R.
Madras—Shoranur—Madras	Over the M. & S. M. R. and S. I. R.
Madras—Secunderabad	Over the M. & S. M. R. and N. S. R.
Secunderabad—Bhusawal	Over the N. S. R. and G. I. P. R.
Bhusawal—Moghalsarai—Dinapore—Calcutta	Over the G. I. P. R. and E. I. R.
Calcutta—Ranaghat—Calcutta	Over the E. B. R.
Calcutta—Khargpur—Dantan—Calcutta	Over the B. N. R.
Calcutta—Lucknow—Agra	Over the E. I. R.
Agra—Delhi—Lahore	Over the G. I. P. R. and N. W. R.
Lahore—Simla	Over the N. W. R.
Simla—Delhi—Bombay	Over the N. W. R. and B., B. & C. I. R.

We travelled nearly 7,000 miles by rail, and made our headquarters for most of the time in a special train which the Government of India kindly placed at our disposal. We were accompanied by certain General Managers and by the principal Civil and Mechanical Engineers of the different Railway Administrations; also by some of the Senior Government Inspectors.

During our tour, we interviewed 63 officers, representing the Railway Board, the Central Standards Office, and the nine Railway Administrations referred to above. We also had the benefit of hearing evidence from the Chief Controller, Indian Stores Department, and from the Senior Government Inspectors of Circles Nos. 1, 4, 5 and 7. The limited time available and the circumstances of the investigation made it impossible to record verbatim the proceedings of the 36 meetings and of the many other discussions which we held; but, so far as was practicable, agreed notes were made of all important statements. No evidence was heard in public.

We visited the following locomotive workshops :—

September—		
2nd	Parel	G. I. P. R.
5th	Perambur	M. & S. M. R.
10th	Lallaguda	N. S. R.
15th	Jamalpur	E. I. R.
21st	Khargpur	B. N. R.
24th	Lucknow	E. I. R.
28th	Moghalpura	N. W. R.
October—		
13th	Dohad	B., B. & C. I. R.

We visited the following locomotive running sheds :—

September—		
7th	Erode	S. I. R.
9th	Arkonam	M. & S. M. R.
10th	Lallaguda	N. S. R.
15th	Bhusawal	G. I. P. R.
19th	Chitpore	E. B. R.
21st	Khargpur	B. N. R.
22nd	Asansol	E. I. R.

We also visited the Engineering Workshops at Arkonam, M. & S. M. R.; the timber sleeper Creosoting Depot at Dhilwan, N. W. R.; and the Walton Training School at Lahore, N. W. R.

We covered some 3,100 miles on the footplates of 29 engines of different types; at the same time the condition of the track over this mileage was observed by a Hallade Recorder, which was situated in the same vehicle throughout the tour. Numerous detailed inspections were also made, by trolley and otherwise, of the many varieties of permanent way. We are satisfied that generally no preparations were made to present conditions, either in respect of engine or track, in an unduly favourable light.

Further, we had opportunities of examining representative experiments made by officers from the Central Standards Office, to assess the extent of flange forces and to determine their effect on track; these were carried out between Akola and Bhusawal, on notoriously difficult black cotton formation of the G. I. P. R., and at Moghalsarai on the E. I. R.

We sailed from Bombay on 15th October, and reached London a fortnight later. During November we held 7 further meetings, which were attended by 23 representatives of Consulting Engineers, and of Locomotive Builders; also certain retired officers of Indian Railways. During the course of this Inquiry, therefore, apart from many inspections and informal interviews, we held altogether 50 meetings, at which we met 89 persons for the purpose of discussing our terms of reference.

4. *Acknowledgments.*—We desire to express our obligations to all those who, by their representations or evidence, have materially facilitated our investigation of the problems which confronted us. We also wish to express our appreciation of the care and trouble taken by officers of the Railway Board, and by Consulting Engineers, in preparing the mass of information regarding the history, design, purchase and trials of locomotives of the Pacific type, covering the long period since they were introduced into India.

Our acknowledgments are due to the General Managers of the Administrations, who placed office accommodation at our disposal, and made such complete arrangements for the handling of the special train and for hauling it with engines in various conditions of maintenance and design; as also for our numerous inspections on the footplate and of workshops, running sheds and track. We are also indebted to the Railway Board and to individual Administrations for so promptly presenting all documents and information required by us in the course of this Inquiry.

We desire to acknowledge the ability and efficiency of our Secretary, Mr. K. C. Bakhle; he has been untiring in his attention to the business of the Committee, and his technical experience as an Engineer has been of great value. He joined the Committee on 1st September and accompanied us to London, where we completed our inquiries and this Report.

We have also to thank the clerical staff, in India and in London, the operators of the Hallade Recorder, and the other staff on our special train, for the conscientious manner in which they carried out their duties under considerable pressure.

The foregoing references cover those to whom our thanks are chiefly due, but we should like here to include in our acknowledgments the many railwaymen of all grades, with whom we came in contact, and who, by their interest or assistance, materially aided the Inquiry.

The General Aspect of the Problem.

Before we proceed to deal with our specific terms of reference, it may help towards a clearer understanding of the various matters, to which we shall make reference, if we state, as briefly and as simply as possible, our views on the general aspect of the problem on which we are asked to advise.

5. *Relationship between rolling stock and track.*—The most important consideration in the investigation of the performance of a locomotive as a

vehicle, and of the track upon which it runs, is that they are in effect two parts of the same machine. The essential feature of an engine in this respect is that it should run smoothly and steadily, subjecting the track to a minimum of stress at the highest designed speed. The track should also be laid on such a formation, and be so constructed and maintained, that it is able to resist, without effective distortion, the forces imposed upon it at that speed.

Much has been written about the relationship between rolling stock and track. It is well known that if, on the one hand, engine design is effective, rails may be broken, the gauge may be spread, or the road as a whole may be distorted, although the track itself is good; in such cases, whilst derailment may not result, the engine is exceedingly mischievous in its effects and is therefore unsatisfactory as a vehicle. On the other hand, if the track is badly designed, weak, or inefficiently maintained, the same effects may become apparent, even if the locomotive has been correctly designed and carefully maintained.

6. *Permanent Way.*—The locomotive itself is subjected to two forms of disturbance arising respectively from external and internal forces. External disturbances in the smooth running of the engine will be initiated if the permanent way is uneven; if it is also weak, these disturbances may obtain sufficient magnitude to cause displacement to a greater or less degree. Again, substantial and well maintained track may mask the lateral instability of a locomotive, so that it may appear to be a good riding engine, and yet it may prove unsatisfactory when running on weaker track or over more yielding formation.

It is axiomatic that no track can be so perfectly designed and maintained that it will not contain some irregularities, however minute; and, similarly, no engine can be so perfectly designed that it will not respond in some measure to these inequalities. Apart from mere physical imperfections, it must also be borne in mind that permanent way is, by its very nature, an elastic structure which can never be completely unyielding. The difference between good and bad track is, therefore, one of degree, and any vehicle which is intended to run thereon must be so designed that the effect of track imperfections on its stability is reduced to a minimum.

7. *Locomotive design.*—When the natural features of a country add to the difficulty in maintaining the road-bed, there is the more need to pay attention to the design of the locomotive as a vehicle; the features of a given country are inescapable, and the engines provided must be made to run satisfactorily under the prevailing conditions. The task of the designer and builder is not only to provide an engine which can pull a train, but also to reduce to the lowest possible point the effects of the external disturbing agencies due to defects in the track, which can never be perfectly level or smooth. It is not enough to obtain sufficient boiler horse power with a large firebox to burn inferior coal; the design of the engine as a vehicle, capable of high speed over track as normally maintained, is an equally important matter.

Because the permanent way and its supporting formation, and the wheels and frame of the engine, are all elastic in varying degrees, there has always been difficulty in calculating the actual forces involved. It is well known that different locomotives, doing the same work, on the same road, and at the same speeds, have widely differing effects on the permanent way; all through the history of the locomotive, cases have occurred from time to time, in all countries, where particular types of engine have been found to behave unfavourably, and have had to be altered. Too much stiffness, too much flexibility, bad springing systems, bad weight distribution, and inappropriate wheel arrangements may individually contribute to the damage, usually in conjunction with excessive speed.

8. *Examples of unsatisfactory design.*—In England, in the early days of railways, such cases were not infrequent; there was the "Great Liverpool" designed by Crampton in the 1850's for the London and Birmingham Railway, which broke rails and could not be used. Early in the 1890's,

certain 0-4-4 type tank engines on the Great Western Railway were converted to 4-4-0 tender engines, as the result of excessive oscillation. More recently, on the Southern Railway, may be cited the "River" class tank engines, 2-6-4 type, which became derailed on three occasions in 1927 at Sevenoaks, Bearsted and Wrotham. These engines were oversensitive to track irregularities, and in such circumstances reacted dangerously by rolling when speed was high; trouble ceased, however, when the trailing bogie was removed and the type converted to a 2-6-0 tender engine.

Similarly, the mixed traffic tank engines, 0-6-4 type, of the L. M. S. R., which were derailed at Swinderby in 1928, and at Moira and at Ashton in 1935, afford another example of unusual sympathy to track defects, so that distortion and hunting occurred at high speed; such of these engines as were not subsequently scrapped, were relegated to slow speed goods work. Another case of unsuitable wheel arrangement was that of the 4-4-4 type 3-cylinder tank engines of the L. N. E. R., which were prone to excessive hunting; this was cured by converting them to 4-6-2 tank type. In France, some years ago, an electric locomotive of the B+B type was also subject to this unforeseen defect, which was only overcome by providing a spring controlled articulated connection between the bogies; this alteration resulted in increased speed with a greater margin of safety.

The foregoing examples, although not strictly parallel to the case before us, are quoted to show that improvement in locomotive design has been largely a matter of experience, trial and error, and profiting by the mistakes of others. With demands for higher speed, increased axle loading, and heavier trains, the relationship between track and vehicle is undergoing close and scientific research. It must also be borne in mind that track design differs from structural design, owing to the obscure nature of the stresses, which have not yet been completely determined. Until recently, standards of track, like some of those relating to the locomotive, have been evolved as the result of experience and economic limitations, often unrelated to any scientific basis.

9. *Research.*—Experimental work on track stresses has been carried out on the Continent, in America, and in India; there is no doubt that this line of approach is yielding very valuable results, which will be referred to later in more detail. In France, in particular, tests have been undertaken for several years with numerous types of locomotives, steam and electric; the forces and displacements between wheel and rail, both vertical and horizontal, have been recorded. Complementary to the determination of vehicle stability characteristics, special vehicles have also been fitted up to register continuously the characteristics of the track, *viz.* superelevation, alignment and level. Thus the peculiarities of the state of the permanent way, which are so important in their influence, are determined simultaneously, and the stability of the vehicle is directly assessed in relation thereto. In France, further tests have been developed to determine, as accurately as possible, lateral movements of track under load. In the course of day-to-day maintenance, it is also becoming the practice in several countries to determine, and limit, the vertical movements of sleepers under load by the use of void meters and measured shovel packing.

10. *Track maintenance.*—The importance of this cannot be overstressed in connection with speed; even first-class permanent way material, perfectly installed and in perfect alignment, will soon give disappointing results if the standard of maintenance is permitted to fall. Minor defects, of little consequence when speed is low, may become of serious moment when speed exceeds 50 m.p.h. and when axle loads exceed 17 tons. Under similar conditions, the blow caused by a lurch at 70 m.p.h. is almost twice as great as it is at 50 m.p.h. In fact, good running can only be maintained by constant attention to apparently small defects; if these are neglected, the standard rapidly deteriorates and track damage, or worse, results. No track, however suitable in design, can be efficiently maintained to carry high speed heavy traffic unless it is properly supported on a stable and well drained formation. On account, however, of many variable

factors, such as weather, formation, and strength of track material, it is not possible to attain a degree of precision in permanent way maintenance, which is comparable to the standards of mechanical engineering in the locomotive.

11. *The Economic Aspect.*—Further, the economic aspect of the problem cannot be overlooked. The type of permanent way material, and the cost of maintenance, are closely related to the speed, frequency, and weight of trains. Maintenance is influenced by the capacity of the rails to carry the loads, by the number of sleepers over which the load can be distributed, and by the nature of the formation on which the sleepers are laid. The formation, in turn, is influenced as much by good drainage as by the nature of the subsoil and the depth and quality of the ballast. It follows that speed is limited by conditions of formation, drainage, ballast, and type of permanent way material, however good the standard of maintenance. Compromise, therefore, based on experience always becomes necessary, and if higher speeds and heavier loads are required, the standards of both construction and maintenance must be correspondingly raised for the same factor of safety.

12. *Springing and Control of the Locomotive.*—It is hardly necessary to say that the locomotive is confined to its path vertically by its own weight, and horizontally by the flanges on its wheels; but these considerations are fundamental to the problem before us, in that impact forces are set up on the wheels and track in both horizontal and vertical planes. To relieve the rail of excessive stress, it is necessary to mount as much as possible of the weight of the engine on springs, and movement of the spring-borne mass is inevitable; the design and maintenance of the engine in this respect affects the problem. Further, to enable the engine to run satisfactorily, clearances have to be provided between flange and rail, between frame and axleboxes, etc. The state of maintenance of such clearances is also a matter of importance.

In its simplest form, the whole of the locomotive is carried on its coupled wheels, and the frame is the structure which links up the various forces involved; it must so compromise between flexibility and rigidity as to avoid cracking or fracture, and experience guides the designer as to the best proportions for the particular material. As engines got larger and more powerful, the impact forces increased, and those with lateral effect would have become excessive had the coupled wheel flanges alone been left to transmit the forces to the track. Carrying wheels were, therefore, introduced in the form of Bogie and Bissel trucks, and they require special consideration in connection with the problem of hunting. Their chief function, besides guiding the engine round curves, is to ensure a measure of centring force and to hold the centre line of the engine parallel to the track. In practice, there are different ways of providing this essential side control, which is such an important factor in the lateral stability of the engine; the selection of the right force for a given design has a vital influence on subsequent operation.

13. *Necessity for compromise.*—The various considerations affecting the behaviour of a locomotive as a vehicle are set out later, but attention should be drawn here to the compromise which has always to be made. An engine must have side control on its carrying wheels, sufficiently strong to avoid hunting on the straight, and yet not so strong as to affect its free passage round curves; the amount of this control must be appropriate to the vertical load on the carrying wheels, and to the distance of the supporting points from the centre of gravity. The engine must be sprung flexibly enough to accommodate itself to normal track imperfections without undue displacement of the spring-borne mass, and at the same time not so flexibly as to cause undue rolling. It will thus be seen that the design and maintenance of engine and track, whilst being mutually interdependent, call for compromise at practically every point; the obvious line to take is to be guided by sound first principles, by accumulated experience, and by intelligent experiment with careful deductions.

CHAPTER II.

History of Pacific Locomotives in India.

14. *Terms of Reference and Scope of Chapter.*—Under our terms of reference, we are called upon to consider, first, the suitability of the designs of XA, XB and XC Pacific Engines and the procedure connected therewith, and, secondly, the circumstances attending, and the justification for, the initial and subsequent purchases. These engines have now been running for over 10 years, having been introduced in January 1928, and they were preceded in 1924 by six Pacifics of an earlier type. Our task, therefore, must include the review of decisions taken before that time, and, in order to depict the circumstances in which this type of locomotive was brought into use in India, it is necessary briefly to survey the facts since the rehabilitation of the Railways after the Great War.

From information obtained from a number of sources, chiefly the Railway Board, the Consulting Engineers and the Administrations, we shall also deal with some of the difficulties which were experienced in the operation of these engines, and with the steps taken to effect improvement, up to the time of the accident at Bihta in July 1937. We have read the Proceedings and the Reports of the two Inquiries which were subsequently held into that accident, and certain information thus provided will be included in this review.

At the outset, however, we think it well to state that, as our Inquiry is primarily of a technical nature, we have not felt called upon to pursue the attribution of individual responsibility over so many years. It would, indeed, be impossible to do so, for the design and manufacture of these engines was the outcome of much committee work, and prolonged correspondence between the Railway Board, the Consulting Engineers, and the Builders. But, apart from this, we think that consideration of what is to be done now is of more importance in the public interest, in order that mistakes may be avoided in the future.

15. *The Acworth Committee.*—The decision to introduce Pacific locomotives on Indian Railways formed part of the policy following the Acworth Committee's recommendations. Appointed by the Secretary of State primarily to report on future administration, the Committee toured India during 1920-21 at a time when the system was suffering acutely from the effects of the Great War. From 1914 to 1919, renewals and betterments were held up; repairs and maintenance had also fallen into arrears largely because material was either not available, or only available at prohibitive cost. The following extracts from their Report give the Committee's impression of the situation :—

> "*For years past, even long before the War, public opinion in India has constantly complained of the entire inadequacy of the Indian Railway system to meet the needs of the country. It has been expressed not only in the newspapers but by Chambers of Commerce and in discussions in the Legislative Council at Delhi. The evidence given before us in all parts of the country and on behalf of all sections of the community has been overwhelmingly strong as to the urgent need for drastic measures of reform and reconstruction of the entire railway machine.*"

(*Chapter II, paragraph 25.*)

The Committee emphasised the regrettable extent to which the system had been allowed to degenerate during the Great War :—

> "*There are scores of bridges with girders unfit to carry train loads up to modern requirements. There are many miles of rails, hundreds of engines and thousands of wagons whose rightful date for renewal is long overpast.*"

(*Chapter III, paragraph 68.*)

"*The Great War is an explanation, if not an excuse, for many practices which no one would defend under normal circumstances. We cannot think that even the War is sufficient to explain the treatment of Indian Railway revenue in the last few years. Till quite recently India produced hardly any of the supplies that her railways require. Locomotives, carriages, wagons, or at least their component parts, rails, signalling work, bridge work—all were imported from Europe. Even now India produces only a very small part of what she needs. At an early stage of the War it became difficult to obtain from Europe the customary supplies. Later on it became practically impossible. The inevitable result was that maintenance and renewals fell seriously into arrears from 1914 to 1918 as is shown by the percentage of expenditure on programme revenue works to gross earnings :—*

	Per cent.		Per cent.
1913-14	*6·1*	*1916-17*	*3·3*
1914-15	*5·7*	*1917-18*	*2·1*
1915-16	*4·6*	*1918-19*	*2·4*"

(*Chapter III, paragraph 70.*)

"*The railway machine is in urgent need of repair, and funds to put it right are not forthcoming. The position at present is this: maintenance is lamentably in arrears. The cost of materials of all kinds is far above pre-war level. Wages likewise have advanced steeply.*"

(*Chapter III, paragraph 71.*)

The Committee admitted that the call for large capital expenditure for fresh railway development was great, but they urged the prior need for bringing the existing system up to date :—

"*The question today is not one of development, but of putting the existing railway system into such a condition as to be able to handle with reasonable efficiency and despatch, not the traffic of the future, but the traffic which is at present clamouring for accommodation that the railways cannot give. How urgent this need is has been sufficiently shown. . . . but we doubt whether anyone will be able fully to appreciate its meaning unless he has . . . . listened personally to the lamentable tale of the railway shortcomings told by scores of witnesses in all parts of India from Madras to the Punjab and from Bombay to Bengal. In present circumstances . . . . future development must wait. But the rehabilitation and bringing up to date of the existing system in the shortest possible time cannot in our judgment be postponed. . . . It is impossible to put into figures the loss which Indian trade and industry are suffering from the crippled condition of the railways.*"

(*Chapter VII, paragraph 244.*)

They were also unanimous in their final recommendation that :—

"*The money required to put the railways into proper shape should be raised as fast as it can be economically spent.*"

(*Chapter VIII, paragraph 27.*)

16. *Finance Committee of the Legislature.*—As a result, the Government of India, under Resolution No. 800-F. of 17th November 1921, appointed a Committee of the Legislature to consider the following matters arising from the Acworth Report :—

(i) Separation of Railway Finance from the General Finance of the country;

(ii) The requirements of the Railways with regard to capital expenditure during the next 10 years.

The Legislative Assembly deferred consideration with regard to the first, and reference to this is made later; but the Finance Committee generally supported the Acworth recommendations as to the need for liberal expenditure on the Railways. They showed, for instance, that so far as coal alone was concerned, the production in 1919 had outstripped transport facilities by more than $2\frac{1}{4}$ million tons. They forecasted a more serious position in the near future, unless steps were taken to rehabilitate the Railways; the consumption of coal in India had nearly doubled in the previous 10 years, and the Committee anticipated great development in metallurgical and other industries. To quote their words :—

> "*It is not merely a question of buying more wagons and locomotives. Lines must be doubled, bridges strengthened yards remodelled and the Railways generally fitted to handle more traffic. We are greatly impressed by the wastage in the use of existing rolling stock due to the incapacity of bridges to carry the increased axle loads involved in the use of the newer and heavier types of engines and wagons.*"

Their final recommendations were as follows :—

> "*After weighing all the factors involved we consider that funds to the extent of Rs. 150 crores should be devoted to railway capital purposes for the next five years. In placing their case before us the Railway Board asked for a minimum expenditure of Rs. 30 crores a year for the next five years and the conclusion to which we have arrived after considering the financial issues to which we have referred above is that we should be justified in recommending that funds should be provided to this extent. . . . We desire to state our opinion that immediate steps should be taken by the Railway Board to obtain a five-year revised programme from Agents which, after scrutiny by the Board, should be available for the information of the Legislative Assembly.*"

On the 27th March, 1922, the Legislative Assembly recommended the Governor-General-in-Council to accept these proposals, which had been based on the following estimate of minimum requirements framed by the Railway Board :—

	Crores.
1. Engines	30
2. Wagons	$48\frac{1}{2}$
3. Coaching Stock	18
4. Strengthening track and bridges	10
5. Doubling lines	$12\frac{1}{2}$
6. Yard and station facilities	20
7. Workshops	10

The issue, however, was ultimately complicated by certain practical difficulties in the distribution of available funds between Capital and Revenue, and the fact that rehabilitation generally did not progress strictly to programme.

17. *Survey of Financial Conditions, 1924—1937.*—We have thus shown how the Acworth Committee urged the need for spending money on the railway system to bring it up to date, quite apart from the question of coping with extra traffic, and, following the Great War, a spirit of optimism in India, as elsewhere, anticipated extensive trade development. Hence the figures quoted above, as indicating what were considered in 1922 to be minimum capital requirements.

In March 1923, however, after a succession of deficit budgets of the Government of India, the Inchcape Committee reported on the question of Retrenchment generally, and, as regards Railways, they expressed the following opinion :—

> "*We consider that, with economic working, it should be possible for the railways in India to earn sufficient net receipts to yield an average return of at least $5\frac{1}{2}$ per cent. on the total capital*

at charge. . . . A return of 5½ per cent. on the total capital at charge in 1922-23, after allowing for all interest annuity and sinking fund payments, would yield roughly Rs. 8·5 crores to the Central revenues . . . . the failure of the railways to yield an economic return on the capital invested by the State is one of the main factors responsible for the present financial difficulties of the Central Government." (*Inchcape Report, Part II, paragraph 5*).

In September 1924, a Resolution was adopted by the Legislative Assembly with the object of separating the Railway budget from the general budget; but the Railways were to pay each year to general revenues a definite contribution amounting to 1 per cent. on the Government capital at charge at the end of the penultimate year, *plus* one-fifth of any surplus profits after payment of this fixed return. During the next six years, 1924-25 to 1929-30, the Railways earned a surplus of Rs. 52½ crores, of which Rs. 36 crores were paid to general revenues, and Rs. 16½ crores were placed to reserve. In 1930-31, however, when there was a deficit, a contribution to general revenues could be found only by seriously depleting the reserve, and, thereafter, no contribution was forthcoming until 1937-38, when a payment of nearly Rs. 3 crores was made.

During each of the five years 1931-32 to 1935-36 deficits continued, and to meet these not only was the reserve fund exhausted (with the exception of about Rs. ½ crore invested in securities) but borrowings to a total of Rs. 31½ crores were also temporarily made from the Depreciation Fund. In 1936-37 a small surplus of about Rs. 1¼ crores was repaid to the Depreciation Fund; but, by reason of these borrowings, as will be seen from table B, reproduced on page 12, the "nominal" balance of this fund was over Rs. 30 crores more than the actual balance.

Naturally, as the result of the depression, which made itself felt in 1930, steps were taken to economise. A Retrenchment Advisory Committee was set up by the Central Legislature, and in 1931 a special Sub-Committee was deputed to examine and report on Railway expenditure. Among other recommendations, this latter body suggested the appointment of an expert Committee who "*should be definitely charged with the task of suggesting such economies and re-organisations as would ensure the railways attaining*" the Inchcape standard of earning at least 5½ per cent. on the capital at charge. (Report of the Railway Retrenchment Sub-Committee, paragraph 214, page 68.) For various reasons, this expert Committee could not be appointed, but the Pope Committee toured India in the winters of 1932-33 and 1933-34, to prevent any flagging in the Retrenchment campaign and to stimulate further efforts.

In April 1936, Sir Otto Niemeyer, who had been invited to report on the financial implications of the Government of India Act, 1935, emphasised the importance of the contribution of State-owned Railways to the general budget in the following terms:—

> "*The position of the railways is frankly disquieting. It is not enough to contemplate that in five years' time the railways may merely cease to be in deficit. Such a result would also tend to prejudice or delay the relief which the Provinces are entitled to expect. I believe that both the early establishment of effective co-ordination between the various modes of transport and the thorough-going overhaul of railway expenditure in itself are vital elements in the whole Provincial problem.*"
>
> [*Indian Financial Enquiry Report, paragraph 31 (2), page 12.*]

As a result, in the autumn of 1936, the appointment of the Indian Railway Enquiry Committee followed, under the Chairmanship of Sir Ralph Wedgwood, and special attention is drawn to Chapter XIV, Financial Outlook, of the Report of this Committee, published in 1937.

Thus, the Railways are expected to provide a definite contribution to general revenues. This was earned from 1924-25 until 1928-29, and for the next two years it was made up by depleting reserves; but from 1931-32 until 1936-37, inclusive, nothing was paid, and, accordingly, during that time, and even up to the present day, there has been pressure to organise and carry on a ceaseless campaign of Retrenchment. An extract from the Board's Explanatory Memorandum of February 1938 on the Railway Budget for 1938-39 may be quoted :—

> "*With the added incentive and guidance supplied in the Report of the Railway Enquiry Committee, every effort is being made to improve revenue, proposals for capital expenditure are receiving more critical examination, and the quest for economies in working expenses is being unremittingly pursued.*"

These facts are related because we think that, if the matters on which we have been asked to report are to be viewed in their proper perspective, it should be borne in mind that the planning of the X class Pacific engines, and their operation and maintenance, belong in effect to two different periods of financial outlook. The engines were designed, and the Railway Board were committed to obtain them in large numbers, at a time when ideas of development were so expansive that such proposals as 3,000 ton trains, a 12 ft. load gauge, 28 ton axle loading, 115 lbs. per yard rails, automatic couplings, and 100 ft. turntables were being seriously contemplated; the engines arrived, however, on the eve of depression, when curtailment of expenditure was the paramount consideration in railway management.

18. *Financial and other Statistics, 1924-37.*—To illustrate the change in the fianacial situation during the period 1924-37, we give below two tables, A and B. The former indicates the trend of relevant Capital and Revenue Expenditure, and gives other information relating to State-owned Railways (all gauges); the latter indicates the state of the Depreciation Fund year by year.

TABLE A.

(Figures in lakhs, except where otherwise stated.)

Particulars.	Average for 4 years 1924-25 to 1927-28.	Average for 4 years 1928-29 to 1931-32.	Average for 5 years 1932-33 to 1936-37.
1. Gross Receipts	100,23	97,04	90,35
2. Expenditure on Track, Capital	3,49	2,26	30
Expenditure on Track Depreciation Fund	4,87	4,82	3,55
3. Expenditure on Bridges, Capital	93	86	34
Expenditure on Bridges Depreciation Fund	65	70	34
4. Expenditure on Locomotives, capital	57	92	—46
Expenditure on Locomotives Depreciation Fund	69	1,61	72
5. Total Programme Revenue Expenditure	8,57	10,25	8,03
6. Maintenance of Track	3,70	4,27	3,52
7. Maintenance and Supply of Locomotives including coal	21,38	19,97	17,19
8. Tons of Coal consumed for loco. purposes (in thousands)	63,77	65,21	61,10
9. Cost of Coal consumed	9,47	8,08	6,72
10. Maintenance of Locomotives excluding cost of coal (*i.e.*, 7-9)	11,91	11,89	10,47
11. Engine Miles (Steam) (in millions)	2,08	2,17	2,00
12. Total Average Number of Engines in steam daily (units)	58,40	58,00	52,20
13. Route Miles (units)	349,60	376,90	383,40

The averages in this table are based on figures supplied by the Railway Board. The first four years comprised the period of comparative prosperity; the next four years included the end of it, and the commencement of the depression. Expenditure on the Rs. 150 crore programme was not greatly affected at the beginning of the latter period, as commitments had already been entered into; incidentally, the completion of the G. I. P. R. electrification belongs to the close of this period. The third period of five years covers almost entirely the years of depression, and the fall in the proportion of Capital to Depreciation Fund expenditure on track was due to the stoppage of works such as new lines, doublings, marshalling yards, electrifications, etc. Locomotive Capital was in credit each year during this period, due to the fact that engines were broken up without renewal, their original cost being debited to the Depreciation Fund and credited to Capital, electrification was doubtless largely responsible for this.

Although there was thus a cessation of major works, capital commitments in connection with the Rs. 150 crore programme had already been extensive, and the Railways are suffering today from the heavy interest charges which were incurred in the first two periods on the construction of unremunerative new lines and works planned during the period of optimism; it should be added, however, that many lines would probably not have been built at all had the effects of road competition and trade depression been foreseen.

With regard to the very general nature of the maintenance figures, it is hardly necessary to say that care should be exercised in drawing conclusions therefrom; for instance, changing methods of accounting may affect comparisons. Besides covering ordinary fluctuations in the cost of materials, and unforeseen expenditure on account of breaches, we also understand that scales of pay and numbers of staff have varied materially, in respect of both track and engine upkeep. Examination of the former figures (item 6) shows an increase in the second period, followed by a proportionately greater decrease in the third, in spite of the increase in route mileage.

As regards maintenance and supply of locomotives (item 7), a large decrease appears in the third period as compared with the first; but, as the figures include the cost of coal, which is subject to considerable fluctuations, we give its average cost (item 9) for the three periods. Item 10, therefore, shows the expenditure on locomotive maintenance, excluding the coal bill, and the resulting figures indicate that decrease took place in the third period. There were, admittedly, fewer engines in steam (item 12) during the period; but engine mileage (item 11) is proportionately more than in the first period, and yet less money was spent on maintaining each engine, notwithstanding the introduction of pooling and intensive user, which are now in operation on certain railways. On the other hand, progressive methods of repair and modern machinery, which have been introduced in most shops, should tend to lessen expenditure. We attach graphs to illustrate the position year by year (Fig. 4).

TABLE B.

Railway Depreciation Fund.

(In lakhs of rupees.)

Year.	Appropriation to Fund.	Withdrawals towards renewals and replacements.	Net accretion to Fund during year.	Nominal closing balance.	*Temporary loans to meet deficits.	Actual closing balance.
1924-25	10,35	7,29	3,06	3,06	..	3,06
1925-26	10,67	7,99	2,68	5,74	..	5,74
1926-27	10,89	8,05	2,84	8,58	..	8,58
1927-28	11,38	10,95	43	9,01	..	9,01
1928-29	12,00	9,60	2,40	11,41	..	11,41
1929-30	12,59	11,76	83	12,24	..	12,24
1930-31	13,07	11,39	1,68	13,92	..	13,92
1931-32	13,46	8,26	5,20	19,12	4,25	14,87
1932-33	13,77	6,35	7,42	26,54	10,23	12,06
1933-34	13,56	8,07	5,49	32,03	8,05	9,50
1934-35	13,72	8,66	5,06	37,09	5,06	9,50
1935-36	13,25	9,16	4,09	41,18	3,99	9,60
1936-37	13,17	7,88	5,29	46,47	—1,21	16,10

* These are entirely to meet the deficits in the working of the State railways except in 1933-34, the figure for which includes a loan of Rs. 9 lakhs made to certain branch line companies for capital expenditure.

This table is based on the figures printed in the Railway Board's Explanatory Memorandum on the Railway Budget for 1938-39, and shows the changes in financial conditions during the period under review. In the first four prosperous years, the average withdrawals towards renewals and replacements amounted to over Rs. 8½ crores; in the second period of four years, the figure rose to Rs. 10¼ crores, the increase being doubtless largely due to the Rs. 150 crore programme. During the last five years, it receded to just over Rs. 8 crores. In the year 1932-33, when a loan of nearly Rs. 10¼ crores was borrowed from the Depreciation Fund to meet the annual deficit, the amount withdrawn for renewals and replacements fell to rather less than Rs. 6½ crores, the lowest figure during the whole thirteen years. From the Explanatory Memorandum mentioned above, it appears that under Rs. 6¾ crores was budgetted for withdrawals for 1938-39.

As already mentioned, there was due to the Fund in 1936-37 more than Rs. 30 crores borrowed to meet deficits, and it follows that nothing has been repaid to the Reserve Fund. We understand that it has been suggested that both the amounts borrowed from the Reserve Fund (Rs. 19 crores) and the Depreciation Fund be written off, but the Legislative Assembly recommended in 1937 that decision on this question be postponed until 1940. Recently the Government of India have published the following statement showing the action taken on the relevant recommendations of the Indian Railway Enquiry Committee, which were to the effect that the normal balance in the Depreciation Fund should be Rs. 30 crores, and that, in addition to this, a general reserve should be built up of Rs. 50 crores:—

> "*Government accept the need for an adequate depreciation fund and in the light of past conditions agree that a normal balance of Rs. 30 crores would not be excessive. They also agree with the Committee's conclusion that it has not been established that contributions to the fund in the past have been unduly high. They are impressed with the necessity for a general reserve fund from which any deficit on working expenses and interest could be met in years of depression, and so obviate railways becoming a burden on general revenues at these critical times. The figure of 50 crores suggested by the committee as the amount to which revenue balances, after provision for depreciation, should be appropriated to such a fund is possibly a counsel of perfection, but Government are inclined provisionally to the view that this sum should be borne in mind as a suitable maximum for a combined reserve fund (including the Depreciation Fund). The railway reserve funds at the end of 1937-38 amounted, however, to only 19¾ crores, and the need of the railway contribution to general revenues in present circumstances precludes any decision or action in regard to these matters or to amortization of capital at present, beyond the existing basis of the annual contribution to Depreciation Fund.*"

NEED FOR FUEL ECONOMY.

19. *Rise in Cost of Coal.*—Though the conception of the X class Pacific engines took place during the period of prosperity and optimism, we have no reason to suppose that the Railway Board were not actuated by motives of economy and efficiency in ordering these engines. Indeed, the Board were in urgent need of reducing their fuel bill, and they wished to pursue Standardisation as a further measure of economy, an aspect which is dealt with later. As regards the fuel bill, the Inchcape Committee had urged the need for curtailment, and the problem was intimately connected

with the introduction of Pacific type engines. The Great War had materially raised the cost of first grade Indian coal, and the following table, which was furnished to that Committee illustrates the position:—

	Quantity of fuel consumed.	Total cost at Engine Shed.	Average cost per ton.	Average consumption per Engine mile.	Total Engine Mileage.
	Tons.	Rs.	Rs.	lbs.	Miles.
All 5 ft. 6 ins. gauge railways—					
1913-14 . .	3,773,000	4,09,00,000	10·8	67·5	125,400,000
1922-23 . .	5,175,000	8,62,00,000	16·6	82·0	140,100,000
Per cent. Increase .	37	110	54	21	12
All Metre Gauge railways—					
1913-14 . .	785,000	1,05,60,000	13·5	44·4	36,900,000
1922-23 . .	972,000	2,29,92,000	23·7	52·7	40,400,000
Per cent. Increase .	24	118	76	19	4

Necessity for the wide firebox.—It will be seen from these figures that, while the engine mileage between 1913-14 and 1922-23 had only increased by 12 per cent. on the Broad Gauge and by 4 per cent. on the Metre Gauge, the fuel bill had grown by 110 per cent and 118 per cent. respectively. One way of reducing these costs was by extending the use of second grade coal, supplies of which were available over a wider area than first grade, and were ample in certain collieries which had been acquired by the Railway Board as some measure of protection against continually rising prices. We understand, however, that an investigation into boiler ratios then indicated that existing types of locomotives would be unsuitable for the economic use of this coal, and that, to obtain the necessary boiler horse-power, wide fire boxes were considered to be essential. Hence the demand for the wheel arrangement of the Pacific type, in place of the existing narrow firebox 4-6-0 type, if sufficient power was to be obtained to meet the anticipated need for heavier loads.

The Six Preliminary Pacific Engines.

20. *B., B. and C. I. R.*—The need for economy in the use of second grade coal prompted this Administration, in 1919, to initiate experiments with certain Metre Gauge engines, which were specially fitted with wide fireboxes, and as these trials resulted in the purchase of six experimental Broad Gauge Pacific engines, which were the precursors of the X type engines, we briefly recount the facts. In September 1921, the Agent reported that:—

> "*Great success has attended the trials of the specially wide firebox which has been fitted to some of the engines on the Metre Gauge system, and this encourages me to propose the adoption of a somewhat similar arrangement on the Broad Gauge . . . . The use of inferior coal, pulverised or otherwise, is one of the pressing questions requiring solution. It is not considered possible to modify existing engines . . . . I am, therefore, proposing to introduce the new type as shown on the blue print sketches . . . . The boilers of the goods and passenger locomotives are interchangeable. The cylinders and motion, with the exception of connecting, coupling and eccentric rods are interchangeable . . . . A very early decision is requested as there are indents now going forward for 20 new engines against the 1922-23 grant, and, if approved, they will be of this type.*"

In November 1921, the Railway Board agreed to the proposed new types, 4-6-2 passenger and 2-8-2 goods, which had thus been designed to burn low grade coal; but they expressed the opinion that:—

> "*It would be a mistake to order as many as 20 engiens of a completely new design until sufficient experience had proved that their adoption would be a success.*"

The Board, therefore, agreed to orders being placed for 2 engines of each of these types, and they expressed the desire that:—

> "*These 4 engines be thoroughly tried in running for at least a year, in order that any defective details which may show in operation or manufacture can be rectified before bulk orders are placed.*"

In May 1922, the Agent reported that the Chief Engineer saw no objection to the running of these engines on the sections of the line proposed, as existing dimensions would not be infringed, and girders were up to the strength laid down; the Senior Government Inspector's sanction had also been obtained.

E. I. R.—In August 1922, a similar but lighter Pacific was approved for this Administration "*with a view to obtaining a larger firebox*", the Locomotive Superintendent having decided on this type in preference to a three cylinder 4-6-0 engine; he added in a letter that if this type "*proves a success, and I see no reason why they should not, a large number would be required.*"

Design and manufacture.—The above-mentioned four experimental engines of Pacific type were designed and built by manufacturers in England, in co-operation with the Consulting Engineers, to the specifications of the Locomotive Superintendents concerned. The first two, with $19\frac{3}{4}$ tons axle loading, were received on the B., B. and C. I. R. about July 1924, and were known as the P Class; the other two, with $16\frac{1}{2}$ tons axle loading were put into service on the E. I. R. about the same time, and were known as the PS Class. So far as we could ascertain, no more than ordinary conventional consideration was given at the time to the design of these engines as vehicles, namely, to the lateral motion of the bogie and hind truck. No doubt the usual practice was followed by the Locomotive Superintendents concerned of fixing the weights on axles, spacing of wheels, weight per foot run, etc., the design generally being left for settlement between the Consulting Engineers and the Builders.

M. and S. M. R.—In March 1923, this Administration, as a separate approach to the use of low grade fuel, obtained sanction to purchase two Baldwin Pacifics, the design of which was typically American, with bar frames, steel fireboxes, etc., the Builders being given a free hand. These two engines had an axle loading of 17 tons, and their purchase was in accordance with the Railway Board's policy to experiment with the Pacific type. When, however, the M. and S. M. R. applied for sanction for two further Pacific engines of British design, for purposes of direct comparison with the Baldwin engines, the Board withheld approval pending the result of the trials of the four previous engines on the B., B. and C. I. R. and E. I. R. The two Baldwin engines started work on the M. and S. M. R. about September 1924.

The performance of these six engines is referred to later; it is sufficient to note here that the Board (a) allowed their introduction for trial purposes, and (b) refused to permit the Railways concerned to purchase more than two, pending trial for at least a year.

STANDARDISATION.

21. *B. E. S. A. Locomotives.*—The policy of Standardisation in India started about 1901, when it was realised that the development by each Administration of its own locomotives had certain disadvantages as affecting the Indian Railway system as a whole. It was felt that if Standardisation could be adopted, this would admit of exchange of power between

different Railways in case of emergency, it would limit the number of spare parts, and enable manufacturers to deliver engines in less time and at lower cost.

Accordingly, in 1903, the Secretary of State approached the British Engineering Standards Association (B. E. S. A.), and a Committee was set up representative of all interests concerned; it included a member with first hand knowledge of Indian conditions namely, the representative of the Indian Locomotive Superintendents' Committee of the Indian Railway Conference Association (I. R. C. A.). As a result, during the next two years, B. E. S. A. designs were completed for seven B. G. types, and for three M. G. types. Apart altogether from the standardisation of these different types, we understand that the designs which were prepared made provision for the maximum degree of interchangeability of various component parts between the various types. There appears to be little doubt that the reduction of types, which was thus effected, marked a step forward on Indian Railways.

But though these types were widely adopted on the State-managed lines (in those days only the N. W. R., O. and R. R. and E. B. R.), the Company-managed systems, covering a considerably greater mileage, still retained freedom of action, and though they adopted the standards on general lines, they did not accept the designs in detail. It was, therefore, considered that the advantages of complete Standardisation were not fully realised. By 1910, orders had been placed for some 840 Broad Gauge and 470 Metre Gauge standard B. E. S. A. engines; they included all types, and reports showed that, on the whole, notwithstanding small alterations in detail, as is usual in new designs, the engines have been successful, particularly those of the latest 4-6-0 type.

22. *Views of the I. R. C. A. and of the Railway Board.*—Thereafter, although Railways continued to purchase B. E. S. A. type engines, Standardisation does not seem to have been pressed, and in 1912, the Locomotive and Carriage Superintendents' Committee of the I. R. C. A. expressed the opinion that the policy had not been a success and had not achieved the objects for which it had been introduced. The main complaint was that, with different conditions on different Railways, it was nearly impossible to produce standards which would meet all conditions. It was, however, agreed that Standardisation of fittings would be an advantage, and the following Resolution was adopted by the I. R. C. A. :—

> "*This Committee considers that it is desirable to standardise such details of Indian locomotives as are obtained from England for renewals and repairs in a finished or partly finished state, but that it is undesirable to standardise types of locomotives and minor details as it is liable to hamper progress in design.*"

The intervention of the Great War doubtless interfered with the policy, and it was not till 1919 that the Railway Board drew attention to the difference in important parts which existed between different engines of the B. E. S. A. types on the various Railways. In 1921, the matter was again considered by the I. R. C. A. who reiterated their opinion of 1912. In 1922, however, the Board expressed their disappointment to the I. R. C. A., and circulated a note pointing out that the Resolution of 1912 was "*inapplicable to present, or at any rate to prospective, conditions*"; also that with regard to "*standardised types of locomotives*", India had not, up to that time, adopted either the Pacific or the 2-8-2 types which the B , B. and C. I. R. were then proposing, "*an obvious and necessary development to enable us to extend the use of low grade fuels without detriment to train loads. It is fairly certain that other Railways will follow suit.*"

A further extract from the note referred to above emphasised that :—

> "*There is nothing whatever in the principle of Standardisation to prevent the adoption of heavier engines if the traffic needs them.*

The criteria of progress are efficiency in operation and economy in maintenance. Dealing with the latter first, Standardisation aims specifically at economy both in manufacture and maintenance; and no one can deny its effectiveness for that purpose. Therefore we have to consider now only progress in respect of efficiency in operation. The measure of that progress may be taken practically as the fuel consumed per horse-power; and the plain fact is that except for the introduction of superheat no substantial progress has been achieved in this respect. It is perfectly safe to assume that future progress is far more likely to develop on sound lines from the pooled experience of all the railways, than from the isolated and spasmodic experiments of individual lines."

Moreover, by this time, it was generally admitted that the first B. E. S. A. engines contained so many modifications, which had been introduced by individual Administrations, that interchangeability of their components had become almost impossible, and, in September 1923, the I. R. C. A. supported a recommendation of the Locomotive and Carriage Superintendents' Committee as follows:—

> "*that standardisation of locomotives, coupled with the periodical revision of standards, is essential in the interests of economy and efficiency, and that additional types be introduced suitable for burning low grades of fuel*". The Committee also recommended the formation of a permanent Standing Technical Committee to deal with "*progress in, and variations from, standards of locomotives, coaching stock and wagons.*"

23. *Decision to implement further Standardisation.*—The Railway Board therefore decided, in consultation with the Agents in October 1923, that a Committee (known as the Locomotive Standards Committee and referred to later) should be constituted, to implement the above recommendation of the I. R. C. A., and to give effect to the Board's policy which was "*to aim at progressive Standardisation as a continuous process, which it is believed can be ensured by the formation of a permanent Standing Technical Committee to deal with progress in and variations from standards, co-ordinating requirements in respect of existing and future types of locomotives, and to be the authority to whom all modifications and improvements should be referred*". In preparation for the above-mentioned meeting with the Agents, the Board also circulated a Memorandum, which is attached as Appendix II; we were informed that, after full discussion, the views of the Board, which were thus expressed, were accepted as the policy to be aimed at in future, and that the Memorandum generally expresses the policy of the Board today.

Attention is drawn to paragraphs 6 and 16 of this Memorandum; and on the 15th November 1923, the Board addressed all Administrations on the subject of the five-year programme, which was referred to in paragraph 16 above. They remarked that some proposals which had been received for the provision of heavy locomotives, rails and girders could not be justified by the volume of traffic to be dealt with. Further investigation was therefore considered to be essential on this basis, from which train weight was to be estimated, and locomotive axle-loads assessed, as well as the economic weight of rails and the standard of girders, the cost of improvements being expected to be justified by the estimated net increase which was anticipated in traffic. Thus the Board desired to establish a definite relationship between estimates of increase of traffic and the standards of reconstruction to be adopted; they expressed the opinion that consideration of the problem in this manner would simplify some of the difficult questions which were then arising as regards future standards and would "*tend towards placing the future programme of works on a proper business basis*". The Board also stated that those Administrations not having sufficient traffic to justify the strengthening of track or bridges for the new types of engines should specify existing standard B. E. S. A. types.

24. *Consulting Engineers.*—Up to this time, various firms acted independently as Consultants to the Government and to the individual Company-managed systems. One firm, however, supervised the construction of the six preliminary experimental Pacifics, and dealt primarily with the design and supply of the Standard engines. Except for references later, in paragraphs 42, 43 and 44, to three firms, the firms in question is referred to in this Chapter, and throughout this Report, as the Consulting Engineers; they are retained as such by the Secretary of State, the Government of India, and the High Commissioner for India, and they act both as general Consultants and as Inspecting Engineers for bridge work, locomotives, rolling stock, permanent way, and Railway work generally. Orders pertaining to these, whether placed by the India Store Department, or by Departments in India and remitted to the Director General for inspection, are passed to the firm for supervision during manufacture and for certification on completion. The firm's connection with the Government of India is of very long standing.

Locomotive Standards Committee.

25. *Appointment of the Committee.*—This was the first of a number of Standardisation Committees (mentioned later) which was set up by the Board with the object of promoting economy and efficiency. It was formed in February 1924 of two members with a technical secretary, "*to standardise the several modifications introduced into B. E. S. A. types of locomotives, and to prepare diagrams and general specifications for new types required on Broad and Metre Gauge systems*".

The first task of this Committee was to tour India, "*to visit the headquarters of the different Administrations and to obtain from the technical officers all necessary information regarding practical difficulties which have been experienced and the steps taken to surmount them*".

Duties of the Committee.—These are described in the Memorandum of the Board's instructions on the subject, which is attached as Appendix III, and which was sent in February 1924 for information to all Agents, to the Director General, India Store Department, London, and to the Consulting Engineers. Attention is drawn to paragraphs 4, 5 and 10; the Locomotive Standards Committee was expected to lead an organised effort:—

> "*To bring existing B. E. S. A. types up to date incorporating such modifications as practical experience has shown to be necessary, with a rigid adherence in future to accepted standards. Once amended, or new designs are accepted, no modifications are to be introduced by users, Consulting Engineers or manufacturers without the previous approval of the Railway Board. In order to ensure progress and prevent stagnation standard designs should be periodically reviewed.*"

In introducing a modification of an approved design, the C. M. E. concerned was expected to prepare drawings and to give reasons for the modification, "*after consultation with the Transportation Department, where the operating of, and running repairs to, locomotives are not under his jurisdiction*". The Committee was to examine the proposal, and, if approved, arrangements for trials were to be carried out "*not only by the Administration advocating it, but by all systems using the type of locomotive on which the alteration is suggested. The trials and their duration should be restricted to the number of locomotives and to the time considered essential by the Committee to obtain satisfactory results*". On completion of the trials, the Committee was to forward its recommendations to the Railway Board, who would decide whether the modifications proposed should, or should not, be incorporated in standard designs.

For a variety of reasons, the standardisation of details of B. E. S. A. locomotives does not appear to have proceeded to finality, although a fair degree of uniformity was obtained. One of the difficulties was to reconcile the time required for trials with the obvious urgency of certain modifications, and generally to reconcile the often conflicting reports about the same trial from various Administrations.

26. *The Board's instructions as to new types of engines.*—The attention of the Locomotive Standards Committee was also drawn to the letter of the 15th November 1923 (already mentioned in paragraph 23) dealing with the co-ordination of requirements in respect of axle loads, weight of rails, etc., and the Committee were given certain broad principles to follow:—"*New types to be evolved will depend on actual requirements of all Administrations . . . . As far as possible, the Committee should, in preparing diagrams and general specifications for new types, reproduce existing standards where such have proved satisfactory, but there should be no hesitation in departing from existing standard practice where practical experience has shown that an improvement is absolutely necessary*". With regard to new types, the following points were to be given special attention:—

(a) Number of types and classes of a type to be kept down to a minimum;

(b) Axle loads to conform to the standards of loading existing and recommended;

(c) Balancing in co-operation with the Engineering Department;

(d) Lightening of reciprocating parts;

(e) Weight in relation to tractive effort;

(f) Accessibility and economical cost of working and maintenance;

(g) Adequate boiler power; and

(h) Largely increased grate areas to permit of the more extended use of low grade coals.

Careful consideration was also to be given to the merits of a number of specified details, among which were the avoidance of tortuous exhaust passages and the necessity for interchangeability of boilers. Thus the Board's instructions were that the new standards should be adopted where justified; that axle loads were to conform to existing and recommended standards; and that the co-operation of the Engineering Department was to be obtained. The Board further laid down the procedure which was to be observed in the introduction of the new standard engines, and this is referred to in Chapter VIII.

27. *The Locomotive Standards Committee's recommendations.*—As their first task, the Committee toured India from November 1923 to February 1924, and though it had been hoped that they would have been able to benefit by the experience gained from the operation of the six experimental engines already mentioned, it is clear that they could not have done so, for their First Report was submitted in 1924, before any of these engines arrived.

The preamble to this Report discussed the benefits that it was hoped to derive from the restandardisation of the existing B. E. S. A. type engines, and from the evolution of the new I. R. S. designs. The Committee formulated their proposals after consultation with the using Departments of Class I Railways, and prepared a series of recommendations embracing all future types of Broad and Metre Gauge locomotives, as well as existing B. E. S. A. Broad Gauge types; they also recommended that new I. R. S. designs, for five Broad Gauge X types A to E and three Metre Gauge Y types B to D, should be prepared by the Consulting Engineers in consultation with the B. E. S. A. and the Manufacturers. The technical particulars prescribed by the Committee, so far as the XA, XB and XC types were concerned are stated below and the diagrams of the engines as constructed are given in figure 1 :—

	4-6-2 type superheated.		
	Branch XA.	Light XB.	Heavy XC.
Axle load tons (coupled wheels)	12·5	17	19·5
Weight of Engine—tons	59·5	82	94·5
Weight of Tender—tons	40·5	58·5	77·0
Boiler pressure—lbs. per sq. inch	180	180	180
Diameter of cylinder—inches	17½	21½	23
Stroke—inches	26	28	28
Diameter of coupled wheels—inches	61½	74	74
Tractive effort at 85 per cent. boiler pressure	19,810	26,760	30,630
Ratio of adhesion at 85 per cent. boiler pressure	4·24	4·20	4·28
Grate area—square feet	32	45	51
Evaporative heating surface—sq. ft.	1,600	2,250	2,550
Superheater heating surface—sq. ft.	384	540	612

The Committee prepared outline diagrams of these engines and explained that the characteristics had been arrived at as follows :—

(a) The axle loads selected were suitable for rails of the weights given below :—

Axle load. Tons.	Weight of rail lbs. per yard.
22·5	90
19·5	85
17·0	75
12·5	60

(b) The diameter of cylinders had been calculated to give a tractive effort at 85 per cent. of the boiler pressure equal, as nearly as possible, to the adhesive weight divided by 4·25;

(c) The grate area had been fixed by dividing the tractive effort at 85 per cent. of the boiler pressure by 600;

(d) The evaporative and superheater heating surfaces had been obtained by multiplying the grate area by 50 and by 12 respectively.

With regard to track limitations, it was pointed out that the engines met the following requirements as far as was practicable :—

(a) Revolving parts to be completely balanced;

(b) Cylinders to be horizontal in preference to inclined;

(c) Connecting rods to be long in preference to short.

With regard to the lightening of reciprocating parts, the Committee recognised that alloy steels were liable to give trouble and confined themselves to recommending trials with alloy steel piston, connecting, and coupling rods on two locomotives for each Railway requiring them. The desirability of introducing multiple cylinders, mechanical stokers and boosters was discussed with the prospective users; but opinion was unanimous against their introduction under the conditions existing at the time. In particular, it was held that the increased capital cost, complication, and maintenance charges, resulting from the adoption of more than two cylinders could not be justified for Indian Railways.

The introduction of high pitched boilers, increased size of cylinders, and straight line valve gear necessitated an increase in the overall height and width over cylinders. This resulted in the engines infringing the Schedules of Maximum Moving Dimensions of 1922, but the new dimensions were, in the opinion of the Committee, the minimum within which satisfactory locomotives could be designed. Administrations were therefore instructed that it would be necessary to satisfy themselves, prior to the introduction of the new locomotives, that no fixed structures existed which would interfere with safe running. For example, the overall height for the XA type conforms to standard, 13 ft. 6 in.; but this dimension for XB and XC types was increased to 14 ft. 0 in. and 14 ft. 6 in. respectively.

28. *Comparisons of axle loading and total weight.*—With regard to the foregoing figures relating to weight of rail and axle loading of coupled wheels, the statement attached as Appendix IV gives relevant information in respect of the XA, XB and XC engines as built, compared with the existing B. E. S. A. 4-6-0 type, with the previous six Pacifics, with the subsequent 18 B. N. R. M class Pacifics which are mentioned below, with the latest B. N. R. 4-6-0 type engines, and with the latest XP and XS Pacifics. It will be noted that there are now 314 Broad Gauge Pacific engines running in India, of which 113, 99 and 72 are XA, XB and XC types respectively.

29. *B. N. R. Pacific Engines.*—The M class engines on the B. N. R. were ordered in 1928, and are of De Glehn compound type; the Railway Board required that they should follow, so far as possible, the design of the XC class, particularly in respect of springing, compensation, bogie and hind truck features. The low pressure cylinders and crank axle inside the frames and the arrangement of frame stretchers differed from that of the standard locomotives; horizontal racking plates were not used. Axle loading is 21·45 tons. as compared with 19·7 tons of the XC class, and with 17·5 tons of the existing 4-6-0 type B. E. S. A. engine. The object of the design was largely for comparison between the simple and the compound Pacific types, with similar frames and wheel arrangements.

Procedure adopted in the Design of I. R. S. Locomotives.

30. *Preliminary designs.*—From the specification and diagrams laid down by the Locomotive Standards Committee, it appears that the XB type was largely based on the information available regarding the first four British built Pacifics, which by then had been constructed, but had not reached India, and, as the latter were of experimental type, close collaboration had been necessary between the Builders and the Consulting Engineers; for this reason, the same Builders were engaged and paid, by arrangement with the Railway Board, to prepare, under the direction of the Consulting Engineers, the sets of preliminary drawings for the standard Pacifics in compliance with the requirements in the Report of the Locomotive Standards Committee.

The Consulting Engineers also considered that the recommended Standardisation was of such importance that one of their Partners paid a special visit to India, from November 1924 to February 1925 and reviewed relevant matters with the Locomotive Standards Committee and with the various Administrations concerned. He also discussed with the Railway Board the preliminary general arrangement drawings, which he took out to India. Attached as Appendix V is an interesting note on Standardisation of Locomotives in India, dated January 1925, written by him during this visit, and referring to the part played by the B. E. S. A. It was at this time that he also wrote and supported the recommendations of the Locomotive Standards Committee on most details; but having visited nearly every Administration in India, he also strongly expressed the opinion that the existing B. E. S. A. locomotives of the latest type should "*not lightly be set aside or altered*", his intention being that certain B. E. S. A. types should be retained in addition to the new standards.

31. *Criticism of the Board's Policy.*—It was also at this time that the B., B. & C. I R. drew attention to the Board's inability to arrange for the Report of the Locomotive Standards Committee to be discussed by the Locomotive and Carriage Superintendents' Committee of the I. R. C. A., and the Administration submitted a Memorandum (dated August 1924) by their C. M. E. strongly urging such consideration. The Railway Board particularly drew our attention to this Memorandum as being the only reasoned and recorded objections to their policy of Standardisation.

It was contended in the Memorandum that whereas Standardisation of details was highly desirable, Standardisation of complete units was equally undesirable; the organisation of the Standards Committee was criticised on the ground that its powers would be too arbitrary, and it was suggested that it should function as previously, through the medium of the I. R. C. A. The proposals in this Memorandum were not pursued at the time; but, in the light of subsequent events, we feel that the Memorandum as a whole is of sufficient general interest to be attached as Appendix VI, having regard also to our recommendations for future organisation in respect of Standardisation, and of collaboration in design which we shall make in a later Chapter.

32. *Performance of the Six Preliminary Pacifics.*—In January 1925, these engines had been running for some months and, so far as we could ascertain, no complaints had been received with regard to their riding, though no specific trials were carried out, and the Railway Board apparently took no steps at the time to satisfy themselves in this respect. However, later they did avail themselves of the experience of the two B., B. & C. I. R. engines which were running on that line; they sent to the Consulting Engineers a Memorandum by the C. M. E. dated January 1926, with a request that due consideration should be paid to the 17 points of design raised therein. The following relevant extracts are of interest:—

> "*The design of the tender bogie is not satisfactory. It is very 'hard riding' and the Engineering Department complain of the engines spreading the road where the latter consists of flat footed rails spiked on to wooden sleepers. This is undoubtedly due to the great weight of the engine and tender acting on the admittedly weak attachment of rail to sleeper, which consists of one dog spike to take side thrust. It is noticeable, however, that the tyres of the tender leading bogies wear sharp flanges very quickly, and it is suggested that a different design of bogie should be considered which will provide for both lateral movement and rotation.*
>
> *American practice appears to differ in that some tender trucks have both lateral motion and rotation, and some have rotation only. I think we can disregard the Engineers' complaint about spreading the road as they can readily strengthen the attachment of rail to sleeper by using additional spikes and bearing plates on curves. The excessive wear on tyres, however, is presumably due to either (a) excessive friction resisting the rotation of the bogie, or (b) absence of lateral movement. It is possibly due to a combination of these . . . . . .*
>
> *The coupling between engine and tender is reasonably rigid, and the overhang of the rear end of the engine may force the leading end of the tender to deviate a greater amount than can be compensated for by rotation only of the bogies . . . . . . It appears as economical to design a bogie with lateral flexibility as without it, and it is suggested that the question be very carefully considered and lateral movement provided. A reasonable amount of lateral flexibility can obviously be of no detriment, and will probably completely eliminate the trouble, and the increased cost of design will be negligible. In any case, excessive tyre wear is a very expensive item. It is understood that the bogie tender on the G. I. P. R. has also proved very unsatisfactory.*"

33. *Views of the Railway Administrations.*—As the result of the abovementioned discussions with one of the Partners of the Consulting Engineers, the Locomotive Standards Committee issued a second Report in March 1925, which embodied a number of amendments. We understand that the First Report, and the designs submitted therewith, represented the views of the different Railways consulted by the Committee, but the papers giving the details of the interviews have been destroyed, and only the Committee's

Reports remain. We were informed, however, that the views of the various Administrations, expressed in answer to the Committee's questionnaire, received due consideration, and the First Report was actually sent to them for remarks. The modifications thus proposed were embodied in the Second Report, upon which, however, the Railways were not asked to comment, but to state which types of engine they could best utilise. We gather that the Administrations were then asked to place orders for two engines of such types for trial purposes, the choice being limited to the proposed range, which was strictly kept down to the minimum of five types in accordance with the Railway Board's instructions.

While the new standards thus reflected the views of the Locomotive Standards Committee, formed after a measure of consultation with the C. M. E.'s, it cannot be said that they emanated from the Railway themselves. Actually the Committee were implementing the Board's policy, which required engines of greater horse-power than the B. E. S. A. 4-6-0 type, with larger boilers, and wide fire-boxes, features calling for the Pacific wheel arrangement. On the other hand, we were also informed that no criticism was received from any Administration with regard to the adoption of the Pacific type, or to the particular sizes and range of the standards proposed.

34. *Approval of working drawings.*—With regard generally to the recommendations of the Locomotive Standards Committee, we draw attention to their last remark; they emphasised "*the great importance of being given an opportunity to scrutinise the working drawings prior to the trial engines being built*". We understand that no such opportunity was afforded, and that the drawings were not in fact received in India until after the engines had been built; but while the first contracts were in hand, there was intimate collaboration between the Consulting Engineers and the Builders, and close touch was maintained, largely by demi-official correspondence, between the former and the Railway Board.

Moreover, as delay would have resulted (there was no air mail) from a procedure involving submission to India and approval of working drawings, it was arranged that one of the original members of the Committee should collaborate in London with the Consulting Engineers. It was considered that, with his intimate knowledge of Indian requirements and of the views held by the Committee, his services would be of great assistance to both the Consulting Engineers and the Builders, in the event of the Committee's recommendations upon essential details being insufficiently explicit. By this appropriate means, the drawings, which were prepared by the Builders, were examined and approved on behalf of the Board; and it was arranged that, whenever a difference of opinion arose, reference was to be made for decision to the Board, with whom final responsibility in such circumstances naturally rested.

With regard to the four preliminary experimental Pacifics for the B., B. & C. I. R. and E. I. R., we understand that generally the procedure adopted in 1923, as previously, was that no detailed drawings were submitted for the approval of these Administrations, and the Consulting Engineers assumed entire responsibility; the E. I. R. design was based on that accepted for the B., B. & C. I. R. With regard to the two Baldwin engines for the M. & S. M. R., the outline specification was prepared by the Consulting Engineers, and the main design was left to the Builders.

Design of the X Class Pacific as a Vehicle.

35. *Recommendations of the Locomotive Standards Committee.*—In their first Report of May 1924, only three out of 57 recommendations had any reference to the running of the engine as a vehicle, and of these only one, recommending spring compensation in two groups if practicable, was of any importance in this respect. Indeed, it would have been unusual in those days for special instructions to be given to the Consulting Engineers regarding this aspect of design. Further, out of 18 remarks in the Committee's second Report of March 1925, covering alterations applicable to

all the proposed standard types, only two have a material bearing on the point; the first approved overhead spring gear, and the second approved the Cartazzi radial axle on the hind truck for Broad Gauge engines.

As already mentioned, the modifications recommended in the latter Report were no doubt influenced by the visit in the winter of 1924-25 of the Partner of the Consulting Engineers; he had two meetings with the Locomotive Standards Committee on arrival in India, and, after his tour of two months, had further meetings covering three days.

36. *Spring Gear on Coupled Wheels.*—In the original outline design prepared by the Builders of the experimental P and PS class Pacifics, springs were carried on high stirrups on the top of the axleboxes, and the compensating beams were above the centre line of the coupled wheels. When the detailed design was being prepared by the Builders of the X class Pacifics, under the supervision of the Consulting Engineers, the springs were lowered to rest directly on the tops of the axleboxes, and the compensating beams were lowered to positions below the centres of the axles. This matter has given rise to some doubt as to the effect on stability as outlined in Chapter III. The proposal was not referred to the Locomotive Standards Committee, when the alteration was made, but we were informed that had it been submitted, it would have been approved. The main reference from India on the subject appears to have been included in a letter to the Board's representative in August 1926, emphasising that:—

(a) *the spring must be brought down as near as possible to the crown of the box; and*

(b) *the horn stay should preferably secure the frame and the horns, but if this cannot be carried out, the frame should be stayed and not the horns, which has been the practice in the past.*

Owing to the desire to use a combined hornblock and framestay, there was not room for the retention of the compensating levers in the original position, and the Builders informed us that, in conference with the Consulting Engineers, it was not considered objectionable to increase the length of the spring links; it was suggested that the rubber spring pads might, with advantage, be carried below the bottom of the frame, in order to afford more room for a wider rubber pad. This was the arrangement approved by the Consulting Engineers in August 1926 for the new standard 2-8-2 Metre Gauge engines then being built for the A. B. R. In February 1927, the Consulting Engineers approved the whole arrangement of guides and springs for the X class Pacifics being kept uniform. Further, for the purposes of Standardisation, the same arrangement was adopted for the X class 2-8-2 engines, XD and XE types.

37. *Hind truck.*—The Cartazzi type of radial box was discussed by the Partner of the Consulting Engineers during his tour in India, and before the issue of the Locomotive Standards Committee's second Report of March 1925, in which its adoption was accepted for Broad Gauge designs. It was the only type of truck of which there was then first hand experience (about three years) on Pacifics in England, and the Consulting Engineers pointed out that it was light in weight and gave maximum freedom in ashpan design. It also provided for centring force different in nature from that of the spring controlled bogie, and about this time the Chief Mechanical Engineer of the B., B. & C. I. R. expressed the opinion that this type of control (1 in 7 compared with 1 in 10 on the XC) was working satisfactorily on the first two experimental Pacifics on his line.

Later, in May 1926, the Consulting Engineers also received a letter from the Board to the effect that "*the Cartazzi boxes on the B., B. & C. I. R. have not given a moment's trouble, and I feel that, as this arrangement has been so successful on the Broad Gauge, we should adopt it on the Metre Gauge engines for the sake of uniformity if nothing else*". It also seems that the Board and the Consulting Engineers cannot have overlooked the Bissel truck as an alternative, in view of its wide use elsewhere, and it was, in fact, provided on the Baldwin engines which had then been under trial on the M. & S. M. R. for nearly two years. The proposal to adopt the Cartazzi type of radial axle box was finally agreed to, as the result of discussions at the Builders' Works in March 1927, the arrangement having the merit of being the same for both XB and XC engines.

38. *The Drawgear.*—While, as already explained, one of the original members of the Locomotive Standards Committee was collaborating with the Consulting Engineers in London, the other member acted on the Railway Board in India from April to October 1926. It was during this time that final decisions were taken with regard to the design of the drawgear and the bogie; the latter is dealt with in the next paragraph.

As regards the drawgear, the subject was raised by the Board, and, as an example of the discussion, an extract from their letter of 30th March 1926 may be quoted: "*There is an important point which must not be overlooked and that is the coupling between engine and tender. If this is not sufficiently flexible to permit of engine and tender assuming their normal positions on curves, it results in excessive side thrust on the leading tender bogie. With the large overhang behind the trailing coupled wheels of the new standard locomotives, it is essential that the engine and tender should be provided with a coupling which will give a wide range of flexibility*".

The Consulting Engineers replied on 29th April as follows:—"*With regard to the drawgear, I think with you that it has been a mistake in the past not to give more freedom to enable the tender to be guided by its wheels independently of the control due to the friction between the intermediate buffers, and I am accordingly arranging to fit "Goodall" draw bars to all the new engines and tenders*". The acknowledgment of the 29th May from the Board stated that "*I note you propose to fit the 'Goodall' drawgear to all the new standard locomotives, and agree that this is probably the best arrangement on locomotives having a big overhang behind the trailing coupled wheels*". It was therefore included in the specification to the Builders.

This type of drawgear had been on trial on one engine on the M. & S. M. R. since 1923, and was reported to be satisfactory. It appeared to offer a solution of the troubles that were being experienced in India with the drag boxes which accommodated the previous type of intermediate drawgear; play developed therein, which induced heavy shock loads when buffing, and rivets became slack in the built-up type of drag box, while fractures occurred in the steel casting type. As the 'Goodall' drawgear is an articulated ball and socket arrangement, it was anticipated that it would largely eliminate shock loads; moreover, it was considered that the inertia of the tender would be available to absorb the horizontal forces set up by the unbalanced reciprocating parts.

It will be seen later that we recommend a change; in fact, this was foreshadowed in 1932 when the 'Goodall' type was dropped by the Railway Board as a standard. In that year, a Senior Railway Officer was deputed by the Board, with one of the Consulting Engineers, to investigate Continental drawgear practice, and visits were paid to various French and German Railways, a report being submitted to the Board. It was pointed out that French and German authorities then held divergent views on the subject of lateral control, but both agreed that it was advisable to use the tender to assist as a stabiliser, though different means were adopted to achieve this object. Further, it was observed that conditions at that time in Germany permitted Pacific engines to run satisfactorily with considerably lower initial control values than those adopted in France (*vide* Chapter VII), and no clear lead emerged from this visit as to the correct values for Pacific engines. We were informed that the Consulting Engineers received no acknowledgment of their report.

39. *The Bogie.*—The correspondence on this subject appears to have commenced in January 1926 with a letter from the Railway Board to the High Commissioner for India, proposing to substitute a three-point-suspension bogie for a spring controlled mechanism; it was felt that the latter was contributing to the hot box trouble which was then being experienced

on the E. I. R. In September, the C. M. E.'s of the four British Railways were referred to on the point by the Board's representative, and the Consulting Engineers agreed to adopt gravity control. In October, the Board's representative wrote to India saying that design was proceeding on the three-point-suspension link type, which was the arrangement adopted for controlling the Bissel truck of the 2-8-0 engines; the question, however, of wear and tear was raised, and shortly afterwards the Consulting Engineers advised that the cost of maintenance was likely to be greater than for the spring controlled type. Information with regard to heavy wear on pins and links had been received by them, especially relating to the bearing surfaces at the top pins where lubrication was difficult.

Further, the Board's representative in London drew attention to practice on British and German Railways as adhering to spring control; the Board were, therefore, requested to review the question. They wrote on the 27th October saying that "*if you have not already finally decided on the design, it might be as well to follow the Baldwin* (*swing link*) *arrangement, as fitted to the 4-6-2 M. & S. M.* (*experimental*) *locomotives, as I understand that they have experienced no trouble, also the bogies do not run hot and the engines ride extremely smoothly*". The outcome, however, was that on the 18th November, the Board somewhat reluctantly agreed in the following terms, having regard to the representations of the Consulting Engineers:—"*We approve of the engine bogies being fitted with spring-controlled lateral motion, although I must submit I am not altogether satisfied that spring-control is preferable to gravity-control. But in view of the modifications to the engine bogies, which you propose to effect, we should get over the trouble due to hot bogie boxes*", which was to be dealt with by increasing bearing surfaces. By this, as it was explained to us, the Board's concurrence at the time did not go beyond the general design of the spring-controlled bogie; they did not specifically approve the actual amount of the initial side control provided, 15 cwts., as this point was not referred to them, and it did not come into prominence until the first report of hunting was made to the Board by the E. I. R. in January 1929, seven months after the first case occurred.

There is no doubt that prolonged consideration was thus given to this matter; the Board's representative in London visited Swindon for the purpose in October 1926, and afterwards advised the Board with regard to G. W. R. practice and their preference for spring-control rather than for gravity-control. Subsequently, a special arrangement with side check springs was considered, each axle being independently sprung; there is some evidence from the Builders' records that the object of this arrangement was to make the side control springs more accessible for examination and repair than in the B. E. S. A. design. It was decided, however, to abandon this in favour of the arrangement in use on the 4-6-0 engines (except that the wheelbase is longer), thus affording spring compensation between the axles, which was considered to be a desirable feature.

The Consulting Engineers informed us that the decision to retain this design was taken solely because it was considered to be thoroughly satisfactory, and had already proved to be so under Indian conditions for at least 20 years on the 4-4-0 and 4-6-0 types of locomotives. Similar bogies had also been incorporated in the design for the pre-standard 4-6-2 engines which, at that time, had been in use for nearly two years. There was no suggestion that trouble or expense might be saved, and it appears that a reasonably wide view of the matter was taken at the time. The design was finally approved at the Builders' Works in March 1927.

40. *Difficulties of design.*—The Consulting Engineers pointed out that in new designs, certain teething troubles were to be anticipated and their elimination was bound to require a considerable period of running experience. They also pointed out that the principal sources of information open to them about running troubles were the Proceedings of the Locomotive Standards Committee, and that such troubles must, for the most part, be dealt with by the Engineers on the spot; observation concerning influences,

such as the bogie control etc., can of course only be made under running conditions. Further, the Consulting Engineers emphasised that maintenance of the engine itself, and maintenance of the track, materially affect the running of an engine.

In this connection, frame and coupling rod fractures will be mentioned later; the Consulting Engineers were not advised of the full extent of the troubles, but they were informed that cracks had developed in the leading coupled horns of some of the original engines. More rigid construction was, therefore, embodied in later designs by means of horizontal cross-bracing from the saddle casting to the trailing coupled wheels. The matter was referred to in the Proceedings of the Locomotive Standards Committee of 1929 and 1931; but the Consulting Engineers informed us that, in the absence of reports to the contrary, they assumed that the measures taken had prevented recurrence of fractures. They did not, however, consider that the original design was faulty, and, in support of this, pointed out that the M. & S. M. R. had experienced fewer frame fractures than other systems. They attributed the incidence of this type of failure elsewhere "*to rough permanent way, indifferent locomotive maintenance, and the existence of abnormal side clearances in the axle boxes*".

PROCEDURE ADOPTED FOR, AND THE CIRCUMSTANCES ATTENDING, PURCHASE.

41. *Contracts.*—When the stage of tendering was reached, design had developed to the extent of a set of four basic drawings for each type, and these, together with the specification covering the details, had been prepared by the Consulting Engineers. In July 1926, contracts for 68 locomotives (26 XA, 30 XB, and 12 XC) were placed with the firm of Builders in England who had submitted the lowest suitable tender. The Firm, with the representatives of which we had the benefit of discussing the matter, is one of long standing, with an established and world-wide reputation and experience in the construction of locomotives for many countries including India. Some of the later engines were constructed by other well known British Locomotive Builders, whose representatives we have also interviewed. The following statements give the details of the contract dates, present distribution, etc., for all the 284 I. R. S. Pacific X type engines, which are included in our terms of reference.

Contract dates for XA Engines.

Railway Board's letter authorising purchase.	Railway.	No.	Indent No.	Contract date.	Rear truck spacing.	
204-S of 10th December 1925 to High Commissioner for India.	N. W. R.	2	66/1926			
	G. I. P. R.	2*	3/1926	28-7-26	7'-0"	
	E. I. R.	2	47/1926			
314-S of 5th October 1927 to High Commissioner for India.	G. I. P. R.	20*†	112/1927	3-4-28	7'-0"	XA1.
314-SI of 18th October 1928 to High Commissioner for India.	G. I. P. R.	25*	112/1927	8-6-29	7'-0"	
	N. W. R.	14	45/1929			
1173-S of 28th November 1929 to High Commissioner for India.	N. W. R.	27	32/1929	14-7-30	8'-0"	XA2.
3200-S of 19th June 1930 to Railways concerned.	N. W. R.	7	12/1930	22-12-30	8'-0"	
	G. I. P. R.	10	14/1930			
	N. S. R.	4	529/1934	Not known	9'-0" Shipped in Sept. 1935.	
Total		113				

* Al XA type engines on G. I. P. R. (including 8 subsequently transferred to N. W. R.) have had rear truck spacing increased in India to 9'-0".

† 8 engines since transferred to N. W. R.

Present distribution :—

E. I. R.	2
G. I. P. R.	49
N. W. R.	58
N. S. R.	4
Total	113

Contract dates for XB Engines.

Railway Board's letter authorising purchase.	Railway.	No.	Contract date.	Rear truck spacing.
204-S of 10th December 1925 to High Commissioner for India.	E. B. R.	5*	28-7-26	8′-0″
	E. I. R.	14		
	G. I. P. R.	9†		
	S. I. R.	2	14-7-27	8′-0″
314-S of 5th October 1927 to High Commissioner for India.	E. B. R.	12*	1-6-28	8′-0″
	N. S. R.	3	1-8-28	
	S. I. R.	9	23-8-28	
314-S of 23rd August 1928 to High Commissioner for India.	E. B. R.	11	30-4-29	8′-0″
	M. & S. M. R.	12‡	3-5-29	
	N. S. R.	4	20-6-29	8′-0″
3200-S of 19th June 1930 to Railways concerned	E. I. R.	10	22-12-30	9′-6″
	M. & S. M. R.	6	29-12-30	
35/70/S of 5th July 1934 to M. & S. M. R.	M. & S. M. R.	2	12-6-35	10′-6″
Total		99		

Present distribution :—

E. B. R.	18
E. I. R.	38
M. & S. M. R.	25
S. I. R.	11
N. S. R.	7
Total	99

Contract dates for XC Engines.

Railway Board's letter authorising purchases.	Railway.	No.	Indent No.	Contract date.
204-S of 10th December 1925 to High Commissioner for India.	N. W. R.	2	66/1926	28-7-26
	G. I. P. R.	6§	3/1926	
	E. I. R.	2	47/1926	
	B., B. & C. I. R.	2	B/23/1926	15-9-26
314-S of 5th October 1927 to High Commissioner for India.	E. I. R.	20	78/1927	18-10-28
	B., B. & C. I. R.	8	B/1/28	22-10-28
314-SI of 18th October 1928 to High Commissioner for India.	N. W. R.	26	45/1929	17-5-29
	E. I. R.	6‖	52/1928	
Total		72		

Present distribution :—

N. W. R.	28
E. I. R.	30
B., B. & C. I. R.	14
Total	72

* 4 Engines from 1st batch and 6 engines from 2nd batch subsequently transferred to E. I. R.

† Subsequently transferred, 5 engines to M. & S. M. R. and 4 engines to E. I. R.

‡ These 12 engines (together with the 5 engines transferred from G. I. P. R.) have had rear truck spacing increased to 10′-6″ in India.

§ Subsequently transferred to E. I. R.

‖ 4 Locomotives subsequently transferred to the B., B. & C. I. R.

42. *S. I. R. X Class Pacifics.*—The Consulting Engineers to this Company informed us that, in 1924, they were asked to express their opinion upon the First Report of the Locomotive Standards Committee; but the information available therein did not then permit of criticism. It was subsequently left to the Company in India to decide on the types of I. R. S. engine best suited to their requirements, and, when the firm received an indent in 1927 for two XB and two XD engines for this system (the Indent being included in a combined call), it was ascertained that the detailed drawings were under preparation by the Consulting Engineers to the Government of India; the firm, therefore, confined themselves to inspection and certification, in accordance with the terms of the contract. In view of the Railway Board's conditions that, without their permission, no alterations were to be made to standard designs, either by the Railway using them, or by the Consulting Engineers, or by the Builders, we were informed by the firm that they did not interfere, nor were they invited to offer criticism. Moreover, as the work progressed, and they had opportunities to examine the detailed drawings, they had no occasion to take exception to the design; they were satisfied that, so far as the track and local climatic conditions were concerned, these engines would be suitable for use on this system. Subsequently, in October 1927, a further Indent for nine XB engines was received and dealt with as a repeat order.

43. *N. S. R. X Class Pacifics.*—Until the 31st December 1931, the firm concerned in this case were the Consulting Engineers to the Government of India, and they dealt with the purchase of seven XB engines in 1928 and 1929. Subsequently another firm advised this Administration, and dealt with the order for four XA engines in 1934; certain modifications were specified for these later engines as follows:—

(a) The substitution of a laminated spring control bogie for the standard design;

(b) The cutting away of the frame to permit of clearance for the trailing bogie wheels.

The latter firm of Consulting Engineers were advised that these modifications were considered necessary to improve the riding of this class of engine, which had been in use in India since 1928; they did not, therefore, feel competent to question the design, which was not new, nor were they asked to do so. Moreover, they had no reason to consider that the design was unsatisfactory, and they confined themselves to functions of inspection and certification in accordance with the terms of the contract.

44. *B. N. R. Pacifics.*—Reference has been made in paragraph 29 to the 18 B. N. R. M class Pacific engines, which were brought into service about 1930. The Railway Board agreed to the purchase of these engines on condition that they generally followed one of the standard designs and that all standard details were incorporated; as already stated, the underlying idea was to compare simple and compound engines of the Pacific type. The Consulting Engineers to this Company informed us that they accepted no responsibility for the standard features, for example, the springing, compensation, bogie, and hind truck construction, etc., as these were specified in the Indent as follows:—"*These engines shall have, as far as possible, wheels, tyres, axles, axleboxes, springs, parts, fittings, etc., which are standard for the standard XC type of engine.*" The firm were, therefore, merely concerned in assuring that the engines were built to the specification which was received from India.

The Central Standards Office.

45. *Inauguration and Duties of the Office.*—The Locomotive Standards Committee continued to function until 1930, up to which time the technical work of the Committee in the way of design, and preparation of drawings, etc., had been carried out by the Consulting Engineers, and by a Technical Section in the Railway Board's Office. We understand that the object

aimed at in forming the Central Standards Office, under the Chief Controller of Standardisation, as part of the Railway Board's organisation, was to standardise all equipment, commonly in use on Railways, and to provide means whereby "*Standardisation could be progressively effected in accordance with changing conditions and as a result of practical experience*". On the Mechanical side, the Office appears to have confined its attention, until 1936-37 and onwards, almost exclusively to I. R. S. designs of rolling stock. Since then, however, it has become increasingly recognised that the Office should concern itself in various matters arising from the use of the pre-I. R. S. designs, such as—

(a) The examination of dynamometer car reports, and development arising therefrom;

(b) Proposals for modernising B. E. S. A. type engines, etc.

46. *Work undertaken by the Office.*—Subject to the above, the work has been based on the advice of the following seven Standing Committees :—

(i) Locomotive Standards Committee formed in 1924.

(ii) Carriage and Wagon Standards Committee formed in 1924.

(iii) Track Standards Committee formed in 1925.

(iv) Bridge Standards Committee formed in 1925.

(v) Signal and Interlocking Standards Committee formed in 1926.

(vi) Stores Standards and Specifications Committee formed in 1928.

(vii) Electrical Standards Committee formed in 1935.

The Central Standards Office provides a Secretary for each of these Committees, the personnel of which consists of a few selected officers from Class I Railways. We were informed that the advisory functions of these Committees remain unchanged, but it appears that the Chief Controller of Standardisation has an overriding authority and acts for the Railway Board.

Originally, the work of preparing standard drawings and specifications was dealt with, on behalf of the Board, by the Consulting Engineers, by officers on special duty, and by various Railway Administrations. In 1931, however, it was decided, for the first time, to invite tenders for locomotives simultaneously in England and in India, and, following upon this decision, the Central Standards Office had to undertake, in addition to the work already devolving upon it, the preparation of tender documents, namely, Specifications, Tender Forms, and Schedules.

47. *Relations between the Central Standards Office, the Consulting Engineers and Manufacturers.*—Since 1930, when the Central Standards Office was formed, the technical control which was formerly exercised by the Consulting Engineers, has been modified. Very briefly, the history of events was that when the Government of India decided in September 1928 to institute the system of Rupee Tender Purchase in India, an endeavour was made to bring the organisation of the Consulting Engineers into closer accord with Indian requirements. A Branch Office was, therefore, established in Calcutta in 1929 for the purpose of providing expert advice in the preparation of technical projects, specifications and drawings, and for the examination of tenders for technical stores, etc. The cost of this Branch was partly defrayed by the Government of India, and the primary object was to assist in the establishment of the Rupee Tender Purchase System; a secondary function of this Branch developed later, by which a liaison was maintained between the London Office, the Central Standards Office, and the various Railway Engineers. The impossibility, however, of the firm keeping experts in every type of engineering in India, together with the establishment of a regular Air Mail, which made communication easier and enabled a large number of cases to be referred to England, were among the reasons which brought about the closing of the Branch Office in December 1931.

The functions of the Controllers of Stores were increasingly transferred to the Chief Controller of Stores, Indian Stores Department, in accordance with the Rupee Tender Purchase Policy. The effect of the above and other changes was, first, that the technical control of rolling stock and stores purchase was largely transferred from England to India, with the result that the onus of preparation of specifications fell upon the Central Standards Office, and, secondly, the office had to undertake all the drawing and specification work which had previously been delegated to the various Railways. With regard to locomotives, however, the Consulting Engineers, in collaboration with the Builders, continue to deal with the detailed design; they are also responsible for inspection and general liaison with manufacturers.

The Railway Board informed us that the relationship between themselves and the Consulting Engineers is, and should be, exactly the same as between any other organisation or firm which employs Consulting Engineers; the latter, being specialists in touch with modern practice in Europe and America, advise the Board and offer such criticism as they consider necessary on any proposals which may be put forward by the Board. It is also intended that they should assist and guide the Manufacturers, who, in accordance with general practice, accept, as contractors, responsibility for what they supply. Calculations in connection with the design are made by the Consulting Engineers, who must accept responsibility for the same; but as the Railway Board were, and are, generally kept advised on details of design, there is joint responsibility between them and the Consulting Engineers.

We understand that one of the most important duties devolving upon the Central Standards Office since 1930 has been the preparation and distribution of part-drawings, of which some 2,800 are in existence today. In 1937, a decision was also made that the part-drawing system should be extended to all the standard types of locomotives and, as a beginning, the Consulting Engineers were asked to arrange with the Builders for their preparation, as part of the fulfilment of current contracts.

SUMMARY OF PERFORMANCE OF X CLASS PACIFIC ENGINES IN SERVICE.

48. *Statistics.*—Up to the 31st March 1938, the mileage run by the 113 XA engines was over 34 millions; by the 99 XB, $34\frac{1}{2}$ millions; and by the 72 XC engines, $21\frac{1}{2}$ millions; for the 284 engines concerned, therefore, the total was 90 million miles. Owing to the system of accounting, it has not been possible to segregate the cost of maintenance of any particular type of engine; but there have been 347 frame fractures on the 284 engines, and no less than 205 fire-box tube plates have had to be changed, due to cracks in the radius. The XC engines on the B., B. and C. I. R. were withdrawn just prior to our visit because of coupling rod breakages, a trouble which has also been experienced on other lines. On the E. B. R., operating 18 XB engines, it appears that the average time these spent in the shops under repairs was three years out of a total average life of eight years, *viz.*, no less than 37 per cent. of their time.

Derailments.—It appears that while XA and XB class engines were hauling passenger trains. 10 derailments, attributed, or since believed to have been due, to hunting, occurred prior to that at Bihta, the last in October 1933. Two such derailments of an M class Pacific also occurred in 1930. Some of these accidents, and perhaps all, were accompanied by distortion of track.

Distortion of Track.—Information on this subject is contained in the Proceedings of the Judicial Inquiry into the accident at Bihta. It appears that recorded track distortions by 38 XB and 30 XC engines on the E. I. R. alone amounted to 64, between June 1928 and September 1937, the majority in 1932—1934. Of these, 41 had been reported before this accident (the last in November 1933) and 23 after it. It was subsequently realised that the absence of reports of distortion after November 1933 was not sufficient to justify the assumption that the alterations which had been made to the engines had effectively eliminated their propensities to distort track, and the E. I. R. accordingly carried out a special investigation. The Investigating Officer reached the conclusion that certain Permanent Way Inspectors had unfortunately refrained from reporting such cases "*preferring to adjust the defects and remain quiet rather than risk disciplinary action for an occurrence, the cause of which they were not responsible.*" Twenty additional cases of distortion were disclosed, the extent of which would have necessitated the imposition of a speed restriction. As a result, the Investigating Officer also concluded that :—

> "*The design of the X class engine is such that, given circumstances favourable to its peculiarities, the tendency to hunt is much more accentuated than in the case of other classes of engines. For example, it will be seen that of the cases now recorded no less than 17 occurred where one of the following conditions existed :—*
>
> (*a*) *The bank was constructed of either black cotton soil or yellow clay, and, therefore, difficult to maintain, especially during the Monsoon.*
>
> (*b*) *A change of alignment, as, for example, from the straight to a curve or* vice versa.
>
> (*c*) *Defective cross levels.*
>
> (*d*) *Lack of ballast.*
>
> (*e*) *Absence of lateral stability in the design of the rail and the composition of the permanent way as a whole.*
>
> *Speed would also appear to be a definite factor, for, in each case, distortions occurred where conditions were favourable to high speeds.* . . . . .
>
> *Of the 821 miles of track inspected, there is only one section where it can be said that the conditions are as near perfect as possible for any considerable length, and that is between Salanpur and Jhajha. The banks of this section are constructed in very good soil, moorum and clay. The track consists of 115 lbs. F. F. rails on wooden sleepers (n plus 3) with the exception of portions of the Up track, which are laid with 100 lbs. F. F. B. S. and 90 lbs. F. F. R. B. S. rails. The section is well ballasted, the alignment good, the track well-drained, and practically all curves of 2° and over transitioned. On this section very high speeds are attained, and yet not a single complaint was received of track distortion.*"

Other examples of extensive track damage took the form of gauge spreading on the B., B. and C. I. R., during the monsoons of 1930 to 1932, on the Nagda-Muttra section. In 1930, 71 places were affected on 13 days; in 1931, 28 places on 9 days; and in 1932, 25 places on 8 days. This Railway was operating 14 XC engines.

49. *Object of the Summary.*—This summary of the more important facts and correspondence (some of demi-official nature) relates to the performance as vehicles of the engines concerned, to the accidents in which they were involved, and to the steps taken to improve their riding after delivery in India. Having regard to the mass of information before us, the references must necessarily be brief, and this is emphasised because we do not wish any of the matter recorded to be misinterpreted, or to give rise to unnecessary criticism and contention. Our sole object in including this summary is to provide a representative and historical picture of the views held at the time about the troubles which were being experienced, and of the action taken; also of the uncertainties, contradictions and disappointments encountered in overcoming the problem which the operation of these engines presented. It is evident that the nature of the problem was not appreciated until recent years, during which time material strides have been made in research on Indian Railways, to the credit of all concerned.

1928.

50. *Commencement of Operation.*—The first XB engines were despatched in October 1927 and were placed in service for the first time on the 24th January 1928, on the E. I. R.; after a fortnight the Bridge Engineer reported that they were the "*most wonderfully smooth running engines*". In June, 14 were in service on this line, five at Jhajha and nine at Asansol; the Divisional Superintendent in control of the former reported that the engines "*run and steam very freely and are simple to operate. There is no difficulty in making up time. At present a slight amount of trouble is experienced with certain parts of the engine, but there is nothing that cannot be put right*". As already mentioned, however, it was in May that hunting was first reported, and, on the 26th June, the first disturbance of track occurred on the E. I. R.; a report made to the C. M. E. of the G. I. P. R. in October also stated that "*on bad road XB type engines are more sensitive so far as side oscillation is concerned than the D/5*" (B. E. S. A. 4-6-0 type). They had been operating for seven or eight months on that line.

1929.

51. *Report that bogie control springs were weak.*—The Railway Board reported to the Consulting Engineers in January that "*the bogie and lateral control springs have been found very weak, permitting excessive lateral movement of the bogie table and a tendency to spread the track*". The engines had then been in service a year, and, having regard to the Board's instructions that no alteration was to be made without authority, consideration of the necessary modifications was pursued by the Consulting Engineers in correspondence, which went on for some months, in connection with the engines then building. The springs which had been provided for XB engines did not differ materially in strength from those fitted in the two lighter PS engines, which had been running since 1924 on the E. I. R., and the point will be referred to later.

Talandoo, E. I. R.—In the meantime, in February, at Talandoo, the derailment took place in the early morning of the rear 4-wheeled coach of an express passenger train, which was being hauled by an XB engine; the train was closely following a mail, also hauled by an XB engine, and both were travelling at about 50 m. p. h. The first driver felt a lurch which he attributed to broken or weak bogie control springs, and it was sufficiently severe to make him stop, to examine the engine (found in order), and to send a message back to impose a 10 m. p. h. restriction. The second driver actually observed distortion of the track ahead, and was thrown down on the footplate as the result of severe oscillation; there had been insufficient time to warn him. This distortion, and the derailment, took place on 88½ lbs. B. H. rails on new *sal* sleepers, but D. & O. plates with wood sleepers (some very old) at the joints were also distorted at several places for a considerable distance.

It was stated that the bank was well consolidated, that there was plenty of ballast, that joints were in good order with room for expansion, and that there was no trouble from creep. The Permanent Way Inspector attributed the accident "*to excessive side play by the XB engines pushing the track out of alignment*"; but the S. G. I., who held an Inquiry, found difficulty in explaining the deformation of the track. The Chief Engineer, however, immediately imposed the first speed restriction on all XB engines on the E. I. R. of 45 m. p. h., which was "*on no account to be exceeded*", and, in consequence, they were removed from mail and express services. On the other hand, the Railway Board appear to have considered that there was not sufficient evidence to show that the XB type of engine was to blame. They published no Report of this accident, but they took action and initiated trials (referred to later) with stiffer bogie control springs and many other alterations.

Experience on G. I. P. R. and E. B. R.—In July, an XC on the G. I. P. R., after mileage of only 43,347, was apparently the first to develop a cracked frame (2½ in.) in the root of the leading horn. This Administration reported in September that all three types of Pacifics were giving satisfactory service, except that the XC showed up unfavourably in fuel consumption, as the economic load was "*greatly in excess of the normal loading of mail and passenger trains*". There were then at work on this system 22 XA, 9 XB, and 6 XC engines; the last-named 15 were subsequently transferred.

In August, the E. B. R. reported spreading of 75 lbs. and 90 lbs. F. F. track by XB engines and the fact that a trial had satisfied the Executive Engineer concerned that running these engines over reasonably maintained track, even with the existing bogie control springs (15/50 cwt.) was not at all dangerous; but it was established that over bad track "*nosing was easily set up and built up until a condition was reached which was undoubtedly dangerous*". The Chief Engineer concerned was advised of the tendency, as it necessitated a higher standard of track maintenance; still further strengthening of the bogie control springs was recommended, and an increase in the rectifying force of the Cartazzi axle box. The engines had then been working on the E. B. R. for about 15 months.

Railway Board's Trials.—In consequence of the speed restriction thus imposed by the E. I. R. and by the E. B. R., and the recognition of the inadequacy of the strength of the bogie control springs, the Railway Board, as mentioned above, initiated a long series of trials which commenced early in 1929 and continued until September 1930; these trials incorporated many detailed changes, besides the strengthening of control springs, of which the more important were :—

(a) Alterations to the Cartazzi trucks, slides, etc.

(b) Various alterations in spring compensation.

(c) The introduction of intermediate buffers between engine and tender.

(d) Cartazzi bogie slides in place of spring control.

For instance, on the E. I. R., in February, the PS type bogie control springs were tried, and ⅜ in. washers were fitted to increase pressure. In March, the engines were being carefully watched "*with a view to getting them back on the fast services early*". In June, the Chief Mechanical Engineer, having ascertained that PS type springs were unsuitable, refused to allow XB engines to return to mail and express services until the fitment of 22/70 cwt. control springs.

In September, consideration was given to increasing the distance between the trailing coupled wheels and the hind truck. At this time, the 22/70 cwt. springs were tried up to 73 m. p. h. and appeared to afford no improvement; collars on the leading and trailing coupled journals with flangeless driving wheels were suggested by the Testing Officer. Later, orders were issued for the re-introduction of the original 15/50 cwt. springs on all X class engines.

In October, the Consulting Engineers reported having interviewed a former Chief Mechanical Engineer of a British Railway, who also advised against increasing bogie spring control, his experience having been that when all clearances were restored to normal, after an engine had passed through the shops, hunting entirely ceased. At the same time, the Consulting Engineers suggested that, as nothing had been heard of hunting when the engines went into service, "*it looks as though this trouble has only developed after the engines have been running some time . . . . the idea of tightening up clearances generally all round may be worth following up. I quite think that the trouble results at the hind end and not at the front*".

In November, at the instigation of the Board, the E. I. R. also tried rubber control springs on an XB engine at speeds up to 72 m. p. h.; this was not deemed successful and "*lateral movement was not easy but jerky*". By the end of this year it had been established that XA and XB engines were liable to hunt, and the co-operation of the Locomotive Standards Committee was sought; it appears that during the trials and experiments that were being carried out in India at this time, the Consulting Engineers were also generally kept informed of what was being done, though not formally asked to assist.

1930

52. In January, a meeting was held at which the Board was represented, to discuss the running of XB and XC engines on the E. I. R.; it was decided to run trials for a fortnight, on an ordinary express service, with XB engines having further modifications. In February, speeds up to 75 m. p. h. were attained and, subject to maintenance of track in the same condition, it was considered that the engines could safely be put back into mail service; but the Consulting Engineers advised trial with an inclination of 1 in 7 for the Cartazzi slides, as this was then being used on some of the latest L. & N. E. R. engines. In April, the Locomotive Standards Committee called upon the E. I. R. to test this, with 22/70 cwt. springs and combinations of $\frac{1}{8}$in. and $\frac{7}{8}$ in. liner plates on the bogie frames, and $\frac{3}{4}$ in. and 1 in. washers on the spring pin; also with intermediate buffers. The Board thus concluded that the hind truck control could with advantage be increased, and they decided, in June, that the truck should be moved back 1 ft. 0 in. and 1 ft. 6 in. on all future XA and XB engines respectively. This was probably the most costly single alteration made on existing engines.

In February, the Board also indicated to the Consulting Engineers for the first time that the Goodall drawgear was a possible contributory cause of oscillation *"due to the fact that when the train overrides the engine, the drawbar is in unstable equilibrium which tends to aggregate any oscillation which may be set up. . . . I have consequently decided to fit a gear similar to those in general use in America to an XA engine on the G. I. P. R. for experimental purposes"*.

In September, the Board initiated trials with the balancing of reciprocating parts altered from 66 per cent. to 33 per cent. and in the following February it was decided to effect this reduction in future. In December, the Locomotive Standards Committee discussed the hunting of XB engines, and an inclination of 1 in 5 for the Cartazzi slides was subsequently tried. The Board also agreed to the experiments which the Committee suggested with still greater strength, 31/90 cwt., for bogie control springs, combined with reduction of lateral movement to 4 in.

Wardha-Balharshah, G. I. P. R.—In the meantime, in April 1930, an XA engine, hauling the Grand Trunk Express, was derailed on the straight between these stations, and the Consulting Engineers were informed, as the result of enquiries from all divisions, that *"the oscillation at times is so severe that the engine crew find it almost impossible to stand on the footplate without holding on to a cab pillar or other support"*.

Further Experiments.—In June, the Consulting Engineers suggested tests with the removal in turn of the spring compensating beams, saying that *"when an engine is new with normal journal and axle box clearances, etc., the tendency for oscillation to be set up is less, and the damping effect or friction greater"*; they added that no reports had then been received from Metre Gauge railways of bad riding of the new Pacific engines, presumably on account of lower speed. On the other hand, we heard evidence from a Chief Mechanical Engineer, who stated that *"these engines hunted extremely badly from the start (1932), and, after 10,000 to 15,000 miles only, this defect became so bad that a severe speed restriction had to be imposed involving a slower time-table"*. He stated, however, that he quickly cured these engines, and others, by providing the rubbing block type of spring loaded drawgear in place of the Goodall coupling.

In July, the Board informed the Consulting Engineers that the trials on XA type engines had not proved entirely satisfactory, and that stops were being fitted to cut out the spring compensation; the Manufacturers of the 27 XA engines which were then building were therefore told to hold up the bogie frame castings and the details of hind trucks, pending instructions. On the other hand, in August, improvement in riding was reported, due to the elimination of compensation between the leading and driving wheels; it had "*a most remarkable effect in steadying the engine*", and similar alterations were to be made to the XB type.

Bina-Jhansi, G. I. P. R.—In October and December, however, two more derailments of mail trains, hauled by XA engines, occurred, and the causes will be referred to later.

Majdia, E. B. R.—At the end of July, the tender of an XB engine hauling the Darjeeling mail, while travelling at 40-50 m. p. h. was derailed; it had been in service for two years. An Officers' Inquiry found that the track had been distorted for about ½ mile, and the cause of the derailment was attributed to this buckling of the line; they also considered that the XB type of engine, at high speed, was severe on the track, which consisted of 90 lbs. F. F. rails on wooden sleepers. The tender was of the six-wheeled type, and it was suggested that, had the tender been of a bogie type, it might have ridden through the distorted portion of the track without derailment. The S. G. I. did not hold an inquiry, but, after visiting the site, he disagreed with the finding because, in his opinion, the line could not have buckled (due to temperature), the accident having occurred at night; one of the control springs of the bogie was found to be broken, and the S. G. I. in his final note remarked that :—

> "*. . . . the cause of the derailment was excessive speed for this type of engine. The usual and probably regular oscillation of this type of engine, increased perhaps by the staggered joints on a very flat curve, was suddenly modified or arrested by the change of resilience in the track at the level-crossing, resulting in the sudden fracture of the right hand bogie check spring, which in turn set up a screwing motion in the engine and the distortion of the track, probably by side blows of the trailing (radial) wheels of the engine just ahead of the tender. The distorted track and the broken axle box were, I think, the results of the accident, not causes.*
>
> "*Similar distortion of the track occurred at Talandoo Station accident on the E. I. R. on the 8th February 1929 where an XB type Engine was concerned, and the Chief Engineer imposed a speed restriction of 45 m. p. h. for XB type engines throughout the line. A similar restriction should be imposed on the E. B. R. until such time as there is definite improvement in the steadiness of these engines. They are hard on the track, the upkeep of which apparently does not keep pace in the rainy months with the damaging effect of those engines.*"

He recommended a general slowing down of the faster trains hauled by XB engines: but the Administration decided to impose local restrictions of speed, wherever these were considered to be necessary, as alterations were then in hand to reduce the oscillation of these engines.

Kotarlia, B. N. R.—In July also an M class Pacific engine was twice derailed when hauling passenger trains. On the first occasion the leading driving wheels only left the road; this was attributed to slack packing which had been adversely affected by heavy rain, and which "*threw out the alignment and superelevation*" on a curve; the track had been re-sleepered some months previously when the ballast had been disturbed, and consolidation had necessarily been destroyed. The Chief Engineer remarked that the engine was very heavy and "*appears to be susceptible to considerable side oscillation when any slight irregularity of track is met with. I am of the opinion that a GS engine (B. E. S. A. 4-6-0) type would not have left the rails under the conditions which caused this accident*".

Hathbandh, B. N. R.—When the second derailment occurred, the S. G. I. held an Inquiry, from the report of which it appears that serious results were fortunately avoided. Straight track was involved and consisted of 90 lbs. F. F. rails, secured by two screw spikes to N *plus* 3 Sal sleepers laid in 1912-14, with a full section of stone ballast. Gauge varied from an $\frac{1}{8}$ in. tight to $\frac{3}{8}$ in. slack, and, due to weakness of fastenings and sleepers, which required renewal, the rear of the engine, the tender, and some coaches dropped between the rails. The bogie brasses showed signs of weight having been thrown on to the outside of the boxes; the horn cheeks indicated binding at top, back and front. The engine had been in service for only seven months and had had 11 hot boxes; the maximum recorded was 34 during this period on another engine of this class. Designed maximum axle loading was 21·45 tons, but the actual average was $22\frac{1}{4}$, with a maximum on the leading coupled wheels of $22\frac{3}{4}$ tons. Engine and tender weighed 171 tons, and the train 287 tons; speed was not less than 50 m. p. h.

The reports of the Permanent Way Inspector had not been given the attention they deserved, and the S. G. I. concluded that the derailment resulted from the existence of unserviceable sleepers, which afforded insufficient lateral support to the rail fastenings; also that high speed and the condition of the engine were contributory factors, the case illustrating the punishing effect which a heavy engine is likely to exercise on laterally weak track, when the margin of safety has been unduly lowered. In violation of rules, the engines had been put into service before the sanction of the S. G. I. had been obtained.

The Agent reported to the Railway Board upon the engine as follows:—

"*The condition of the track was not good. The fact that this class of engine has been concerned in two or three derailments in which the engine has remained on the track clearly proves, in the opinion of my Chief Mechanical Engineer, that the engines have no serious defects in their running design which warrant any alterations being made. There is, however, no doubt that this particular engine had marked tendency to hunt and nose when running over weak spots in the track, this tendency being noticeably worse than in the case of any other engine of the same class. Experiments are, however, being made to strengthen the bogie transfer slide springs which will help to overcome the undue hunting and nosing action on a rough track. The compensating gear on its coupled wheels and the radial truck is also being modified by cutting out the compensation between the trailing coupled wheel and the radial axle. This it is hoped will have a tendency to steady down the running of the engine.*"

The Chief Engineer's explanation with regard to track condition was as follows:—"*Due to the fact that our demands for funds for sleeper renewals were so drastically cut down by the Railway Board, I had been unable to let the District Engineer, Bilaspur, have the sleepers he had asked for.*" The action taken was to provide bearing plates and an additional spike at each rail seat on wooden sleepers, where M class engines were running. Following this accident, the Chief Engineer also caused a series of footplate examinations to be made at the end of the rains, after which conclusions were formed that M class Pacific engines were very sensitive to track irregularities; that their oscillation was damaging to the track; that the bogies were "*not guiding the front end of the locomotive on curves*"; that there was little, if any, difference in riding on 85 lbs. and 90 lbs. track; that the track in places "*is not maintained in the condition necessary for these engines at speed*"; and that "*in several places there is an unstable road bed (black cotton soil) and in these places the irregularities in the track cause definite bad riding with M class engines.*" The resulting recommendations were that the earlier engines should be restricted to 45 m.p.h., pending alterations; that all the engines should be restricted to 50 m.p.h. where unstable road bed existed on black cotton soil; that experiments be carried out to improve the riding on poor track; and that a higher standard of track maintenance should be initiated by footplate inspection and possibly by increased staff on the sections of line concerned. In this connection it was pointed out that these engines were "*exceedingly powerful and fast, and without being driven hard in any way will commonly accelerate to 60 m.p.h. by the third or fourth mile from a start. The track is, therefore, required better than it has ever been before—not merely as good as it was previously*".

XC Engines on B., B. & C. I. R.—At about this time also, XC engines commenced to give trouble, and the Consulting Engineers received an account from the B., B. & C. I. R. which indicated that it was almost entirely due to the state of the permanent way, which experience was subsequently confirmed. The Chief Engineer complained that the track between Rutlam and Kotah was being distorted and cases of gauge widening were being detected; he imposed a speed restriction of 45 m.p.h. for the monsoon period, and, following the G. I. P. R. experience with their XA's, the B., B. & C. I. R., in December, tried cutting out compensation. It was found that hunting did not occur at less than 60 m.p.h., but the tendency was not eliminated, and the proposal was abandoned as a possible solution. It may be added that, at the same time, the E. I. R. experienced similar trouble with their XC engines.

The B., B. & C. I. R. took prompt action to improve the track. Rails on timber sleepers were double spiked, a course which, as it did not afford an effectual remedy, was subsequently stopped; dirty ballast was screened and replaced; additional ballast was provided under and around the sleepers and for strengthening of the shoulders on curves. Drainage was improved by means of side drains; dry stone walls were built to maintain the ballast in position; and additional sleepers, unspiked, were temporarily placed under the rails on very soft banks. Bearing plates were fitted on all bridges and gauge bars on bridges where distortion had occurred. The existence of water-logged and soft spots, though not detectable by ordinary visual inspection, was indicated from observation of track under load; as an additional indication, paper bags of powdered lime were dropped by hand from the foot plates of engines at spots where serious lurches were felt. If no improvement resulted from repeated re-packing of track where these defects were present, the removal to a depth below sleepers of spent ballast and sodden soil, and replacement by clean ballast, supplied the remedy. To cope with the effect on track of monsoon rains, temporary additions were made to the manning strength to enable these works to be undertaken.

Conflicting Reports.—In December, a letter to the Board from the Consulting Engineers referred to the conflicting nature of the reports received, and said that "*it looks as though the engines (B. G. Pacifics) were all right on good track, but rather too lively on bad track; but I agree with you that they should be capable of running at high speeds even on a poor track*". An example also of the conflicting ideas which then prevailed, and which led to much delay and uncertainty, was the fact that contradictory reports were being received from all over the country, often even from the same railway at different times. One D/O letter of December from the Railway Board to the Consulting Engineers may be quoted:—

> "*Although the G. I. P. R. reported that excessive nosing of the XA had been overcome by eliminating the compensation between the leading and driving wheels, this has not proved to be the case, as the engines working between Itarsi and Delhi are reported to set up a very violent oscillation when they strike a bad patch of track.*
>
> *On my way back to Bombay last week, I travelled on the footplate of an XA on which the compensation had been cut out, and $\frac{3}{8}$ in. packing plates fitted to the bogie side frames, and I must admit that the oscillation set up at times was alarming. It appears to develop at the front end of the engine and increases until the bogie stop comes into contact, after which the engine steadies up until the next bad patch is struck. The engine I travelled on was fitted with 1 in 10 slides and I arranged to travel over the same section on my return journey on an engine altered to 1 in 5 slides.*

The difference in the riding of the two engines was most marked, there being practically no oscillation on the engine fitted with steeper inclination slides, and I was of the opinion that the riding generally was better than the B. E. S. A. 4-6-0 on a similar track. At the same time, the front end appeared to be too lively, and I am convinced that a very much stiffer bogie control spring is required.

I am arranging for trials to be carried out immediately with a stiffer spring to give approximately 40 cwts. in position, and 70 cwts. when the stops come into contact, which I think will materially assist in overcoming the trouble now being experienced..............

I have just received a report from the M. & S. M. R., in which it is stated that they are quite satisfied with the running of their XB's, and as no trouble has been experienced on the N. W. R., it appears to be more a question of track maintenance than defective locomotive design..............

Except for the trouble we are experiencing with the 4-6-2 Broad Gauge engines, which I have not the least doubt will very shortly be overcome, and the YF type, I think we may congratulate ourselves on the success of the standard engines, as they have proved to be capable of doing all that we expected of them when burning the lowest grades of Bengal or C. P. coals. The cost of maintenance is remarkably low, and I am told that when the engines pass through the shops for periodical overhaul after running 100,000 to 120,000 miles, there is practically nothing to do except renewal of a few brasses, brake blocks etc."

1931.

53. *Derailments of XA Engines on the G. I. P. R.*—In the first half of this year three more derailments of XA engines took place when hauling passenger trains, making six in all within 15 months; none of these accidents, which occurred at 40—60 m.p.h., was enquired into by a Government Inspector, and it seems doubtful whether the circumstances were conclusively probed in every case. However, after the first (April 1930) the cause was attributed to "*a combination of the high speed (50 m.p.h.), the lightness and age of the track (69 lbs. D/H rails on 10 cast-iron pot sleepers per 30 ft. rail, fully ballasted, on black cotton soil) and the hunting tendency of the engine at high speed.*"

Local and general restrictions of 30 and 40 m.p.h. respectively were immediately imposed, and, under instructions from the Railway Board, speed trials were carried out with stronger bogie control springs, with reduced side-play in the bogie, with increased inclination of the Cartazzi slides to 1 in 7, and with the addition intermediate buffers between engine and tender. It was found that with these alterations there was no pronounced tendency to hunt up to speeds of 50 m.p.h., but at 60 m.p.h., severe oscillation developed. The Chief Engineer thereupon agreed (July 1930) to relax the speed restriction to 50 m.p.h. over 82 lbs. rails and heavier, and, indeed, after further trials, he removed that restriction in the following month, subject to stronger control springs being fitted, to the reduction of bogie side-play from 3½ in. to 2¾ in., and to the elimination of spring compensation between the leading and driving coupled wheels.

Subsequently, however, three further derailments occurred in succession, and in no case apparently were the officers who conducted the Inquiries able to ascertain the cause; in January 1931, therefore, the Chief Engineer re-imposed a general restriction of 50 m.p.h., and, after the last two derailments (May and June), this was reduced to 40 m.p.h. in July, on the ground that "*there had been six derailments of XA engines between stations, whereas no other type of engine has become derailed in similar circumstances*". The engines were removed from mail and express trains until a new time-table was prepared in September, allowing for the reduced maximum permissible speed of 40 m.p.h. Thereafter, under the advice of the Railway Board and the Consulting Engineers, many further experiments (for results see later) were carried out in 1932 with the hind truck moved back 2 ft., with bogie side-play reduced to $2\frac{3}{4}$ in., and with the engine frame cut away above the trailing bogie wheels to give greater clearance.

With regard to the last-named alteration, all these six derailments of XA engines were attributed, or are since believed to have been due, to hunting on defective portions of track (varying from 69 lbs. D. H. to 90 lbs. F. F. rails), and it was not until the end of the year that the trailing bogie wheels were noticed to be fouling the frames; a clearance of only $1\frac{1}{4}$ in. had been provided compared with $2\frac{1}{4}$ in. on B. E. S. A. 4-6-0 engines, which had considerably longer rigid wheelbase. This fouling had apparently been occurring even on the straight when the bogie hunted in a direction opposite to that of the frame. When play in the boxes and horns had developed, combined with wear of flanges, it seems that the bogie wheels could have become displaced laterally by as much as 1 in. from the position they would otherwise have assumed, had clearance been sufficient. It is doubtful whether this defect directly contributed to oscillation of the engine as a whole; but we feel that it ought to have been noticed by the Builders and the Consulting Engineers, even though it might not have been readily apparent from examination of the drawings.

Borgaon, G. I. P. R.—In August, an express, hauled by an XB engine, was also derailed, and an Officers' Inquiry found "*that the hunting of XB engines on 82 lbs. track was a contributory cause*". The evidence showed that distortion of track by XB engines at night was not an infrequent occurrence. As a result, this Administration devised means of taking dynamometer car autographic tests to determine for an engine as originally equipped :—

1. The critical speed at which XB engines started to oscillate.
2. As far as practicable the extent of this oscillation.
3. The average time of oscillation.
4. The locations at which oscillation commenced.
5. The occasions on which the bogie stops came into contact.

Typical records were also obtained of the time period of oscillation when hunting took place, the test train being run up to 70 m.p.h. The conclusions were that there was no critical speed; that maximum relative movement between engine and bogie frames was $5\frac{3}{8}$ in.; that the period of oscillation varied from 0·82 to 1·32 seconds, the lower at the higher speeds, period and speed being apparently connected by a straight line law; that the XB engine was sensitive to track irregularities, and had a greater liability to hunt over particular places, the hunt not being limited to curves; that occasions on which the slide hit the bogie frame occurred mostly on curves; that oscillation was as bad on 100 lbs. track as on 82 lbs.; and finally that "*the condition of the track is a very important factor in the combination that induces hunting*".

Further tests and action by the B., B. & C. I. R.—With regard to XC engines, another comprehensive series of tests, in January and February 1931, were carried out on the B., B. & C. I. R. under varying conditions of control and with recording apparatus to measure the amplitude of oscillation; the conclusion was reached that the best combination was 22/70 cwt. bogie control springs, $4\frac{1}{4}$ in. total bogie side travel and Cartazzi slides as designed. All engines were accordingly altered, but the Chief Engineer complained of further cases of track distortion, and he re-imposed the 45 m.p.h. speed restriction during the monsoon. The track improvements, which had by then been effected between Rutlam and Kotah, have been mentioned, and intensive examination by officers on foot was ordered; the speed restriction was finally removed in November, and, with the exception of a few slight distortions in 1932, trouble ceased. The permanent way repair works had cost about Rs. $2\frac{3}{4}$ lakhs. Commencing also in 1933, all wooden sleepers were replaced by steel troughs, laid 15 per 36 ft. rail on the straight and 16 on curves; there are now no wooden sleepers in this main line, and, since these renewals and the provision of stronger bogie control springs, no further trouble has been experienced on this section of the B., B. & C. I. R.

Further tests and action by the E. I. R.—As previously mentioned, tests were also in progress on the E. I. R. with XB and XC engines, and they were pursued throughout 1931 under various conditions, 22/70 cwt. and 31/90 cwt. control springs being tried again up to 72 m.p.h. In April, the Chief Engineer agreed to XB engines returning to one of the mail links, provided hunting could be corrected; otherwise the 45 m.p.h. restriction was to remain. In connection with these trials, it is interesting to note that XB engine, No. 1916, which was involved later at Bihta, was one of those under test, and a speed of 72 m.p.h. was obtained without excessive oscillation.

In April, an XC engine in original condition, with 15/16 in. wear in the hind truck bearings, was tested at 66·6 m.p.h., and there was easy, but not dangerous, hunting when speed exceeded 60 m.p.h. In May, the E. I. R. considered that 31/90 cwt. springs were essential to eliminate hunting, and in August it was decided to fit such springs to all XB engines. In June, the Agent asked the Railway Board to sanction a permissible maximum speed of 60 m.p.h. for XC's over 85 lbs. and $88\frac{1}{2}$ lbs. track, and submitted the results of his tests; but, in August, the Board made this maximum conditional on the existence of 15 sleepers per 36 ft. rail. As therefore, only 13 and 14 sleepers per rail existed in 85 lbs. and $88\frac{1}{2}$ lbs. track, maximum speeds of 50 and 55 m.p.h. respectively were permitted.

Gangpur, E. I. R.—In July, however, distortion of track at Gangpur, which comprised $88\frac{1}{2}$ lbs. B. H. rails in C. I. chairs on Sal sleepers was thought to have been caused by an XB engine (with 22/70 cwt. springs, $\frac{3}{4}$ in. liners, and $\frac{7}{8}$ in. washers) hauling the Imperial Mail; in consequence, three other XB engines were taken off mail service. Inquiry, however, showed that the track, in reverse curvature, was insufficiently superelevated and was short of ballast; a local restriction of 30 m.p.h. was, therefore, imposed, and the Chief Engineer agreed to the return of the four engines to the mails.

In November, further trials with XC engines, at speeds of 61 to 66·6 m.p.h. were carried out with 15/50, 22/70 and 31/90 cwt. control springs, and $\frac{7}{8}$ in. liners on the bogie frames. No track disturbance took place, but the results were not entirely satisfactory.

European experience.—At this time the Consulting Engineers wrote to Germany and to France, to ascertain whether similar troubles had been experienced with Pacific engines. Advice from Germany indicated that the Cartazzi hind truck arrangement and the Goodall drawgear did not sufficiently stabilise the rear of the engine, while a spring controlled hind truck and intermediate buffers between engine and tender were suggested. One Chief Mechanical Engineer in France attributed the oscillation of I. R. S. engines to the existence of two outside cylinders, and he also suggested that axle boxes of the Cartazzi type did not possess sufficient centring effect to nullify the displacement of the rear of the engine. Drawings of French Pacifics were made available.

It was also in November that the Railway Board wrote to the Consulting Engineers, saying that Ferodo discs had been received for trial on XA bogie centres, and that the proposal for a modified bogie would probably be based on the German design, with laminated spring control.

1932.

54. *Continuation of trials on E. I. R.*—Experience had been showing that previous anticipations were unfounded, and trials were continued during January of individual XB engines at speeds up to 70 m.p.h.; they

were more successful, however, and many engines were recommended for mail services, while others *"required the wear in their axle boxes taken up"*. The Chief Engineer gave permission for the posting of both XB and XC engines to Jhajha for mail services *"provided the Chief Mechanical Engineer was satisfied that their hunting had been corrected."*

In February, as emphasising attention to maintenance, the Chief Mechanical Engineer issued a warning to foremen, inspectors and drivers *"that in the event of any of these engines (then being used on the mails) developing a tendency to hunt, the engine or engines were to be stopped immediately, to permit of the bogie control gear being examined, cleaned, lubricated, and any excessive lateral play due to wear on the axle box face liners being rectified by the replacement of the worn liners"*.

In March it was decided to fit 31/90 cwt. control springs to all XC engines, like those already fitted to XB's. With regard, however, to the ten new XB's, then being assembled in the Lucknow shops 15/50 cwt. springs were to be retained in the meantime. From March till the end of the year, further tests were made, and a number of XB and XC engines were individually approved for mail services.

Results of trials with XA Engines on G. I. P. R.—In June, the Board intimated to the Consulting Engineers (this is the first reference to it) that, in place of the Cartazzi slides, plain horizontal slides *"had been tried on some of our worst riding engines with remarkable results. Until the trials now in progress are complete, no definite information can be given, but reports so far received suggest that the Cartazzi control is the main cause of the oscillation of the XA."* In the meantime, it was considered that although the adoption of side bearers to the bogie and laminated spring control would enable the existing 40 m.p.h. restriction to be raised to 60 m.p.h., the trials, which appear to have been favourably reported on by the Chief Mechanical Engineer, *"brought us no nearer to the actual cause of excessive oscillation"*; the engines concerned had been previously given a general overhaul at the time of fitting side bearers, and two variables had thus been altered simultaneously, making conclusions indefinite. Further, it was stated that trials with the American type drawgear had *"shown no improvement"*, that the Paterson hydraulic oscillation damper *"did no good"*, and that the effect of adding loads at the front and rear ends had *"somewhat indefinite results"*. On the other hand, the moving back of the hind truck was considered to have definitely improved the riding.

In August, the full details of these trials were sent to the Consulting Engineers, with the following comments :—

> *"We came to the conclusion that although the flat slides had effected an improvement in riding, it was desirable to maintain some control at the trailing end, and that further trials should be carried out with the two XA 2's with side bearers, laminated spring control, and 1 in. 20 inclination slides....................*
> *I do not think it will be possible entirely to eliminate nosing on the I. M. section of the G. I. P. R., as the track in places is laid on black cotton soil, and the engineers frankly admit that they cannot ensure that low spots will not develop, especially during the monsoon season....................*
>
> *Personally I should have thought that a 50 mile speed restriction would enable the G. I. P. to work trains to booked schedule and in any case it does not appear desirable to increase the speed in view of the fact that coupled wheels are only 5 ft. 1½ in. diameter.*
>
> *We propose to hold a meeting of the Locomotive Standards Committee early in December, and in view of the satisfactory results obtained from side bearer bogies and laminated spring control, I think the Committee will, in all probability, recommend this type as the future standard. From the shed maintenance point of view, it is preferable to helical spring control,*

as it enables a broken spring to be more readily detected. Further, initial compression can be adjusted to give the best results, which is a very desirable feature.

I will keep you informed of the results of any further trials, and in the meantime shall be grateful if you will investigate the Système M intermediate draft gear adopted by the Eastern Railway of France, as it would appear that it should have an appreciable effect in reducing the hunting tendency of the engine."

In reply, the Consulting Engineers in September remarked "*that every possible modification which could be suggested, both here and in India, seems to have been tried, but one cannot help feeling that it boils down mainly to the state of the track*". We understand that the section concerned was that between Itarsi and Agra on the main line of the G. I. P. R., which, with the exception of short lengths laid with either 100 lbs. B. H. or 90 lbs. F. F. rails, was laid entirely with 80 lbs. F. F. rails on cast iron sleepers. There was also black cotton soil, and since that time all the light track has been removed and re-laid with 90 lbs. F. F. material. It is also appropriate to conclude this brief account of the trials on the G. I. P. R. with the following extract of a D/O letter to the C. M. E. stating that, as it was "*essential to improve the riding of these engines, I feel sure that the Board will agree to sanction any additional funds which you require for this purpose*".

1933.

55. *XC Engines on the E. I. R.*—During the cold weather of 1932 till May 1933, large numbers of XC engines, fitted with 31/90 cwt. control springs, were individually ridden on by Inspectors who reported that they were fit for mail services. In March, the Chief Mechanical and Civil Engineers agreed to engines altered in this fashion being utilised on mail services. In September, the Agent informed the Board that it had been possible to correct the excessive hunting of XC engines by fitting 31/90 cwt. springs; further, that each engine so fitted had been tested at high speed, and had been certified as fit for mail services, subject to the general restrictions already mentioned, *viz.*, 50 m.p.h. and 55 m.p.h. over 85 lbs. and 88½ lbs. track, respectively. During this month two XC engines were also tested at 70 and 75 m.p.h., bogie lateral movement being 4 in. and 3-7/16 in. respectively, the former, however, not being considered satisfactory.

Sagarbhanga, E. I. R.—In July, displacement of track at Sagarbhanga was caused by an XB engine, and the subsequent Inquiry found that this resulted from "*flange pressure......as a result of hunting action set up when coming off the 3,820 ft. radius curve, and in all probability the hunting was accentuated by the crossing being worn at the nose of the switch. This hunting resulted in the track being thrown out bodily.*" This seems to be the first occasion on which "*flange pressure*" is mentioned as having been an important factor; but the finding of the Inquiry was not unanimous, and a Power Officer was of the opinion that there was "*no inherent condition of the engine to cause abnormal periodic side to side movement*", and that the track was displaced due to weakness, probably owing to (i) sodden soil due to monsoon conditions, (ii) wet surface of formation due to about 0·95 in. of rain during the previous 24 hours, and (iii) the level of the rails differing by more than a proper working tolerance.

Ganjkhwaja, E. I. R.—At the end of October a mail train, hauled by an XB engine, and travelling at high speed (probably not in excess of sanctioned speed) was derailed on a curve; the track was distorted and a coach, probably the second, was derailed and pulled off the rest of the train. The permanent way comprised 88½ lbs. B. H. rails (minimum 83·9 lbs.) on new Sal sleepers (15 per 36 ft. rail), and the S. G. I. who held the Inquiry, found that "*maintenance of the track was not up to a sufficiently high standard to resist the lurching which the XB engine develops at high speed*"; the Agent did not accept this opinion and considered that "*the distortion of the track* *was possible because of its condition, due to recent heavy rain*". The S. G. I. did not hold anyone directly responsible, but he also found that "*as the track laid with 88½ lbs. B. H. rails is barely able to withstand the lurching of the engine, even if the track is maintained to a 100 per cent. standard of efficiency, there is therefore no factor of safety, and it is quite possible for other accidents to occur under similar circumstances*".

The S. G. I. recommended that XB engines be restricted to 50 m.p.h. on B. H. rails of 85 lbs. and over (and, of course, further restricted on rails of lighter section); further, that special observations be made to see how 90 lbs. F. F. track stood up to the lurching of these engines, with a view to obtaining information as to "*which type of track (particularly in regard to the type of sleeper) is the most suitable to adopt in order to resist the disturbance set up by heavy locomotives now in use on fast trains*".

The Chief Engineer subsequently stated that :—

> "*It had been definitely proved that under monsoon conditions the track had been displaced, probably by XB engines, and that, so long as we still have 85 lbs. and 88½ lbs. bull-headed rails in the track, it will not be practicable under such conditions to maintain the track so that displacement at high speeds would not be possible.*"

The Chief Engineer also stated later that :—

> "*So far as I am concerned, the matter is already settled. It will definitely be necessary to impose a restriction of speed of 45 m.p.h. over 85 and 88½ lbs. B. H. rails on XB and XC class engines during the monsoon, and in revising the time-table it should be assumed that this restriction will be imposed on the 1st June, 1934*".

The restriction was therefore brought into effect *for the second time*, and arrangements were thereafter made to adjust the time-table.

1934.

56. *Remarks of Administrations.*—The Railway Board drew the attention of all Administrations to the S. G. I.'s Report on the Ganjkhwaja accident, and, for the first time, asked for statements as to experience with XB engines. The M. & S. M. R. stated that :—

> "*None of the XB's on this line gave any trouble at first, but several are developing a tendency to lurch now; a speed restriction of 55 m.p.h. has been imposed on all rails lighter than 90 lbs., and the alteration of the locomotives by throwing back the trailing wheels is being pushed on. Meanwhile, any engine that shows any undue tendency to lurch will be sent in for repairs. There have been no cases of damage to track under single locomotives, but there has been one under coupled XB's. As a result the running of coupled XB's has been forbidden.*"

The S. I. R. stated that :—

> "*Trouble was experienced with XB class engines since they were introduced on the mail service on 90 lbs. B. H. rails on pot sleepers, between Podanur and Erode, on this railway. It was found that the track became kinked and thrown out of true alignment in certain parts, especially on banks. This was in 1929, and was due, in my opinion, largely to the fact that the ballast was not up to full section. No trouble of this nature has been experienced since, but there is no doubt that the XB class engines demand a high standard of maintenance and good ballast, which it has been difficult to provide during the present severe restriction of expenditure.*"

With regard to the E. B. R., which were operating 18 XB engines at 55 to 60 m.p.h., five cases of distortion had occurred since 1930, when making up time, the track being 90 lbs. F. F. on Sal sleepers "*in fairly good condition*"; generally speaking, hunting was said to be aggravated "*whenever there are any inequalities and weak points in the track. The engines are hard on the track, cause undue creep, require a higher standard of maintenance of track, which must be fully ballasted and laid with the best sleepers; soft wood sleepers are unsuited to the running of these engines*".

The Chief Mechanical Engineer of the E. B. R. stated that:—

> "*Our experience has been that hunting becomes pronounced after these engines have been in service about 18 months and a certain amount of wear has taken place on the inside bosses of the coupled wheels, the wearing faces of the coupled wheel axle boxes, the spring guide plate lugs, and the horn block edges of the radial boxes. The wear at all these points has the effect of increasing the side-play of the engine frame relative to the wheels, and it is found that when this wear is taken up, the hunting entirely ceases, or is at least very greatly reduced. The improved running of these engines is therefore attributed to action being taken in sheds and shops to guard against excessive side-play developing.*"

As the result of running XB engines on the N. S. R. "*the track was displaced and had to be realigned every few days*", between Vikarabad and Gollaguda.

The N. W. R. stated that when XC engines came into use in 1930, one Division had reported that, due to oscillation, track damage and distortion took place where cast iron plate sleepers existed and where ballast was deficient; special measures were then adopted to bring maintenance of track on all sections concerned up to the "*highest possible standard, and certain alterations were made to the locomotives also*". No serious trouble appears to have subsequently arisen, and no speed restrictions have, until recently, been imposed on XC engines on this system.

Action by the Railway Board.—Attention was thus focussed upon the lateral strength of permanent way, and the Board initiated researches to determine flange forces and track stability. The E. I. R. were instructed, in February 1934, to carry out further tests with Cartazzi slides with reduced inclinations. In December, engines, modified accordingly, were reported as satisfactory, and those of XB type were thereafter restored again to express passenger services during the dry season only; the restriction, however, of 45 m.p.h. remained applied to the monsoon period, and nothing further appears to have transpired till the Bihta accident.

In May 1934, the Board informed the Consulting Engineers that, although setting back of the hind truck was reported to have effected improvement in the running of XA and XB engines, excessive oscillation was still being experienced during the rainy season, "*due to it not being possible to maintain the track up to the required standard*"; further, that the question of locomotive oscillation was again being taken up as the result of the derailment at Ganjkhwaja, and it was pointed out that the S. G. I. had attributed the distortion of the track on that occasion to oscillation of the XB engine hauling the train. Extracts from the letter are as follows:—

> "*Whether the engine in question was responsible for the distortion, it is not possible to say, but the fact remains that several cases of displacement of track have occurred on sections on which the XB engines are running......*
>
> *At one time, we were of the opinion that the hind truck was possibly the cause of the trouble, but we are now inclined to think that the distortion is caused by the coupled wheels as, on a straight track, the flanges of the diagonal leading and trailing wheels are hard up on to the rails long before the stops on the bogie and hind truck come into operation.*

Experiments carried out on the B., B. & C. I. R. with the XC engines show that the displacement of the bogie is at times considerably in excess of the throw over obtainable from the rigid wheel base; in fact, it would appear that the coupled wheels must spread the track at least ⅜ in. on either side to obtain the displacements recorded. In the ordinary course, this spreading of the track is taken up in the elasticity of the rails and ballast, but when the track is sodden, the sleepers are liable to become displaced.

The B., B. & C. I. R. graphs show that the initial displacement of the bogie is not appreciable, and that the oscillations build up. So far as I can see, the only means of preventing this is to introduce some form of friction damper in one or other of the control gears.

This will be provided for to some extent in future engines by utilising laminated springs in the bogie, but I think something considerably more effective will be found to be necessary. We have therefore decided to try out flat slides on the hind trucks with Ferodo rubbing surfaces. We are, however, a little doubtful if the co-efficient of friction of Ferodo is not too high for this purpose, as it is understood to be in the neighbourhood of .3, whereas something about half this would be equivalent to the existing 1 in 10 slides, and should be sufficient."

In August, the Board instructed the G. I. P. R. to fit Ferodo slides to the hind trucks of two XA engines.

1935.

57. *Trials with Ferodo.*—In March, the results of the above-mentioned trials with Ferodo on XA engines were considered by the Locomotive Standards Committee, who recommended that further experience should be accumulated. The trials were continued on the G. I. P. R. throughout the year.

Hallade Tests on the E. I. R.—In April, consideration was given to the possibility of retaining XB engines on the mails throughout the monsoon; but after an examination of Hallade Records, which had been taken on XB engines, it was decided not to withdraw the restriction of 45 m. p. h. However, it was then decided to carry out more comprehensive Hallade tests in July, comparing an HPS (B. E. S. A. 4-6-0) type engine with three XB engines in original and modified conditions. The three XB engines were all considered to show "*better riding qualities than the HPS engine, which gave unsatisfactory results as regards oscillation* (i.e. *swinging side motion*) *and actual side play. The records taken on 90 lbs. track were better than those on 85 lbs. and 88½ lbs. track. The rolling and lateral movements were less*".

The Chief Engineer, however, would not remove the monsoon restriction "*even if the hind trucks were altered and the bogie springs changed*" and, in September, it was considered unlikely, from the Hallade test results, that these engines "*would work the mails at unrestricted speed during monsoon seasons until the relaying programme had been completed in 1938.*"

Track Stability.—In January, as the result of the consideration being given to flange forces and track disturbances, following the Ganjkhwaja derailment, the subject of track stability was included in the agenda of the Track Standards Committee, and the Board approved of the matter being investigated by Research Officers, whom they had appointed. It was not until the end of 1936 that any data became available, and then it related only to the lateral stability of track under static condition in dry and monsoon weather. Certain further data has recently become available regarding track stability under moving loads during monsoon conditions, and this will be dealt with in Chapter VII, in its relation to the data on flange forces which has been collected since August 1937

1936.

58. *Further trials with Ferodo.*—The Railway Board had developed the theory that it would be practicable to utilise Ferodo to damp out the energy developed by hunting engines, and, in February, the G. I. P. R. were instructed to fit two more trial XA engines with Ferodo on the bogie pivot slides and hind truck, in conjunction with German buffing gear.

The beneficial results of providing damping by this means having been established in concurrent tests on B. E. S. A. and XA types, the B.N.R., N.W.R., S.I.R., and E.B.R., were also instructed to carry out similar trials on XB and XC type engines. Preliminary reports on engines fitted with the above-mentioned alterations were received in April 1937, but, as the Board had given instructions that 40,000 miles of service should be developed before final reports were submitted, such reports did not materialise until after the Bihta accident.

Measurement of Flange Forces.—As far back also as 1936, the Research Officers began to develop electrical apparatus for recording engine and track reactions, and by July 1937, they had succeeded in adapting their apparatus for synchronous recording of bogie and hind truck movements and flange forces. It was not until these records were available that it became possible to determine the true efficacy of the various measures that had previously been tested. Indeed, it appears that it was only then realised that a number of previously held conclusions were untenable.

1937.

59. It was not until 1937 that a translation was available to the Board dealing with Research in France with regard to the measurement of flange forces on the Piézo-electric principle. It is, therefore, satisfactory to record that the Research Officers have developed their equipment on independent lines. The descriptions of the tests which they carried out are dealt with in Chapter VII, and the modifications which were decided upon by the Board, as the result of these tests, are described and discussed in Chapter IX.

CONCLUDING REMARKS.

60. *XA Engines.*—The G.I.P.R., operating 49 of them, with a mileage of 17 millions, has been the only line seriously concerned with bad riding, and six derailments occurred between April 1930 and June 1931. The N.W.R., operating 58 of these engines, with roughly the same mileage, has not suffered any accident and there has been little trouble; the engines run without restriction and are of the same detailed design as when delivered.

By August 1933, the engines on the G. I. P. R. had been restored to 55 m. p. h. services, and it was apparently believed, until 1937, that they were satisfactory, although trials on this line were conducted with Ferodo damping from 1934 onwards. Trouble was largely confined to sections laid over black cotton soil, and notwithstanding certain endeavours to improve formation, oscillation persisted until damping devices were introduced.

Reference will be made later to the Board's recent instructions for alterations, and, after these had been carried out, the permissible maximum speed of the engines on the G.I.P.R., was raised by the Board to 60 m.p.h. in June last, as the result of certain trials, and of recommendations by the S. G. I. concerned.

We understand that, under instructions from the Board, XA engines, of the original design, on the N.W.R., are now restricted to 45 m.p.h., as an absolute maximum over any section where track distortion attributable to actual hunting, or tendency to hunt, has been experienced within the last 12 months.

XB Engines.—The M. & S.M.R., S.I.R., and N.S.R. have suffered no passenger train derailments. Trouble in the main has rested with the

G. I. P. R. (one derailment), E. B. R. (one derailment), and E. I. R (two derailments, prior to that at Bihta). The nine engines which commenced work on the G. I. P. R. in 1928 were transferred, five to the M. & S.M.R. in 1933, and four to the E. I. R. in 1934. The mileage on the E. B. R. is 6·2 millions, and on the E. I. R. 14·4 millions.

The E. I. R. conducted a large number of trials, and on several occasions both the Mechanical and Civil Engineers were satisfied that the engines were safe for mail speeds. Subsequently, however, unperceived changes in the state of maintenance of the track, or of the engines, or both, proved that these conclusions were ill-founded; in the meantime, orders to apply experimentally certain means to control hunting were issued by the Railway Board in February 1936, as the result of tests on XA engines which were initiated in 1934.

With regard to the Board's instructions (subsequent to the accident at Bihta) relating to the maximum permissible speed restriction of 45 m.p.h., the M. & S. M. R. reported no case of track distortion up to May 1938, and considered that there was no reason to impose the restriction. In June, however, this Administration reported that they had decided to reduce the speed as notified to drivers of XB engines to 50 m.p.h. in some areas, and to 45 m.p.h. in others, as an additional precaution, not because of unsatisfactory performance. The S. I. R. reported, in May, that they had imposed a restriction in accordance with the Board's instructions; as also the E. I. R. and N. S. R. On the E. B. R., the engines are now being used on slow trains only.

XC Engines.—These engines have run 21 million miles on the N.W.R., B.,B. & C.I.R., and E.I.R., without accidents, and events followed closely the sequence of developments with the XB type, which are outlined above. We understand that on the N. W. R. these engines have recently been restricted to a maximum permissible speed of 50 m.p.h.; on the B. B. & C. I. R. they are not running owing to the breakage of connecting rods; on the E. I. R. the Board's restriction of 45 m.p.h. is being enforced.

CHAPTER III.

THE DISTURBING FORCES IN A LOCOMOTIVE.

The Characteristics of its movement on the Track.

61. *Definition.*—In practice, terms to describe movements of engines on the track are often loosely used to refer to more than one movement; it is advisable, therefore, to define such terms as follows:—

Oscillation.—This inclusive term is generally used to describe movements of the engine in any plane.

Nosing.—Transverse oscillation of the engine on the track about a vertical axis. Pursuing a sinuous path along the track.

Rolling.—Transverse oscillation of the engine on its springs, about a longitudinal centre line.

Hunting.—The two movements defined above rarely occur separately but are generally found acting together in varying proportions. The resulting oscillation is described as hunting.

Lurch.—One semi-amplitude of movement in the action of hunting, *viz.*, an individual deflection from the centre line towards one or other of the running rails.

Shuttling.—Oscillation in a fore and aft direction parallel to the track.

Pitching.—The front and back ends of an engine alternately rising and falling about a transverse horizontal centre line; this is sometimes referred to as galloping.

Trimming.—A settling down of the engine, either at the front or rear end, so that the line of the foot-plate is no longer parallel to the track.

62. *General.*—In this Chapter, we intend to deal with the technical aspects of ten disturbing forces, to which a locomotive is subject when running on the track. We shall distinguish between those which primarily affect its stability as a vehicle, and those which have only a secondary effect. We attempt a rational explanation as to how hunting occurs, and of the circumstances in which it will either die away or build up to undesirable proportions. For reasons set out in the text, the matter is not dealt with mathematically, and, in avoiding such treatment, we have had regard to the valuable investigation of Carter(1) in England, Cain(2), Langer and Shamberger(3) in America, Marié(4), Levi(5), and Rocard(6) in France amongst others who have approached the problem from that aspect. Their work has pointed the way, but for immediate results, which can be put into practice forthwith, less rigid methods of analysis have to be pursued.

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(1) "The Electric Locomotive."
Proceedings Inst. Civil Engrs., 1916.
On the action of a Locomotive Driving Wheel.
Proceedings Royal Society, 1926.
On the Stability of Running of a Locomotive.
Proceedings Royal Society, 1928.
Running of Locomotives with reference to their tendency to derail.
Proceedings Inst. Civil Engrs., 1930.

(2) Safe Operation of High Speed Locomotives.
Transactions of American Soc. Mechanical Engineers, 1935.

(3) Lateral Oscillations of Rail Vehicles.
Transactions of American Soc. Mechanical Engineers, 1935.

(4) Traité de Stabilité du matériel des Chemins de Fer.
(Treatise on the Stability of Rolling Stock).
Pub. Ch. Beranger, Paris, 1924.

(5) Etude relative au contact des roues sur le rail.
(A Study of the Contact between wheel and rail).
Revue Générale des Chemins de Fer, Feb. 1935.

(6) La Stabilité de route des Locomotives.
(The Stability of Locomotives on the track).
Pub. Herman et Cie, Paris, 1935.

63. *Summary of Disturbing Forces.*—These may be divided into three groups :—

A Those which act solely in a longitudinal direction and do not, therefore, affect the problem at all.

B Those which by their direction have a tendency to produce hunting, but, due either to the period at which they act, or to the small amplitude which they attain, have little practical bearing on the problem.

C Those which have a direct bearing on hunting and the resulting flange forces.

In Group A, the forces concerned are :—

(1) *A Shuttling force*, causing a fore and aft vibratory movement due to the uneven turning moment, namely, the varying tractive effort arising from the piston load and the crank angle, as the piston moves from one end of the cylinder to the other.

(2) A further *Shuttling force*, which is superimposed on the above and arises from the effect of the unbalanced portion of the reciprocating masses.

(3) A *trimming* movement of the engine, namely, deflection of the horizontal centre line, when the centre line of the crank axle does not lie in the same horizontal plane as the drawgear.

In this group are mentioned disturbances which only affect the engine in a direction parallel to the track, and as they have no bearing on the present investigation, further reference will not be made to them.

In Group B, the forces arise from :—

(4) *Surging effect* of the unbalanced masses acting in the different planes of the several cylinders, which cause a couple tending to make the engine oscillate transversely about a vertical axis.

(5) *Rolling*, which is set up by the vertical reaction of the crossheads on the slidebars.

(6) *Pitching*, which is set up by slidebar pressure being accompanied by an equal downward thrust at the crank axle.

(7) *A Nosing Couple*, which may also be set up by the variation in piston pressure on the two sides of the engine at any one time; this is effective if there is twist on the axles due to this piston pressure, or if there is longitudinal play in the boxes.

This group comprises the disturbances arising from the function of the engine as a power unit; they would affect the engine even if it were slung clear of the rails by a crane. It will be shown that these disturbances have little direct bearing on the question of flange forces and track distortion; they are dealt with fully, in order to demonstrate this fact, as misunderstanding sometimes exists.

In Group C, the forces arise from :—

(8) *Periodic Nosing*, which is set up by the coning of tyres, by transverse flexibility of the frame and wheel centres of the engine, and by irregularities in line and level of the track under load.

(9) *Rolling*, which is set up by track depressions under load, and is affected by stiffness of the springs, by the transverse moment of inertia of the engine, and by the transverse spacing of the axleboxes.

(10) *Centrifugal action* during the passage of an engine round a curve.

As already pointed out, (8) and (9) are nearly always found together, and it is in this group as a whole that the complementary effect of engine and track, as components of one machine, is most clearly indicated. The consideration of this, with regard to the whole question of the behaviour of the engine as a vehicle, is of immediate importance.

Group B. Disturbances Arising from the Engine as a Prime Mover.

64. The disturbances in this group consist of the following:—

Nosing Couple Due to Unbalanced Reciprocating Parts.—Due to the combined surging effect of the unbalanced reciprocating parts, forces acting in the different vertical planes of the cylinders are set up; this subject has been fully dealt with by Prof. Dalby(1). The value of this couple varies directly as the square of the speed, the weight of the unbalanced parts, the radius of the crank circle, the distance between the cylinders, and the obliquity of the connecting rod. Thus, an increase in the values of any of these involves an increase in the nosing couple. This couple tends to oscillate the engine about a vertical axis, the frequency being once per revolution of the wheels.

The action of this couple is resisted by the weight of the engine resting on the journals, and by its inertia; it is possible to calculate the actual value in inches of the amplitude of this oscillation at the bogie centre, since the value of the initiating couple, the radius of gyration, and the length of the engine can be determined. The following table shows the order of the values which this amplitude attains:—

Class of Engine.	No. of Cyls.	Wt. of unbal. recip. parts lbs.	I for Engine tons ft.	Dist. bet. C. of G. and bogie pin. ft.	Sprung Wt. Tons.	Displacement on each side of C. L. ins.
XA . .	2	209	3616	13·2	49·6	0·024
XC . .	2	291	7775	15·1	75·8	0·020
XB . .	2	281	6542	14·6	69·6	0·022
XB . .	3	253	6750	14·6	72·0	0·020
XB . .	4	238	6750	14·6	72·0	0·007
XB . .	2	570 (only 33 per cent balanced.)	6542	14·6	69·6	0·045

There are no 3 and 4 cylinder XB engines, but these figures have been prepared to show what the effect would be were these engines rebuilt with either 3 or 4 cylinders. This displacement depends on the moment of inertia of the engine, and is independent of speed. It will be noted that the displacement at the bogie centres, due to this couple, is very small, being in all cases less than the usual side clearances between axleboxes and horns. This is true even in the case where a very small proportion of the reciprocating masses have been balanced. Moreover, the above values ignore the effect of friction, which will tend to reduce the displacement still further.

As already stated, the frequency is once per revolution. Stated in seconds, the values are:—

Period in seconds at speed.

Class of Engine.	20 m. p. h.	45 m. p. h.	60 m. p. h.
XA	0·53	0·25	0·18
XB	0·66	0·29	0·22
XC	0·66	0·29	0·22

The above values are well below the observed natural nosing period of the engines concerned, namely 0.75 to 1·0 second at 60 m.p.h. These considerations show that there is little to choose between 2, 3 and 4 cylinder engines, so far as the nosing effect due to reciprocating parts is concerned; moreover, the percentage of the reciprocating parts which are balanced has no appreciable effect on the nosing tendency, although there may be a slight possibility for this to build up, when the nosing period is an odd multiple of the natural engine period. A multi-cylinder engine, however, does produce a reduction in hammer blow and greater evenness of turning moment.

(1) Balancing of Engines, Pub. Arnold, 1929.
Bridge Stress Committee's Report, 1928.

65. *Rolling and pitching due to reaction of cross head on slidebar.*—A rolling couple is set up due to the variation in slidebar pressure during a revolution. This pressure varies according to piston thrust, corrected for inertia and angularity of the connecting rod for every portion of the stroke. To this is added, or subtracted, the effect of the further reaction due to the dynamic effect of the connecting rod itself, namely slidebar hammer blow.

At the same time, the resultant upward force at the front end of the engine causes a longitudinal galloping or pitching action, due to the pressure being accompanied by an equal downward thrust on the crank axle. The arm of this couple is the length between the centre of the crosshead and the centre of the crank axle, a distance continually varying with the position of the crosshead.

Both these forces have to be resisted through the bearing springs; stiffer springs reduce the amplitude of movement in each case. The period of oscillation is twice per revolution, and the amplitude of movement increases with the piston load, the distance between cylinders, and the obliquity of the connecting rod. It will be less with stiffer bearing springs, and as the moment of inertia of the engine increases. It decreases as the speed increases, due to the reduction in the mean effective steam pressure in the cylinders, unless the slidebar hammer blow increases at a greater rate. This effect influences the riding of the engine only at very low speeds.

66. *Couple due to Piston Thrust.*—It is commonly thought that in addition to the disturbing forces described above, there is also another nosing couple arising from the varying piston pressure, which acts on the axlebox guides, and which is continually altering in value and direction on either side of the engine. This, however, is not the case, if all the parts concerned are rigid. The forces and reactions concerned are within the framework of the engine; the force of the steam on the piston reacts through the cylinder attachment to the frame, and through the axle on to the same frame *via* the hornblock attachments. The variations in pressure will cause stress in the axle and frame, but will not produce a couple tending to slew the frame in relation to the track.

A nosing oscillation can only occur from this cause if the inequality in loads on either side of the driving axle produces a torque in the axle sufficient to twist it. There will obviously be such a torque, but axles are designed with sufficient stiffness to avoid twist of any appreciable value from this cause. Moreover, if there were a large amount of longitudinal play between the axleboxes and the horns, it might be possible for the axle to get out of alignment, and thus cause a similar oscillation; but usually the amount of play at this point is insufficient to allow such an effect to take place.

The effect of the uneven piston pressure on the two sides of an engine is reflected in a linear shuttling effect, giving variations in drawbar pull; whilst the visible oscillating effect, so often seen on outside cylinder engines working hard at low speed, arises from the slidebar reactions already dealt with. The foregoing disturbing forces have no practical influence on the problem of hunting, a fact which can be verified by observing the behaviour of engines on a stationary test plant. Practical demonstrations of this, by slinging engines from a crane, were made in Germany by Nollau in 1848 and in France by Le Chatelier in 1849 and by Baudry in 1890.

Group C. Disturbances which immediately affect the Engine as a Vehicle on the Track.

67. *General considerations which concern the behaviour of engines on the track.*—In the early days of railways in all countries, sinusoidal deformations of the track have often been observed after the passage of certain engines, and derailments have resulted from time to time. The engines concerned were not so heavy as modern ones, nor was the track so strong as it is today. In France, for example, before the War, certain engines which caused such distortion did not weigh more than 40 tons, and ran at comparatively high speed on rails weighing 60 lbs. per yard; the same

kind of engine and track is used on branch lines to this day, generally at lower speeds. In England, similar cases with relatively light engines have also been referred to in Chapter I.

It is evident, therefore, that, as this kind of track deformation is not new, it has not been brought about solely by the advent of heavy locomotives. It is rather due to the fact that certain engines, whatever their weight, can develop flange forces of greater magnitude than can be withstood by the particular track on which they run; in this connection, the heavier the engine, the better the adhesion between sleepers and ballast, and, consequently, the greater is the force required to distort the track laterally.

Records of derailments show that the actual cause is often unsatisfactorily established. In many cases the engine has been found to be in good order, and without any defects which appeared to contribute to the occurrence. With regard to the track, it is often possible to examine only the sections ahead of, and behind, the site of the accident, and here again nothing abnormal may be found.

But on close examination, and with the knowledge gained from continued experience, it sometimes transpires that the engines concerned, although not heavy, were of a type known to have a tendency to cause transverse track deformation; they either had no guiding wheels, or, where these existed, there was ineffective side control, usually in conjunction with a large overhang at front or rear.

With modern engines, having guiding wheels, cases of sinusoidal deformation of the track are rarer than in the early days, but none the less a certain number have occurred. In some cases, as already mentioned, the engines have been condemned or radically altered, but in others, the conclusion was reached that excessive speed, or local weakness of the track, was the main contributory cause.

68. Generally speaking, in the many different engine designs all over the world, designers have arrived at an arrangement, based on engineering instinct and experience, which has been quite satisfactory in practice. Due to trials made recently in several countries, it is now possible to visualise what is necessary to improve the running of engines on the track, and thus to avoid lateral deformations.

To the best of our knowledge, however, the actual mechanical process by which track distortion occurs is not yet exactly known. Mathematical theory has been used to work out equations of motion, but these have been so complicated as to be insoluble. Moreover, to make calculation possible, it has been necessary to make numerous assumptions, in order to allow of the possibility of integration and final solution. But these assumptions, however carefully they are based, have had the effect of altering the interpretation of the problem, and therefore the results obtained have not up to the present been of great assistance.

As an example of this, the Central Standards Office had, before our arrival, been attempting to gain some information on the critical speeds of hunting of X Class Pacifics, based on the theoretical and mathematical research of certain investigators, to which reference has already been made. In endeavouring, however, to apply the formulæ which have been worked out, differences were found in the assumptions, which has been made, principally affecting the way in which the lateral action of the wheel on the rail was treated, and the way in which the amount of effective side displacement was considered. This variation in assumptions made a material difference in the critical speed obtained by the two methods, and indicated that practical results cannot yet be obtained by substituting values in a theoretical formula.

This is, of course, no discredit to mathematical investigators, but arises from the very nature of the problem in which all the main elements, locomotive frames, wheels, and the track itself, are not rigid, but elastic in a varying degree. We do not, therefore, propose to give a definite explanation of so complicated a phenomenon as distortion of the track, but we will try to consider the matter as logically as possible, based mainly on experimental findings, checked by the recorded circumstances of various accidents and by our own observations in India.

As in the early days most of the engines had no guiding wheels, deformation of the track can obviously not be attributed to that feature. Even on engines with guiding wheels trials made recently for assessing flange pressures have shown that generally it is the coupled wheels which bring about the highest reactions. It is evident that neither track nor engine can be perfect, but the better the one, the less perfect may be the other by a corresponding amount. If the total of the imperfections of track *plus* engine exceeds a certain value, the sequence of events, depending on speed, the state of the rail, etc., is first, an abnormal movement of the engine on the track, secondly, deformation of the track itself, and thereafter even derailment.

69. *Movement of a single pair of wheels on the track.*—If it were possible for the flanges of the wheels to remain in permanent contact with the rails, and if track, wheels and axle could be perfectly rigid, then there would be no problem or lateral oscillation. As a practical necessity, however, some clearance, varying in different countries, is always left between flange and rail. Because of this clearance, the two wheels on an axle cannot make lateral contact with both rails simultaneously; the movement of wheels and axle along the track takes the form of a series of successive contacts between flange and rail, and of rebounds from one side to the other at variable distances. If this movement occurred on a perfect track and was solely due to the coning of the tyres, the path followed by the wheels would be a sine curve, the length of wave remaining constant irrespective of speed, but depending upon the degree of coning of the treads, the diameter of the wheels, and the gauge.

In practice, however, the track is not perfect, and there are a number of causes which, acting either singly or in combination, alter the form of this lateral movement. The principal causes are:—

(a) Irregularities in gauge and level of the track under load, which tend to direct the pair of wheels towards one rail or the other.

(b) Irregularities in wear of the tyres and rail, and therefore in the effect of the coning of the tyres.

(c) Differences in the diameters of the wheels on the same axle.

When the amplitude of the lateral oscillation, measured from the centre line of the track, exceeds the clearance between flange and rail under load, and each time that a flange strikes a rail and is deflected towards the other, a force is exerted. The magnitude of this force depends on the weight of the wheel and axle assembly, and on the transverse velocity with which the flange strikes the rail. This velocity, for a given running speed, is related to the total amount of side movement of the wheels and axle, the movement being made up of the static clearance between flange and rail, *plus* any elastic deformation in wheel, axle and rail.

70. *Movement of several pairs of wheels united under one chassis.*—We will now consider several wheels and axles on which is mounted a locomotive frame without carrying wheels, *viz.*, an engine such as the 0-6-0 type. Lateral oscillations arising from the passage of the individual wheels and axles along the track will be imparted to the chassis through the wheel boss face, axlebox flanges and horn guides. The sinusoidal movement, however which is pursued by an independent pair of wheels on an axle, will no longer be simple when it forms part of a complete vehicle.

When an engine chassis, from whatever cause, is taking up a position at an angle with the centre line of the track, there are a number of forces acting simultaneously at the tread of the wheels; in considering the effect of these forces, it is important to remember that adhesion between wheel and rail exists not only in the forward direction of movement, but also transversely across the rail head.

First, there is the lateral force, arising possibly from some track irregularity, which causes the engine to depart from its central position on the track. Secondly, there is the traction force, due to the steam acting in the cylinders, which is impelling the engine in a forward direction. Moreover, when the several axles, which are mounted under the same frame, are rigidly connected by coupling rods to one another, the wheels are compelled to turn at the same angular velocity, in spite of differences in diameter. These may be due not only to variations in the turning of the different tyres, but to the effect of coning of the tyres when the distances of the flanges from the corresponding rails are not equal. As the result of these differences in diameter, further tangential forces are set up at the points of contact of the different wheels on the rail.

These tangential forces, when acting in opposite directions on two wheels of the same axle, will form a couple which will act in two different ways. It will tend to produce torsion in the axle, and it will also tend to pivot the axle about a vertical axis. The arm of this couple is a function of the gauge of the track, and, under equal factors of adhesion (vertical loading and coefficient of friction), the moment of the couple will increase with the width of gauge.

The forces mentioned above, due to traction, side displacements, and inequality in effective wheel diameter, can be resolved and the direction of the resultant will vary in relation to the longitudinal axis of the engine, according to the relative direction of the original forces. The value of the resultant is dependent on the factor of adhesion. Transverse slipping of the wheel across the rail will take place when the resultant force at the wheel tread exceeds the limit of adhesion.

We are mainly concerned with the transverse component of this resultant force, and it will, for a given value of the resultant, attain a maximum value, when the force due to traction acting in a longitudinal direction is low, as, for example, when working with early cut-off, or when coasting. This consideration indicates why hunting of locomotives is more often observed on the level and down gradient when tractive effort is small. On the other hand, elastic deformation of all the members, which are subject to transverse reactions between track and engine, has the effect of delaying the rate of increase of the force at the tread of the wheel, and, in consequence, of delaying the instant at which slipping will occur in the direction of the resultant force.

71. Certain recent theories introduce the idea of elastic deformation of the actual metal of wheel and rail at the point of contact, to explain the possibility of certain relative movements of small amplitude of the wheel on the rail, without actual slipping taking place. *Creep or pseudo-glissement* (1) are names given to this conception, and the coefficient of friction under such conditions will be high. This is important, because, it allows the possibility of high tangential forces at the point of contact between wheel and rail.

We will now consider what tendencies are produced by these forces on the passage of the engine along a straight track; still assuming that the engine has no guiding wheels, let us consider it deflected obliquely towards the left hand rail. The left hand leading wheel then exerts a flange force on that rail, the reaction to which tends to return the engine to its central position; but the tangential forces at the points of contact of all the wheels, other than the left leading wheel, oppose any change of direction of the engine, and tend to make it continue to run obliquely towards the left hand rail, so long as slipping of the wheel treads towards the right does not occur.

In these circumstances of increasing pressure, the left hand rail deflects outwards and the left hand leading wheel and its axle also deflect. Since the reaction between wheel and tyre is at rail level, namely, at a point below

(1) Etude relative an contact des roues sur le rail.
(A Study of the contact between wheel and rail.)
Revue Generale des Chemins de Fer, Feb. 1935.

the centre of gravity of the engine, a rolling movement of the sprung weight is then started towards the left, which has the effect of partially unloading the right hand side of the engine. Thus, on the one hand, the tangential forces at the points of contact of the remaining wheels increase as the lateral reaction between left hand leading wheel and rail increases; on the other hand, the vertical load on the right hand wheels diminishes, as a result of the rolling. The limit of adhesion is thus attained and the right hand wheels suddenly slip laterally, thus destroying the state of equilibrium between the different forces. The sensitivity to rolling of a particular engine design will affect the degree to which the above sequence of events can occur, but it appears that some degree of unloading of the wheels can take place on the side opposite to that on which a leading flange is striking the rail. The rolling action on a curve is more complicated, and weight may even be relieved from the wheel on which the reaction from the flange is taking place.

Under these conditions, there is a flange force on the left hand leading wheel acting at the leading end of the engine, and all the elastic members under deflection (rails, wheels, and axle) unite in turning the front of the engine towards the right hand rail. Since, however, the lateral slipping of the right hand wheels takes place when these wheels are partially unloaded due to rolling, the resistance to transverse displacement is reduced; the engine goes beyond its position of equilibrium, so that after having pivoted about its vertical axis, and at the instance when lateral slipping stops, the engine tends to make the left hand rail an angle of return greater than the angle of approach. In continuing its lateral movement and striking the right hand rail, the same phenomenon is produced at the instant of contact as is outlined above; for the same running speed there is an inherent tendency for the characteristics to be enlarged, as the transverse velocity of impact increases with the angle of incidence of the chassis in relation to the track. This angle also tends to increase at each rebound for the reasons given.

72. Three different results may follow the foregoing tendency :—

(1) If the track is strong enough laterally not to undergo any measurable deformation, elastic or permanent, if the engine is very rigid in its frame, wheels, and axles, and if the clearances between wheel and rail are tight, the initial deflection at the left hand rail is reduced. The various members are able to resist the forces arising from the tendency to increased transverse velocity in the second-half of the first oscillation. The angle of incidence of the chassis in relation to the track is, therefore, prevented from increasing, and can be retained at a small value, in which the *creepage* effect between wheel and rail, with its very high resistance to lateral slipping, is the predominant factor; in consequence, the oscillations of the engine are self-damped and its passage along the track returns to normal, until the next track irregularity is encountered.

(2) If the track undergoes material elastic deformation in the form of rail tilting or side displacement as a whole, and, in addition, if the frame and wheels of the engine are relatively flexible, the effective clearance between flange and rail is increased by the sum of the resulting deflections. This total amount of side movement affects the angularity of the engine to the track, and, therefore, governs the transverse velocity with which the leading wheel flange strikes the rail; this velocity, in turn, determines the magnitude of the reactions at the rail, in conjunction with the moment of inertia of the engine about a vertical axis, assumed to pass through its centre of gravity.

These reactions at the rail, commonly known as flange forces, can only attain very high values when the mass carried by the wheel is great, and when the transverse velocity with which the flange is running towards the rail is sufficiently high.

These two elements are interdependent; for a given engine and for track of given gauge, the predominating features in the production of high flange forces are clearance between flanges and rail, and elastic deformation of engine parts, and of track.

Lateral track flexibility, therefore, tends to induce oscillation to build up, and the engine proceeds along what is in effect a sinusoidally deformed track; so long as this deformation remains within the elastic limit of the track material, no residual deformation can be seen after the passage of the engine. Oscillation will build up if nothing intervenes in the meantime to damp it, or if, in the case of such an intervention, the forces coming into action are not sufficient, in relation to the kinetic energy of the engine.

If the lateral weakness of the track exists only over a short distance, and if the engine can reach a more resistant portion of track, before a serious degree of oscillation has built up, the conditions of (1) predominate. On the other hand, if weakness of the track continues, side displacement, and in consequence flange forces, increase at each successive contact between wheel and rail, and the following case has then to be considered :—

(3) When flange forces increase to such an extent that the spreading of rails (whether by tilting or by bodily displacement on sleepers) is no longer elastic but becomes permanent, and attain values higher than in (2) above, derailment of the wheels can occur, generally commencing with the leading coupled axle. In these circumstances, the wheels may fall between the rails; alternatively, instead of individual rails becoming displaced, the track as a whole may become distorted if its lateral resistance on the ballast is insufficient. In this case also derailment can occur, the track as a whole assuming a sinusoidal form.

If the rail does not fracture, and if the rolling action is out of phase with the nosing of the main frame, the leading coupled wheel, which is exerting high flange pressure, can become unloaded, and the flange may therefore ride on to the rail head. For this to happen, the vertical load on the wheel has to be reduced to approximately half the flange pressure for a normal tyre profile; but worn flanges can ride up with a smaller reduction in vertical loading.

73. The above represents the sequence of events set out in its simplest terms and taking extreme cases; but it is possible for every degree of intermediate condition also to exist. In practice, track deformations do not always result in derailments, but a very important aspect of the problem is that material disturbances can be set up in the engine by elastic deformation of the track, which is not readily visible after the passage of the engine.

This is because even considerable lateral and vertical deformations of the permanent way, in certain conditions of construction and maintenance, can remain purely elastic, so that after the passage of the engine the rails regain their former alignment and position; thus, it might well be disputed whether any track defect was present in order to account for an oscillation experienced on the engine. It seems likely that some degree of spreading of the gauge precedes the sinusoidal disturbance of track as a whole, but if it has been purely elastic, no evidence is readily available afterwards.

74. *Elastic Deformation of Track.*—This important initial condition to permanent deformation and derailment, namely, the extent of elastic spreading of gauge, can easily be verified by applying a jack between the heads of the two rails; it will be found that a considerable force will have

to be applied, causing an appreciable spreading of the gauge, before any permanent distortion is left, after the jack is removed. It is possible, therefore, for an engine to bring about equally large track deformations, and to leave no trace afterwards, although the deformations have been sufficient to promote severe lateral reactions. Elastic spreading of the gauge may be caused by one or more of the following :—

(a) Vertical play under spike or screw heads.

(b) Lateral play due to looseness of fastenings.

(c) Rotation of the bull or double headed rail about its support.

(d) Flexing of the F. F. rail about its base, if lateral stiffness is insufficient.

(e) Bending of the sleeper, if it is of the rigid type; spreading and/or tilting of the pots or plates, if the sleeper is of the semi-rigid type with a tie bar.

(f) Insufficient number of sleepers to compensate for relative lightness of rail, and/or weakness of formation.

(g) Absence or looseness of keys on bull or double headed rails, and of wedges on steel trough sleepers with F. F. rails.

In this connection, we would emphasise that the term track defect is relative. Most of the defects outlined above can start even a well designed engine hunting if they are sufficiently pronounced; but even within normally accepted standards of track maintenance, they are sufficient to start an engine hunting, if it is badly designed as a vehicle and in a bad condition of maintenance. Speed also is of the essence of the problem. The higher the speed, the smaller is the range of permissible imperfection in either track or engine; on the other hand, the effect of undue oscillation can always be brought within the range of safety by a sufficient reduction in speed.

The fact that track and engine parts deflect elastically suggests the possibility of resonance between the nosing oscillations of the engine and the natural period of the track, or engine frame, considered as a form of spring; such resonance has been suggested as a contributing factor in the building up of oscillation. The ascertained period of nosing of an X class Pacific, taken from numerous high speed tests, lies between 0·75 and one second. Although no tests have been made of the natural period of track, considered as a spring, it is obvious, in view of its lateral stiffness, that its period must be something very much less than 0·75 second. A resonance effect, therefore, seems to be unlikely.

In practice, the relationship between engine and track is not so simple as outlined above, and, in fact, it is highly complex; experimental verification is, therefore, of the first importance, and this aspect of the matter will be dealt with in Chapter VII. Lateral deformation of the track under load represents only one of the elements giving rise to high flange forces. The moment of inertia of the locomotive about a vertical axis through its centre of gravity represents another. Without guiding wheels, a light short engine would be expected to produce only small flange forces, but a heavy engine with a large overhang fore and aft would produce large flange forces.

75. *Effect of Engine Rolling.*—It has been stated that when a wheel flange strikes the rail, unloading of the opposite wheel due to rolling of the sprung mass of the locomotive is also an element which influences the building up of transverse oscillation on the track. The characteristics of the bearing springs are important. The more, flexible the springs, the less the amount of unloading of the wheels; very stiff springs may even cause derailment before material deformation of the track takes place.

Also, just as the longitudinal moment of inertia of the engine has its influence on the flange force, when one of the leading coupled wheels strikes the rail, so the transverse moment of inertia, the height of the centre of gravity, and spring stiffness, have effect on the amount of weight which is transferred from one wheel to another on the same axle, as the engine rolls.

For springs of given stiffness, this value will be affected by variation in the cross section of the engine, and particularly as weight is disposed at a distance on either side of the centre line. Side tank engines are thus more prone to rolling than tender engines.

The engine rolls on a base which is represented by the distance between the transverse centre lines of the axleboxes. The greater this distance, the less will be the periodic time of rolling, and a broad gauge engine should, other things being equal, be somewhat less prone to rolling than a narrow gauge engine.

These features, concerned in rolling, are important, but they have this in common, that they are much less amenable to control for the sake of good riding, than are such matters as side clearances and length of wheelbase. Flexibility of the springs, for instance, is severely limited in all cases by other considerations of design. The extreme range of spring deflection, which is attainable in ordinary designs, is from 0·15 in. to 0·35 in. per ton, in the case of coupled wheels. Further, when power requirements have been met, the cross section of the engine is capable of but little adjustment while the distance between axlebox centre lines is governed by the gauge of the permanent way.

Practical tests show that there is little possibility of purely rolling oscillations building up because of the damping effect of the laminated bearing springs. Therefore, whilst the significance of the foregoing factors must be borne in mind, we must turn to other considerations in engine design for factors which can be of use in the control of hunting. In so far as rolling is a contributory factor, vertical deflection of the track is one of the decisive elements, and, in this connection, stiffness of rail joints and packing of sleepers assume importance. These matters will be dealt with in Chapter IV. Staggered joints may also have some influence, *vide* paragraph 52, Chapter II.

76. *Running of Pacific type Locomotives on the track.*—What we have said for a locomotive without guiding wheels is equally true for an engine having such wheels, if, for certain reasons, these do not effectively perform their functions. If the mainframe of a Pacific locomotive is free to move transversely in relation to the bogie and hind truck, and if the cross slides offer no resistance (as, for example, if they were fitted with roller bearings), the guiding of the engine on the track would be performed solely by the coupled wheels, the wheelbase of which is generally short on a 4-6-2. The overhang, front and rear, will be considerable from the point of view of nosing, and in these circumstances the engine can assume an excessive angularity with the track. There would, therefore, be undesirably large flange forces at the leading coupled wheels, even at relatively low speeds. A Pacific under these conditions would run less satisfactorily even than an 0-6-0 type, because, the latter is not, in practice, provided with so large an overhang.

The above represents an extreme case, but it shows how necessary it is to provide certain characteristics to decrease, so far as possible, flange forces at the leading coupled wheels. The ideal value to be aimed at for these forces is zero, when the engine is running on straight track. On curves, this cannot be attained, but the lowest possible value must be sought. To achieve the best results, and to relieve the leading coupled wheels as much as possible of any guiding function it is not sufficient only to provide a bogie, the bogie must have the greatest permissible centring force in relation to the weight it carries. Engineers have sometimes been reluctant to take this course, feeling that any flange force taken-off the coupled wheels in this manner was simply added to the bogie wheels, thus transferring the possibility of derailment to those wheels. Such, however, is not the case, and it can be shown that it is possible to decrease, to a considerable degree, the reactions on the leading coupled wheels, by increasing to a small extent the flange pressure on each of the two bogie wheels.

For example, in the case of an XB engine, the distance from the leading coupled wheel to C. of G. is 5·83 ft. and from bogie centre to C. of G. is 14·58 ft.; assuming that the guiding reactions have the effect of deflecting the engine round a vertical axis passing through its C. of G., the transverse force to be applied to the engine to obtain a given rotation, is inversely proportional to the distance of the point of application from the axis of rotation. By increasing the lateral reaction on each bogie wheel by one ton, it is possible to relieve the leading coupled wheel flange pressure by about 5 tons. An actual increase, therefore, in the centring force of 4 tons applied to the bogie, as a whole, would decrease the flange pressure on the leading coupled wheels by about 10 tons. This states the problem in the simplest terms, but, in practice, the values are affected by friction and other considerations.

From trials made in France, and for the special features of French track, Blondel (9) has found, by means of special tests with rolling loads on main lines in the worst condition, that it is possible to apply a side pressure equal to 40 per cent. of the vertical load without risk of track displacement. This proportion must, of course, be verified for representative conditions in each country, having regard to varying natural features and standards of construction; in India, it should be possible to adopt 40 per cent, because, the conditions of track appear to be no worse than those under which Blondel, by means of deliberate preparation, obtained his limiting figure. Reverting to the simple illustration referred to above, it follows that, with a vertical load of 20 tons on the bogie wheels, it is possible to have a centring force of 5 to 6 tons, which should be able to decrease the coupled wheel flange forces by 12 to 15 tons; in effect, this would practically suppress them on the straight. It is evident that lateral pressure of 2½ to 3 tons on each bogie wheel will not have the same effect on the track as a pressure of 12 to 15 tons on the leading coupled wheels.

The best that can be done on the engine has been clearly shown to be the reduction of coupled wheel flange forces; this can be achieved by increasing, so far as is practicable, the side control on the bogie, having regard to the characteristics of the hind truck. This, in essence, is the most important practical measure which can be taken in engine design, to reduce the reactions on the track.

77. *The Effect of engine wear and maintenance.*—The above considerations have been largely theoretical, but, in practice, there are a number of factors entering into the problem which tend to detract from the parts played by the bogie and hind truck in the guiding of the engine. There is, for instance, side play of all kinds, which delays the instant when the centring action of the bogie and hind truck begins to take effect, after a side displacement of the engine. The different factors can be described as follows :—

(1) Sideplay of bogie pivot pin in the bogie centre casting.

(2) Flexing of the engine mainframe, between, the bogie pivot and the leading coupled axle.

(3) Sideplay of the axleboxes in the horns of bogie and hind truck.

(4) Sideplay of the bearings on the journals of bogie and hind truck.

(5) Clearance between flange and rail in the case of bogie and hind truck.

(6) Working of bogie control springs in opposition, at the beginning of their stroke, owing to bad fitting or wrong design.

(7) Breakage or loss of strength of control springs.

(8) Flexing of bogie frames.

If the total of all these displacements and deflections is considerable, the guiding of the engine, whatever the amount of the spring control, will be practically provided by the coupled wheels, for all angular displacements of

(9) Revue Générale des Chemins de Fer, December 1932.

the mainframe which do not entirely absorb the side clearances. This is the very condition which should be avoided, if possible, and it is at this point, therefore, that the maintenance of the engine assumes importance; this is dealt with in Chapter VI.

If, in addition, the initial spring control is too weak, an additional displacement will occur, which will be greater as the displacement-load curve of the control springs is flatter: this factor will have to be added to all the others before effective control of the engine by the bogie begins. It will, therefore, be realised that, while bogie side clearances have an important bearing on all engines, their effect is increased on engines with weak spring control.

78. *The Effect of Weather*.—Although at first sight remote from the problem of hunting, the weather, as affecting the state of rail surface, can become a factor of some importance. It has already been shown how the limits of adhesion affect the way in which an engine, striking one rail obliquely, will be deflected towards the other, depending on the circumstances in which lateral slipping of the wheels on the rail can occur. Obviously, with a dry rail, slipping will occur much less readily than with a wet or greasy one.

Trials have been made in France, in which, in a certain type of electric locomotive, hunting was proved to be due to a defect in design, which made itself felt when lack of rigidity and insufficient packing of the track were present. In other words, it was a border line case. Even after these factors had been traced and evaluated, the inconsistency in the behaviour of the engine was not accounted for, in that it would hunt over a given piece of track on one occasion, and not on another. At the time no explanation could be found for this, and it was only later when testing a different type of locomotive that the state of the rail was found to be a determining factor.

Under greasy rail conditions, lateral slipping is produced for relatively low flange forces, and the effect of the elements which make for building up of oscillation is reduced. On the other hand, under monsoon conditions, when in other respects track condition is at its worst, adhesion may be extraordinarily good should the rail be dry. When the rail has been well washed by heavy rain, and then dried by the heat, a light coating of oxide can rapidly form, (particularly under conditions of low traffic density) which will increase the adhesion, and consequently increase the tendency to hunt. The weather is obviously a condition which can not be altered, but its effect on the variability of results is worthy of note.

79. *The effect of friction*.—The total initial side controlling force on bogie or hind truck is the sum of two forces, namely, that due to the springs, links, or inclined planes, and that due to friction. These forces may combine in any proportion, according to the design and state of maintenance. A swing link bogie, for example, will have a minimum of friction, as there are no sliding surfaces, while a bogie with a cross slide, faced with friction material, can have greater frictional controlling force than spring force, if a weak spring be fitted. In the case of laminated springs, there is also friction between the plates. Moreover, the amount of friction present will vary with the state of lubrication of the sliding surfaces.

So far as initial control is concerned, it is of little consequence whether force is provided by spring or friction, or any combination of the two. As soon as any side displacement takes place, however, such frictional force as exists will add itself to the spring control for outwards movement; but it will be subtracted from the spring load on the return, and in extreme cases, if friction is high and the spring weak, external work will actually have to be done on the bogie to restore it to its central position. This is very undesirable on curves, since high leading coupled flange forces may result from the virtual cancellation of the controlling force in the return direction. While some degree of friction is inevitable, it is necessary, therefore, to keep it to a relatively low value. High friction and low spring control will give high coupled wheel flange pressures on curves; high spring control and low friction, while giving the same controlling effect on the straight, will also assist in taking some of the load-off the leading coupled flanges on curves. It is important, in any given design, that the coefficient of friction between the sliding parts should be known, and should remain between close limits. The above comments would not apply should damping devices be used which are free from friction.

80. *Magnitude of the Controlling Force on the Bogie and Hind Truck.* —It has been pointed out that a limited controlling force, acting through an arm which is longer than that of the coupled wheel base, can efficiently control both ends of the engine, and replace high flange pressure, between the coupled wheel and the rail, by well defined forces applied at the bogie and hind truck flanges. The value of these forces for a new design should be determined experimentally, in order to avoid excessive pressure between the coupled wheel flanges and the rail. Alternatively, these forces can be calculated from those existing on some former engine, which is known to exert low pressures; the values so obtained should be checked by experiment after the new engine has been running. This will give the most suitable initial value of the control.

When running at high speed on a curve, side displacement of both bogie and hind truck occurs, and the engine is in equilibrium under the action of three moments. One is given by the action of the bogie control, another, of opposite direction, is given by the hind truck control, and the third, in the same sense as the latter, arises from the natural tendency of the engine to follow a tangential course, due to centrifugal force. When the bogie side control balances the sum of the hind truck and centrifugal reactions, the movement of the engine round a curve will be similar to that of an engine without a bogie on the straight; it results in heavy flange forces at the leading coupled wheels. Again, if the spring control of the bogie is of greater value, but is not strong enough to avoid such high forces, the whole mass of the engine will be turned in a pivotal and jerky manner towards the inside of the curve, when track irregularities are present.

From the foregoing, we have shown how to determine the initial control. It is now necessary to ensure that the bogie control, at maximum displacement, does not exceed a certain percentage of the vertical load on the track. On very good track, this figure may, according to the French experiments already mentioned, attain 70 per cent. of the vertical load, but it is not advisable to exceed 40 per cent. Owing to the necessity for limiting the final control, it is important to keep the maximum side play of the bogie as small as possible, consistent with free passage round the sharpest curve.

It is necessary to conduct final tests using flange force recorders, to verify the chosen values; in carrying these out, care should be taken not to vary more than one factor at a time. For example, each set of variations of the bogie spring control must be made with the same setting of hind truck control. It should be noted that any variation in the strength of the hind truck control has the same effect on the behaviour of the engine, as an opposite variation applied to the bogie control, so far as curves are concerned. Methods of carrying out tests and recommendations in this respect are contained in Chapter VII.

81. *Determination of the amount of lateral spring control on the bogie, based on that of engines which are considered to run satisfactorily.*—As already explained, in order to limit nosing movement, it is necessary to introduce some degree of lateral control at the front end of the engine, as far as possible from the centre gravity. This control sets up a force which opposes the nosing movement when the frame is deflected from its central position. The value of the resulting moment must have a certain relation to the moment of inertia of the engine.

Assuming, for example, that the initial control on the standard B. E. S. A. 4-6-0 type engine is satisfactory at high speeds on existing track, it should be possible to determine the value of the side control on the XB class, to ensure equally satisfactory flange forces.

For the 4-6-0 type engine, let :—

- I = the moment of inertia about a vertical axis passing through the centre of gravity (tons-ft.)
- d = distance between centre of gravity and centre of bogie pin. (ft.).
- F = initial compression in the bogie side control springs. (tons).
- P = vertical load on bogie. (tons).
- f = coefficient of friction of the bogie slides.

Also, let I^1 d^1 F^1 P^1 and f be the corresponding values for the XB class. The centring force, resisting initial displacement is made up of spring and friction forces, the value in the case of the 4-6-0 type being $(F+Pf)$, and (F^1+P^1f) in the case of the 4-6-2 type. We can now set down an equation for the moment of the centring force about the centre of gravity of the engine; this is proportional to the longitudinal moment of inertia of the engine about a vertical axis.

The equation takes the form :—

$$\frac{(F + Pf)\,d}{I} = \frac{(F^1 + P^1 f)\,d^1}{I^1}$$

Whence,

$$(F^1 + P^1 f) = \frac{(F + Pf)\,I^1 d}{I\,d^1}$$

Assuming that :—

$F = 0{\cdot}75$ tons.

$P = 18{\cdot}5$ tons and $P^1 = 18{\cdot}0$ tons.

$f = 0{\cdot}1$ (for lubricated slides).

$I = 3477$ tons ft., and $d = 12'7\tfrac{1}{4}''$

$I^1 = 6542$ tons ft., and $d^1 = 14'7''$

Therefore, the total resistance to displacements at the bogie of the 4-6-2 type.

$$= (F^1 + 1{\cdot}8) \text{ tons} = \left\{ (0{\cdot}75 + 1{\cdot}85) \frac{6542}{3477} \frac{12{\cdot}65}{14{\cdot}6} \right\} \text{tons} = 4{\cdot}25 \text{ tons}$$

Thus, the value of the total force resisting initial displacement is 2·6 tons, in the case of the 4-6-0 engine, made up of 0·75 tons spring and 1·85 tons friction, while the corresponding value for the XB engine is 4·25 tons, made up of 2·45 tons spring and 1·8 tons friction. This calculation assumes that the XB, like the 4-6-0 engine, has no controlling force acting at the rear. A pacific, however, has a trailing truck, which also offers resistance to lateral movement, either in the form of a control spring (or inclined planes) *plus* the friction of the sliding surfaces, or, in the form of friction only, as in the case of a trailing radial axlebox with flat slides.

If a Pacific engine is oscillating on straight track, compression of, say, a left hand bogie control spring will coincide with compression of a right hand truck spring, as the centre line of the engine forms an angle with the centre line of the track. The resistance offered by both springs, as well as that due to friction in all the slides, will add together and tend to keep the engine straight on the track.

On the other hand, on entering a right hand curve, the left hand bogie spring will be compressed as before, but in this case it is the left hand truck spring which will be compressed, and the latter is tending to turn the engine in the opposite direction to the former. The side control on the truck is thus in opposition to that on the bogie, and, in such circumstances, in order to allow the bogie on a 4-6-2 engine to have the same effective controlling action as on a 4-6-0, it is necessary to increase the value of the moment due to the bogie control by the corresponding opposing moment due to the truck. For instance, we may assume that there is an initial control on the trailing truck of 2·5 tons, which may be made up of spring *plus* friction, or all friction, according to design of truck; also that the arm at which this force acts is 15′ 4″ from the engine C. of G.

Correcting this in proportion to the length of arm from C. of G. to bogie centre, we obtain a value of $\frac{2\cdot5 \times 15\cdot33}{14\cdot58} = 2\cdot63$ tons.

The total initial control of the bogie should, therefore, be $4\cdot25 + 2\cdot63 = 6\cdot88$ tons. But of this force, 1·8 tons arises from the friction of the bogie slides under a vertical load of 18 tons. The value of the initial spring control given to the Pacific engine should, therefore, be $6\cdot88 - 1\cdot8 = 5\cdot08$ tons, in order to provide a sufficient degree of control on curved as well as on straight track.

As already indicated, the bogie control at final displacement should not exceed 40 per cent. of the vertical load on the rails. For the XB class, this is 40 per cent. of 22·6 tons = 9 tons total, or a final spring tension of $9 - 1\cdot8 = 7\cdot2$ tons. Therefore, for this class of engine, the bogie control should be, say :—

Initial 5 tons. Final 7 tons.

Similarly, assuming a coefficient of friction of 0·1 the figures worked out in the same manner for XA and XC engines are :—

XA Initial $3\frac{1}{4}$ tons. Final 5 tons.

XC Initial $5\frac{3}{4}$ tons. Final 7 tons.

The above shows how the amount of side control may be determined in principle, based on known value for a 4-6-0 engine; but detailed adjustments should be made in these values, or, alternatively, in the amount of hind truck side control, when the spacing of the truck from the adjacent coupled axle is varied from standard.

The preceding discussion shows clearly that by increasing the arm of the moment of the centring force at the rear (for example, by increasing the distance between the hind truck and the trailing wheel, or by increasing the inclination of the Cartazzi slides), the initial controlling effect of the bogie on curves will be weakened.

It must not be forgotten that damping of the nosing movement, by friction on the slides, can in certain circumstances especially on the straight, improve the riding as observed on the footplate. This represents, however, only that part of the oscillation of an engine which relates to movement, and does not necessarily give any indication of the magnitude of the forces which arise from the reactions between wheels and rails.

Other influences on the Locomotive as a Carriage.

82. In addition to the foregoing, certain other features of design have to be considered; these are :—

(a) Position of bearing springs.

(b) Length of bearing spring links.

(c) Nature of connection between engine and tender.

(a) *Influence of spring position above or below axleboxes.*—When springs are below the axleboxes, when links are in tension, and when lateral displacement of the frame in relation to the axle occurs, the spring and its links are inclined in the same direction; the full length of the link is then effective in exerting a centring force to return the frame to its normal position. In such a case, the spring is mounted in stable equilibrium.

When, on the contrary, the springs are above the axleboxes, they are mounted in unstable equilibrium, because, when the frame is deflected from its normal position, the spring has a natural tendency to capsize, even if it is guided. This capsizing tendency has the effect of reducing the inclination of the link, which, in turn, reduces the centring force. It should be noted that if the lateral play between axlebox and guides is small, there is theoretically little difference between the two methods of suspension.

The effect of mounting the springs above the axleboxes is made worse in proportion as the spring camber and the length of the links are made greater. In these circumstances, there is a tendency for the axlebox guides to lean over against the axlebox, with a definite pressure on one side or the other. This may give rise to undue lateral wear in the guides and boxes, the clearances increasing in a cumulative manner. Moreover, the heavy unrelieved side pressure on the guides, which sets up friction in a vertical direction, can prevent the free rolling movement of the spring borne mass of the engine, and may give rise to further unloading of wheels.

Generally speaking, and for the reasons mentioned above, we recommend that unstable arrangements be avoided for springs, links, and compensating gear, in the case of new designs. On the other hand, it must be recognised that there are many thousands of engines in the world with overhead spring gear, and there are often sound practical reasons which will justify its use. When well designed, the actual practical drawbacks are hardly noticeable, and in view of this, there can rarely be any justification for reconstructing an existing engine to obtain an underhung spring position.

(b) *Influence of length of spring suspension links on the side movements of the engine.*—A locomotive is suspended at the ends of its spring links in the same manner as a pendulum. For a given transverse displacement, the centring force is inversely proportional to the length of the links, while the period of oscillation is proportional to the square root of the same length. Therefore, for a given side play in the axleboxes, main frame suspended by long links will remain out of centre for a longer time than it would if short links were used. For the same reason the side pressure of the guides against the axleboxes will be greater with long links, because of the lower value of the centring force.

If a blow occurs between rail and wheel when the edges of the guides are in contact with the axleboxes (as frequently happens with long links) the blow will not be reduced by any vertical component due to the inclination of the links, and the frame will move from side to side with alternate blows, the intensity of which increases in proportion to the side play.

On the contrary, with short links, the movement will be rapidly damped out, and the frame will be more readily maintained in the central position in the guides. It is clear that if there is any side play between boxes and guides on a new engine (and some such play is essential), increase in the side play by wear will tend to be greater with long links than with short. As in the case of springs, the relative effect of long links is limited within the working side clearances; whereas a short spring link is recommended for new construction, the suppression of long links, where they exist, can hardly be justified by practical considerations.

(c) *Nature of connection between Engine and Tender.*—If an engine is able to run with satisfactory stability, on both straight and curved track, exerting minimum flange forces, it is self sufficient as a vehicle, and there is no need for anything but an articulated link to connect it to its tender. On the other hand, as few engines attain perfect stability, it will be noted that some attempt, in most designs, has been made to tie up the engine with its tender, so that the inertia of one may be used to damp out the oscillations of the other, depending on their relative natural stability. This is usually obtained by some form of spring side buffer, and, on the straight, this form of connection has the effect of lengthening the virtual wheelbase.

On curves, the effect of intermediate buffers differs according to the particular arrangement. If the buffers are equalised, so that they both continue to exert the same force on the buffer beam on both sides of the horizontal centre line, the only force transmitted to the chassis of the engine is that due to frictional resistance, depending on the strength of the buffing spring, and on the coefficient of friction between buffer head and beam. In some designs, the buffer heads work on inclined planes. The buffers always try to centre themselves in the V formed by the inclined planes, and, in consequence, tend to equalise the throw-over of the back end of the engine and the front of the tender. As the throw-over of the former is usually greater than the latter, there is, in consequence, a centring force which tends to move the rear of the chassis of the engine towards the inside rail, *i.e.*, in the same direction as the trailing truck side control is acting, and in opposition to the bogie control on a curve.

Where the tender is of six-wheel type, or of bogie type without any provision for side displacement, and where the engine is of the Pacific type, with long overhang behind the trailing coupled wheels, the engine throw-over is bound to exceed considerably that of the tender. In these circumstances, the centring force, which arises from the buffers riding up the inclined planes, will try to move the back end of the engine, and, therefore, the front of the tender, over towards the outside rail. Further movement will be prevented when the leading tender wheel bears hard against the outside rail. In consequence, there will be a tendency to undue flange wear on these wheels on curves.

In practice, it is impossible to set the inclined planes at a steep angle, and, in view of the small degree of inclination which is provided, neither the centring effect on the engine, nor the additional flange forces on the tender wheels, are of great magnitude. If, on the other hand, the buffer springs, on each side of the horizontal centre line, are independent of one another, the buffer above the inner rail on a curve will be compressed, and a force will be exerted on the back end of the engine, tending to rotate its front end towards the outer rail. This will also act against the bogie control spring, and, in order to counteract it on curves, the strength of the bogie control will have to be increased for a given leading coupled wheel flange force.

CHAPTER IV.

PERMANENT WAY—MAINTENANCE—SPEED.

83. *Itinerary.*—We have already referred in general terms to our tour. Information showing the types of permanent way and formation over which we passed is given in Appendix VII. Opportunity was taken to examine almost all the types in some place or another. Our attention was specially drawn by Chief Engineers to certain portions of the line which were troublesome in maintenance during the rains; many such places were inspected, and we were interested to hear how local difficulties were being overcome. The Appendix referred to includes the typical kinds of permanent way in existence on the Class I Broad Gauge (5′ 6″) Railways of India, the route mileage of which is about 21,200, and the locomotive stock 5,330.

84. *Weather.*—As previously mentioned, our tour was advisedly undertaken during the latter part of the monsoon, when the track generally was not in its best condition. Statistics of rainfall in the areas through which we passed, together with the averages for recent years, are given in Appendix VIII. These figures are important, in so far as they indicate how rainfall varies in different parts of the country, and how in many places the 1938 rainfall proportionately exceeded that of previous years.

85. *Track—General.*—The rails in use on main and important branch lines in India vary in original weight from 75 lbs. to 115 lbs. per yard; in length they vary from 30 to 42 ft. Types of sleepers used are hard and soft wood (some creosoted), steel troughs and cast iron pot or plate. Of the two last named, there are numerous designs, each having its particular type of fastening for tie bars and rails, and calling for individual methods of packing and gauge adjustment; this factor adds to the difficulties of accurate maintenance, especially when different types are closely interspersed, sometimes within the same gang length. The use of stone ballast is almost general and in conformity with modern practice in other parts of the world.

In this Chapter, we pay special attention to matters which affect lateral resistance of the track, and to factors which, by permitting vertical deflections, may initiate oscillation and hunting of engines sensitive to track conditions.

86. *Track Components—Rails.*—A large number of the lighter sections of rails, which have served to carry traffic for 40 years or more, still remain in main lines, and the fact that they continue satisfatorily to perform their function as vertical load carriers is proved by the low incidence of rail fractures. In the past, as elsewhere, this one function of the rail, *viz.*, its ability to carry certain axle loads vertically, was almost the only criterion by which standards were assessed. It is true that some consideration was given to impact loads, which are also vertical in action, and to the support under the rail by the number of sleepers which carried it; but it is evident that another essential function of the rail, its lateral rigidity, and, in fact, that of the track as a whole, received comparatively little attention. As the result, however, of many cases of track distortion and/or spreading of gauge, which have occurred from time to time since the introduction of the X Class and other Pacific engines, research has been undertaken, and these questions are now being analysed.

Except in areas where, owing to sharp curvature, high speed, and heavy axle loads, noticeable wear has taken place, generally speaking rails in India have not been condemned for loss of weight by wear or by attrition due to corrosion. The renewal of rails has, in the main, been due to crippling or hogging at their extremities, particularly when carried on yielding formation. One of the main causes of bad running is lack of attention to rail joints. When, owing to yielding formation, traffic density, and other causes, the cost of maintaining track to the appropriate standard becomes unduly high, the replacement of rails by those of a section heavier and stiffer than that of the theoretical minimum may be justified.

We understand that the rail standards on which the Locomotive Standards Committee in 1924 based their recommendations were:—

	Axle load.	Rail.
Main Line Standard	Up to $22\frac{1}{2}$ tons .	90 lbs. yds.
Branch Line Standard	Up to 17 tons .	75 lbs. yd.

We were informed that the above standards meant a group of rail sections approximating to those weights. It is evident that the 90 lbs. F.F. section of rail was not adopted as a minimum standard for axle loads exceeding 17 tons and up to $22\frac{1}{2}$ tons; Administrations did not consider the replacement of their lighter sections to be justified on their calculations of rail strengths for vertical loads, insufficient attention having been paid to the lateral rigidity of a rail. The lack of appreciation of this function of the rail is further shown in the Schedule of Standard Dimensions (reprinted in 1933) where it is stated that theoretically an 85 lbs. rail, which had lost weight not exceeding 5 per cent., could be considered suitable for a $20\frac{1}{2}$ ton axle load at "unrestricted speed". The condemning section of a rail cannot be entirely expressed in terms of loss of weight, but must also be related to location of wear, *e.g.*, side cutting, in the rail section. We were informed, however, that the Railway Board have under consideration the revision of the specification for permissible wear of rails, and that it will be based upon the results of research which is in hand.

87. *Sleepers in general.*—These can be divided into two categories, the rigid type, such as the steel trough and timber sleeper; and the semi-rigid type, such as the cast-iron pot or plate with a connecting tie bar. The rigid type is to be preferred, but considerations of costs have largely influenced Administrations in adopting and adhering to the semi-rigid type. The metal sleeper, whether rigid or semi-rigid, has an advantage over the timber sleeper, in that, although higher in first cost, its residual value is considerably greater than that of the latter, the scrap value of which is negligible. The timber sleeper has, however, many advantages, and where the distance of haul from source of supply is not excessive, considerable use is made of it, particularly on certain soils with corrosive effect on metal fastenings. The softer varieties should preferably be creosoted.

With regard to the semi-rigid sleeper, the position of the tie bar, as in the latest C. S. T./9 type, should be as near as possible to the bottom of the rail, in order to resist spreading of gauge and tilting of rails under heavy flange forces. We saw instances of hogged and bent tie bars, which indicated another disadvantage of this type of sleeper, proving that pots can be tilted and gauge irregularities produced by uneven packing. Further, as lateral flange forces are exerted by one wheel of an axle, the resistance of the track to side displacement is assumed by only one of the two pots or plates, until play in the tie bar is taken up, in the event, for instance, of loose cotters. As resistance, in turn, depends upon vertical load, it is obvious that, in this respect, the semi-rigid sleeper may have about half the lateral strength of the rigid type.

It must be recognised, however, that pot and plate sleepers have been in satisfactory use for many years, and that the mileage of track in which they occur is considerable. For instance, they are laid, and packed with sand, on the main line section of the M. & S. M. R., between Arkonam and Madras, where a maximum speed of 65 m.p.h. is permitted and consistently attained. On the other hand, we noticed the difficulties of efficient maintenance in the case of track of this type where the fastenings, *viz.*, gibs, cotters, etc., had become worn. The task of maintaining good alignment, level and gauge assumes increasing importance when it is realised that differences in these respects affect the locomotive to the extent that oscillations may be set up, which must, in turn, react to the detriment of the permanent way.

88. *Denham & Olpherts' Plate Sleepers.*—We would refer here to a particular cast-iron plate known as the D. & O., of which there is a considerable mileage, principally on the E. I. R. This type of plate sleeper calls for remarks as it possesses certain uncommon features; it was designed

to provide head support to D. H. rails, and so, by preventing chair gall, to enable such rails to be reversed after permissible head wear had taken place on one side. This anticipation was not realised, because long before a rail had worn down to the permissible section, it had become hogged at its extremities, and was therefore unsuitable for use in the reversed position.

These sleepers, however, are still in use, mainly with 88½ lbs. B. H. rail, which may be described as an 85 lbs. D. H. rail, converted into B. H. by the addition of 3½ lbs. to the head. The sleepers comprise two cast-iron plates, with a W. I. tie bar connection, on which the rails are head-supported, on the outside by a fixed jaw and on the inside by a loose jaw; the latter is held in position by a cotter and a gib, on which the accuracy of the gauge depends. It is necessary to loosen the cotters and redrive them after packing is finished; otherwise, there is a tendency for the inner jaws to lift the rails off the outer jaws. But, in practice, the loosening and redriving of cotters is liable to be omitted and gauge adjustment is left to be made by unequal packing of individual plates. The result is that the inner or loose jaws may take most of the support of the rail, which thus becomes liable to tilting under load.

This sleeper was designed about 40 years ago and it has obviously rendered satisfactory service for a long time on the E. I. R., and the Administration has had sufficient confidence to extend its use to a heavier rail, *viz.*, 100 lbs. D. H. Under heavy engines, however, which may exert considerable flange forces, it is doubtful whether a D. & O. plate sleeper with worn fastenings is sufficiently strong to resist tilting or lateral movement of the rail. We can only describe this type as obsolescent, and we consider that its early removal from main lines carrying heavy and fast traffic is desirable. The rate at which such replacement should be carried out can be determined by the Administration only after further research on this type of track, as indicated later.

89. *C. S. T./9 Sleepers.*—This latest type of cast-iron plate sleeper has recently been introduced for use with 90 lbs. F. F. rails. While it has certain disadvantages inherent in the semi-rigid type, its fastenings are superior, and the adjustment of gauge can be made with steel wedge keys without having to resort to changing the gib and cotter; disturbance of track is thus reduced. These sleepers, combined with the rail-free Duplex joint sleeper of 1937 pattern, are reported as providing a well-supported track; we travelled over such track on the E. I. R. at speeds of 60 m. p. h. and were impressed with the smooth running.

90. *Timber Sleepers.*—These are extensively used on several railways, which are within close distance of the source of timber supplies, such as the N. W. R., B., & N. W. R., E. I. R., and E. B. R. On other lines, their use is limited on account of the length and cost of haul from the source of supply, which make them uneconomical as compared with metal sleepers. The N. W. R. has a plant at Dhilwan for creosoting about 350,000 per year. The Reupel process is employed, and it is anticipated that this treatment will increase life to 21 years, in which case it will be possible to use with economy greater quantities of such sleepers.

91. *Steel Trough Sleepers.*—These are also extensively utilised, and when properly bedded down are satisfactory, offering as they do considerable resistance to lateral disturbance. Such sleepers seem to be generally suitable for use in India, except perhaps on soil, known as Usar, which contains a high proportion of nitrate of potassium and has corrosive effect on steel. To resist, so far as possible, any tendency for the gauge to spread, we recommend the use of 4 keys per sleeper, as appears to be recent practice. This form of sleeper should also have a transverse moment of inertia sufficient to withstand, without deformation, the bending moments set up by irregular packing.

92. *General remarks.*—We think that consideration should be given to the extended use of rigid type sleepers where formation is unstable. On black cotton and other weak soils, which are incapable of withstanding heavy pressure, perhaps the timber sleeper has an additional advantage

over the steel trough sleeper, in so far that it has a cushioning effect against impact of moving loads. Having regard also to the knowledge recently gained that the lateral rigidity of a track varies considerably according to the type of sleeper used, it would appear desirable to review the present practice of using timber sleepers over arched bridges or culverts, which often occur at short intervals, on track which is otherwise completely laid with pots or plates.

93. *Sleeper spacing.*—This is expressed as a function of N, where N is the length in yards of a standard 36 ft. rail. The latest standard is 42 ft. and as the number of sleepers per mile of track laid with such rails to, say, an "N + 3 standard", would be fewer than for a mile of track laid with 36 ft. rails to the same nomenclature of sleepering, it would appear to be desirable to specify for each standard, the equivalent number of sleepers for different lengths of rails.

The present minimum sleeper spacing, related to the 36 ft. rail, as laid down in the current Schedule of Standard Dimensions is :—

N + 1 for axle loads up to 17 tons.

N + 2 for axle loads up to 18½ tons.

N + 3 for axle loads up to 22½ tons.

We feel, however, that sufficient attention has not been paid to the adequacy of support in the number of sleepers provided to distribute the weight on the various types of formation, and to withstand the lateral forces tending to spread the gauge, and distort the track as a whole. The impression should not be allowed to gain ground that the heavier the rail, the less the need for increasing the number of sleepers. It cannot be too strongly emphasised that, within limits, the greater the number of sleepers under a rail, the greater is the area of formation used for bearing the weight and the smaller the load on it per square foot. As a general rule, rails should be as long as is economically possible; in other countries 60 ft. is the standard, and 90 ft. rails are coming into use. We understand that this point is under consideration by the Track Standards Committee.

94. *Ballast.*—For some years past, it has been the accepted practice in other countries that improvement in alignment and level of track called for the use of stone ballast graduated down from 1½ in. cube, and that the best results are obtained from the use of ¾ in. ballast introduced under the sleepers by means of shovel packing. This method though particularly suitable for timber sleepers, cannot be used in the case of pot, plate and steel trough sleepers, or with track laid over black cotton or similar soil. But, where practicable, better results are invariably obtained from the use of smaller grades of ballast whether shovel packed or not. In areas adjacent to towns such as Bombay and Madras, where the electrified sections of line are laid with timber sleepers, we feel that shovel packing could with advantage be tried, and that it ought to be possible to train local labour in this method. Elsewhere, in the case of pot, plate and steel trough sleepers, packing with bars or beaters will hold the field for many years to come; this has been satisfactory, and there would appear to be little reason to criticise this method.

The standard depth of ballast laid down is from 8 in. to 12 in. below bottom of sleepers. It is evident that on black cotton soil, this depth is inadequate, and to attempt to increase it with more stone, which would sink into the soil, is uneconomical, if not practically useless. The provision of a blanket of ashes, sand or similar material at least 9 in. thick under the ballast, which has been adopted by certain Railways, has much to commend it. Further investigation into the best method of ballasting on various soils would appear to be desirable, and we recommend systematic research into this problem.

We noticed that on certain sections of the M. & S. M. R. and S. I. R., clean sharp sand is used for packing pot sleepers, stone ballast serving to box and blind the sand. The running on these sections was quieter and smoother than over corresponding sections of pot sleepered track ballasted with stone. These Railways have the natural advantage of being able to obtain suitable sand locally in the country through which their line passes. Sand packing fills a pot more effectively than coarse stone ballast, and so affords more stable support to the track. Running at high speed over the Arkonam-Madras section, on pots packed with sand, to which reference has previously been made, was not only quiet but steady; inspection and the Hallade records confirmed that the track was good in gauge, alignment and level. We were, however, informed on the S. I. R. that fine stone ballast had replaced sand on some sections, as it was found to afford better drainage and was not washed away during heavy rain; we observed that joint sleepers (pots) were packed with such ballast in otherwise sand packed sections, and in the Chief Engineer's opinion, this had improved the running.

95. *Formation.*—While it may be said that the components of permanent way in India are, in general, of a sufficiently substantial character for the traffic they have to bear, the major difficulty with which Indian Railway Engineers have to contend, to a greater or less extent, is the measure of support given to the track by certain types of formation. Of these, the most treacherous is the alluvial black cotton soil with loamy clay impregnations; it is peculiarly sensitive to the dry and wet seasons. When dry, it shrinks and cracks, and during the rains it swells and is particularly liable to sponginess at intermediate stages of water saturation. No specific rules can be laid down for dealing with such formation, which calls for special treatment according to the nature of the local conditions. The appropriate treatment must be left to the Engineer conversant with all the circumstances.

Adequate drainage to remove expeditiously as much water as possible from the ballast and formation is one of the essential treatments; the fact that water pockets may exist under the surface of an apparently dry track was proved during our inspections. For instance, some time after heavy rain, on the Madras-Bezwada main line, when drainage was examined on an embankment 6 ft. to 9 ft. in height, water in considerable quantity was found at a depth of 2 ft. below rail level. The importance of providing free outlets for such water cannot be overstated, and it would appear that, generally speaking, engineers are alive to this problem.

96. *Standard of Maintenance.*—Apart from the financial, material and physical factors affecting the standard of track maintenance, efficient organisation and well-trained supervision are two essentials. We specifically questioned Chief Engineers on this subject, and the opinions expressed were divergent. Whereas some considered that definite improvement in the standard of maintenance had been effected during the last 10 years, others felt that the situation was becoming increasingly difficult; with the continuance of financial stringency, some arrears which developed during the 1931-34 slump have not been overtaken, while recent reductions in pay and curtailments of privileges were quoted as being responsible for lowering morale, and for the growing disinterestedness of the personnel in their work. However advanced the technique of an organisation may be, unless the staff are contented, the success which the technique demands is not likely to be attained.

Owing to the fact that literate men are not generally employed in India in the ranks as gangmen, mates, etc., the supervisory staff, such as Permanent Way Inspectors, can rarely be recruited from those who have passed through these various grades. Though we realise the difficulties, we feel that this avenue for recruitment should be explored. As matters stand, it is essential to impart specialised knowledge, and training, to selected men before they can be expected to carry out and supervise efficiently the day-to-day maintenance of the permanent way. The importance of this is recognised, but there is only one Institution on Indian Railways, *viz.*, the Walton Training School of the N. W. R. at Lahore, where, besides training subordinates in railway operation, preliminary classes, both practical and theoretical, are held for men selected to qualify as Permanent Way Sub-Inspectors. On other Administrations, a system of apprenticeship exists under which selected candidates, generally with scholastic attainments, are given a course of 2 or 3 years' duration with the Gangs, under a Senior Permanent Way Inspector, and in the Office of the District Engineer. This system is also deserving of the fullest encouragement and further improvement. We would add that money spent in this direction must result in savings by the better use of railway material and more intelligent supervision. It is not possible to apply any financial formula in order to justify such expenditure, or to evaluate the return; but the resultant improvement in the standard of maintenance will nevertheless show itself in the course of time.

97. *Examination of track.*—The methods followed on the various Railway systems generally appear to be thorough, but they are mostly ocular, and rarely is examination made under load. We noticed, however, on one division of the S. I. R. that each member of the permanent way gangs, when standing clear for passing trains, took up a position opposite a rail joint, so that as the train passed, he was able to observe the condition of the packing of the sleepers at the joint under load. As an education with regard to the work which each man performs, this practice appears to be very desirable, and we recommend that, so far as is practicable, it should be extended throughout India.

We feel also that the use of the void meter, for measuring deflection of track under load, would be of value in certain places, and should be tried; this was introduced some years ago in France by Lemaire, and is now coming into general use in England (*vide* Fig. 5). It consists of a graduated scale carrying two hinged pointers, fitted with a clamp for attachment to a bar, which is driven into the ballast. The pointers indicate on the scale the extent of the depression of the sleeper under load, and this, added to the measurement (by using boning boards) of the visible static inequality in level of the rail, gives the total lift necessary for the sleeper concerned.

We understand that Engineers and Permanent Way Inspectors are also required periodically to travel on the footplate of engines of fast trains; this is a desirable and useful practice, especially when the disturbances due to an engine can be effectively differentiated and recognised from those caused by track irregularities. With a view, however, to more systematic examination of the track under load, we recommend the extended use, by Civil and Mechanical Engineers, of the information afforded by the Hallade Track Recorder, or some such device; by such means frequent comparisons can be maintained of the effect of traffic on the permanent way, and of its condition during dry and monsoon periods.

98. *Expenditure on Maintenance and Renewal of Track.*—We have examined statistics of expenditure on revenue maintenance per equated track mile on various Railways, but we do not propose to quote the figures for the reasons that they are not subdivided between labour and material, and do not differentiate between main and branch lines; nor do they afford a reliable comparison, having regard to variations over a number of years in the cost of materials, and in the methods of allocation to revenue and depreciation fund. Further, the proportion of branch line mileage to the total materially influences the statistical figure, and differs considerably for each Administration.

In common, however, with other Railway undertakings throughout the world, it has been necessary to examine maintenance expenditure very carefully, and the statistics illustrate what has been effected in this respect. Indeed, material economies have resulted, and, in the main, we cannot find that they have come about by curtailment of expenditure which was really essential for the safe operation of traffic. At the same time, we feel that, in some instances, this curtailment has already been carried too far; it must be remembered that deterioration in the general condition of permanent way increases with time, and may well result in an ultimate increase in the cost of remedial measures. We were, therefore, glad to hear that certain Chief Engineers were now taking steps to increase manning strength and to stiffen track by the addition of extra sleepers, ballast, etc., wherever justified.

We have also examined in detail the track renewal programmes of various Railways over the last 10 years. Here again, the available statistics do not necessarily give an altogether accurate representation of the state of affairs; but there has evidently been a general falling off in the number of miles of track and of track components renewed, and of betterments effected. In many cases, however, the work of replacing weak sections of permanent way, which was started just before the slump period, has been completed, though at a reduced rate of progress. Further, restriction of funds under capital account caused a halt in the construction of branch lines, where it had been intended to utilise older types of permanent way released from main lines, which in turn had been programmed to be relaid with heavier material. It appears that, in recent years, Administrations have generally hesitated to propose renewals, unless compelled to do so by considerations of safety, and there has been in consequence a tendency to prolong the life of material and to wait for easier financial conditions, which, unfortunately, do not seem to be materialising. On the other hand, we have noted with satisfaction that certain Administrations have programmed for the future many desirable betterments, which, in our opinion, have been sufficiently delayed; our recommendations in this respect are dealt with in Chapter IX.

As a general rule, an increase in weight of rails on renewal, and the provision of additional sleepers and ballast, can be justified partly by reduction in subsequent maintenance costs; but in India, having regard to the high proportion of track mileage on unstable foundation, expenditure on such improvements must often be faced without the full measure of corresponding maintenance saving. During and after monsoon periods, it is in any case necessary to maintain manning at full strength, to ensure, so far as is possible, the adequate condition of the permanent way.

99. *Man Power in Permanent Way Gangs.*—During the year 1930-31, at the commencement of the depression, the Railway Board placed an officer on special duty to investigate the civil engineering revenue expenditure of State-managed Railways; as a result, certain standards were laid down showing the maximum number of gangmen per mile for ordinary maintenance. Before these standards were fully adopted, however, the Pope Committee in 1933 recommended the introduction of job analysis in all departments, and investigations were accordingly made of the day's work performed by various gangs. The further reduction thus effected went beyond the scale proposed by the officer on special duty; the principle was to assume, as a basis, the minimum number of men required to deal with work under normal conditions, and then to strengthen gangs, either permanently or temporarily, to meet special conditions, such as unstable formation, class and age of permanent way, load, speed of trains, etc. We have heard it suggested, however, that the practical defect in this procedure may be that the amount of work done by a gang, when under close observation, is greater than their average outturn.

The following statistics of personnel employed on the permanent way on certain Railways illustrate the more noticeable reductions which have been effected during the last 7 years:—

Railway.	No. of men employed including mates, keymen and gangmen. In 1930-31.	In 1937-38.	Reduction. %
N. W. R.	27,155	19,022	30
E. I. R.	25,685	19,432	24
G. I. P. R.	16,473	15,346	7

As already mentioned, we are not able to differentiate between the manning on main and branch lines, and the figures are not comparable, as railways with a greater proportion of branch line mileage are naturally able to make greater reductions. But the foregoing figures give a general indication of the measure of economy which has been effected, though they must not be accepted without proper appreciation of the conditions which gave effect to them.

It is true that the Indian Railway Enquiry Committee referred in paragraph 28 of their Report to the possibility of making further reductions, and we appreciate the necessity for curtailing expenditure, particularly on uneconomic branch lines. But our terms of reference have called for careful consideration with regard to the maintenance of the permanent way in connection with the operation of the heavy engines in question over the trunk lines of the country, and, with regard to such lines, we feel that further material lowering of manning standards is not likely to be practicable. Indeed, on many sections, where formation is of unstable character, it would appear that a reversion to previous standards may become essential.

In paragraph 27 of the Report of the Indian Railway Enquiry Committee, it was also stated that the permanent way is maintained to a reasonable standard for the traffic it carries. We agree with this opinion generally; but, as a result of our observations at the end of a monsoon period, we feel that improvements have tended to lag behind those made in locomotives, rolling stock, and the strengthening and reconstruction of bridges. We have already referred to the long life obtainable from rails and metal sleepers, with the high residual value of the material of which they are composed, and it may be that these factors have contributed to the relatively slow progress of betterment of permanent way. We recommend that the whole question of track maintenance should now be subjected to a comprehensive review, with special reference to the determination of maximum permissible speeds in monsoon and dry weather periods respectively.

100. *Speed of operation.*—We recognise that since the War, considerable efforts have been made in India to advance with the times and to adopt up-to-date practices and improved methods as used in other countries. Some of these efforts are no doubt connected with improvement in speed and convenience of service, and this is laudable; but in the matter of speeds, there are certain factors which impose definite limits, if an adequate margin of safety is to be maintained.

In certain quarters an impression appears to be prevalent that the Indian Railway Enquiry Committee recommended an increase in maximum permissible speeds. We do not place this interpretation on the recommendation made in paragraph 27 of their Report; in our opinion this indicated the need for a general increase of overall speeds by means of reduction of stopping time at stations, of improvement in speeds generally on branch lines, and of acceleration of goods trains. In fact, it was made clear in paragraph 59 of the Report that [illegible]

Engineer and the Chief Mechanical Engineer, confirmed by the Government Inspector. Generally, we would strongly urge the necessity for not only avoiding any deterioration in the present standard of maintenance, including the efficiency of supervision and labour, but in certain cases for effecting improvement. This is particularly important on the lighter sections of track on which the heavier engines are required to run, pending renewal to heavier standards.

As regards speed generally, we feel that it is also necessary here to comment upon the pressure for economy which has been exerted during the last few years, and which is again being exerted today. There is no doubt that in this respect the load of responsibility upon the maintenance engineer is increasing. This is fully realised by the Railway Board, the implementing and transmitting agency for this pressure, and we received their definite assurance that it is no part of their policy to deny to Administrations the necessary funds for essential maintenance; we also understand that it has been very unusual during recent years for any reduction to be made in the estimates for track renewals submitted by Railways. We desire, however, to emphasise that reduction in maintenance expenditure on the permanent way cannot be persisted in indefinitely; there is a datum below which track condition provides an inadequate margin of safety for contingencies, when the Engineer, unless authorised to incur the necessary special expenditure, can only impose speed limitation as a safeguard to the public.

CHAPTER V.

FOOTPLATE EXPERIENCE AND HALLADE RECORDS. CHARACTERISTICS OF LOCOMOTIVE AND TRACK.

101. *General.*—To obtain practical experience of running conditions in the monsoon, we travelled during our tour on the footplate and on the front of 29 locomotives, mostly Pacific type, when hauling our special train weighing 353 tons. In this manner, we were able generally to appreciate the varying reactions between engine and track, and were assisted in forming an opinion with regard to Terms of Reference 4, namely, the suitability of the engines for the track on which they are required to run, and, conversely, the suitability of the track for the engines. To this end also, notes were made of the riding of the bogie inspection carriage, which was the last vehicle on our train, while daily continuous graphs of track conditions were made with a Hallade Track Recorder.

Although in this Chapter we have thus recorded our impressions with regard to both the riding of the different engines and the alignment of the track, as seen from the inspection coach and as disclosed by the Hallade graphs, we are conscious of the limitations of any attempt to assess by these means the effect of the engine on the track, and *vice versa.* On the one hand, it is possible for an engine to be lively and uncomfortable, and yet not harmful to the track; while, on the other hand, severe flange forces can arise from a seemingly smooth riding engine, especially on curves. Only on one short run were flange force Recorders fitted to the engine, and our impressions on the footplate were thereby confirmed by subsequent knowledge of the actual reactions which had taken place.

Generally, our remarks with regard to the track are also based on the Hallade graphs, and on personal inspections by trolley and on foot of certain sections of line. The recorder was situated over the centre of the bogie of a coach and remained in that position throughout the tour. It was not possible, however, for the vehicle always to remain marshalled in the same position in the train, and the effects of differences in this respect have been taken into consideration, in those cases where the vehicle was next to a hunting engine. We need hardly draw attention to the difference between opinion based upon examination of unloaded track and that based upon positive records of the behaviour of track under load. Nor need we emphasise the necessity for care when attempting to extend to engines the conclusions arrived at from records of oscillation taken on a vehicle; the flange forces and vertical loads exerted by the former are necessarily greater than those exerted by the latter. The records obtained in a coach are affected by tractive effort (whether push or pull) especially when the coach is next to the engine.

The advantages, however, of the Hallade graph is that it affords a useful comparison of track conditions. From an examination of such graphs, which were taken in France on engine and coach simultaneously, there is no doubt that, as would be expected, the oscillations indicate similar characteristics, though differing in amplitude; those relating to the vehicle do not always indicate the track defects to which the locomotive responds and which affect its running. For purposes of comparison we have also examined graphs taken on British railways, some at high speed showing considerable transverse oscillation; but later records clearly indicate the beneficial effect of subsequent adjustment in alignment. Figures 6, 7 and 8 show examples of records.

To enable us to gauge within reasonable practical limits the appropriate maximum operating speeds over sections of line concerned, the restrictions governing public services were relaxed for our special train, with the consent of the Chief Civil and Mechanical Engineers. Regard has therefore been paid to the fact that when the train was run at speeds in excess of normal permitted maxima, track irregularities, which were recorded on the Hallade graph, would not necessarily have affected, to similar extent, the running of the vehicle at normal speed; conversely, when low speeds were run, although the graphs appeared to be satisfactory in cross level and alignment, it did not follow that some or all of the track irregularities in these respects would not have been apparent at higher speeds.

It should be added that, apart from those caused by the springing of the vehicle vertical pen movements of the Recorder are due to imperfect packing, slack joints and battered rail ends; such movements are naturally worse on weak and unstable formation and tend to increase with speed. Similarly, horizontal movements are due to imperfect track alignment, the lack of transition approaches to curves, and to cross level irregularities, including abrupt changes in superelevation; these movements also tend to increase with speed, as indicative of the increase in lateral forces between flange and rail. This is important when considering the suitability of track, and although the record may relate only to a vehicle, close study of its oscillation is essential, especially when the riding of an engine, such as the X class Pacific (a border line case), is under observation at the same time.

102. *Comments upon Track and Engine.*—It will be realised, therefore, that the impressions gained during our tour correspond in no way to a close analysis, which can only be achieved by research and extended trials. Indeed the following observations are intended to be of a general nature and naturally relate to conditions as they appeared to exist on the lines which we traversed during the latter part of the monsoon, when weather and formation were at their worst in some places.

We desire to emphasise that, when reference is made to speed, this relates to general traffic and not to particular locomotives which may have to be restricted to lower speeds if they are of a type which cause high flange forces. While the final decision as to appropriate maximum speeds should rest with the Chief Civil Engineer concerned, who is responsible for the adequacy of track maintenance, we feel that the Chief Mechanical Engineer and the Traffic Officers should act in close co-operation with him in the determination of working speeds. This matter is referred to later.

For the purpose of the general analysis we have divided the classes of engine on which footplate tests were made as follows :—

(i) X class Pacifics in original condition as designed.

(ii) X class Pacifics, fully modified in accordance with instructions of the Railway Board, *i.e.*, fitted with Ferodo liners on the bogie, flat slides with Ferodo on the hind truck and German buffing gear.

(iii) X class Pacifics, partially modified.

(iv) Non-standard Pacifics.

(v) B. E. S. A. 4-6-0 type engines.

(vi) Non-standard 4-6-0 type engines.

(vii) An XC class engine which was specially modified to our requirements.

103. *X Class Pacifics in original condition as designed* :—

Railway, Class and No. of engine and date.	Routes and Miles.	Maximum Speed m. p. h.	Permanent Way.	Soil.
(a) M. & S. M. R. XB No. 216—				
4th Sept. . .	Raichur to Gooty—93 m.	57	75, 76 and 80 lbs. B. H. on Pots.	Black cotton ; sandy clay.
5th Sept. . .	Koduru to Madras—108 m.	75	90 lbs. B. H. on Pots and Timber (Sand packing).	Sandy clay and moorum.
(b) S. I. R. XB No. 7, 7th Sept.	Jalarpet to Erode—110 m.	77	80 and 90 lbs. B. H. on Pots. 90 lbs. F. F. on steel troughs.	Good firm moorum.

Railway, Class and No. of engine, and date.	Routes and Miles.	Maximum Speed m. p. h.	Permanent Way.	Soil.
(*c*) N. S. R. XB No. 87—				
10th Sept. .	Kazipet to Bibinagar—61 m.	52	85 lbs. F. F. on steel troughs and timber.	Black cotton and moorum ; black cotton.
14th Oct. .	Godhra to Baroda—42 m. (B., B. & C. I. R.).	60	90 lbs. F. F. on Pots and steel troughs.	
(*d*) E. I. R. XB No. 1916—				
14th Sept. .	Moghalsarai to Dinapore—125 m.	65	85 and 88½ lbs. B. H. on D. & O. plates and timber. 90 lbs. F. F. on C. I. plates.	Sandy clay; black cotton in parts.
23rd. Sept. .	Rae Bareli to Lucknow—47 m.	67	90 lbs. F. F. on C. I. plates.	Sandy clay and moorum.
(*e*) E. B. R. XB No. 431—				
20th Sept. .	Sealdah to Ranaghat—45 m.	60	90 lbs. F. F. on C. I. plates and timber. 115 lbs. F. F. on timber.	Soft loam.
22nd Sept. .	Asansol to Dhanbad—37 m.	59	115 lbs. F. F. on timber.	Rock and moorum.
(*f*) E. I. R. XC No. 1955, 22nd Sept.	Dhanbad to Gaya—123 m.	80	100 lbs. D. H. on D. & O. plates. 90 lbs. F. F. on timber. 115 lbs. F. F. on CST/9 plates.	Yellow clay. Some black cotton.
(*g*) N. W. R. XC No. 1854, 26th Sept.	Saharanpur to Ludhiana—120 m.	66	90 lbs. F. F. on timber, C. I. plates and steel troughs.	Sandy clay.

(*a*) This XB engine had run 25,000 miles since light repairs (tyres and boxes) and rode satisfactorily up to the maximum speed attained, 75 m. p. h., without any sign of hunting. The bogie tender did not ride so well on the first portion of the journey over the lighter rails, principally between Raichur and Gooty, where there was some nosing and vertical movement. Steps are being taken to replace in this section the 75 and 76 lbs. B. H. rails, over which considerable vertical movement was recorded on the Hallade graph, apparently due to hogged rail ends. The packing right through to Madras is with sand ballast, and the riding was generally quiet and smooth. Rain had been exceptionally heavy. Appropriate maximum speeds appeared to be 50 m. p. h. between Raichur and Gooty, 50—60 m. p. h. between Koduru and Arkonam, and 65 m. p. h. between Arkonam and Madras. On the last-named section particularly, the track was evidently being maintained to a high standard.

(*b*) This XB engine had a six-wheeled tender, and the hind truck was at 8 ft. 0 in. centres. It had done 50,000 miles since general repairs and ran steadily up to the maximum speed attained; but examination of the flanges of the leading and trailing coupled wheels indicated that heavy reactions between flange and rail had been occurring. In some places stone ballast had been substituted for sand, especially at joints. The graph was fair, but there was much vertical oscillation, apparently due to low joints and, in places, lateral oscillation may also have indicated variation in gauge. There is no black cotton soil in this area, but there had been heavy rain just prior to our tour, 8·5 in. and 7·35 in. having fallen during July and August respectively; this was almost $2\frac{1}{2}$ times as much as in the previous year. It seemed doubtful whether 60 m. p. h. was appropriate as the maximum permissible speed; for instance, alignment on certain curves required attention and did not appear to justify more than 50-55 m.p.h.

(*c*) *First Trip.*—This engine had done 42,000 miles since last heavy repairs. There was slight continuous nosing, and hunting occurred for the first time at 50-52 m.p.h., when the regulator was closed to stop the motion; the inspection carriage rode badly at the same time. Hunting occurred again, not so severely, at 45-47 m.p.h. The bogie tender also rode badly, with nosing and vertical movements; the track, 85 lbs. F.F. rails on troughs, was well ballasted, and generally appeared to be in good condition. Lateral oscillations were considerable on the graph, but the Hallade coach was next to the engine, and the unsatisfactory riding of the tender probably affected this vehicle.

Second Trip.—The engine was specially sent over to the B., B. & C. I. R., and the bogie was examined in Dohad Workshops; this illustrated the kind of features which contributed to hunting and these are considered in Chapter VI. Track conditions on the B., B. & C. I. R. appeared to be generally suitable for 60 m.p.h.; but the engine was obviously lively, and the tender was rough even at low speeds. Hunting was continuous and more or less severe according to speed and the state of the track, 90 lbs. F. F. rails on steel troughs and C. I. pots. On one occasion the regulator had to be closed urgently at about 60 m.p.h. The engine was worse on curves; it was obviously sloppy and not fit for more than 45 m.p.h., and flange forces were presumably excessive beyond this speed.

(*d*) *First Trip.*—This run included the site of the accident at Bihta and the XB engine was the one concerned; it was in good condition with clearances fairly tight. Except for a continuous nosing tendency and a certain amount of roughness, it ran satisfactorily up to 60-65 m.p.h., and there was no building up of oscillation; but the engine appeared to be sympathetic to track defects. Certain horizontal frame stays were loose and vibrated in rivet holes. The track comprised 85 and $88\frac{1}{2}$ lbs. B. H. rails on D. & O. plates, and 90 lbs. F. F. on C. I. plates, and there was plenty of ballast (tested at one place 24 in. below sleepers). There had been heavy rain five days previously and water was standing on each side of the line. Except on curves, little lateral oscillation was recorded on the Hallade graph; but vertical oscillation was excessive and showed up several weak places at a speed of about 60 m.p,h., indicating that rail ends may have become hogged and that joints were insufficiently packed, or that the rail may have been moving up and down, due to its method of suspension on D. & O. plates; generally, however, gauge and alignment appeared satisfactory on the record.

Second Trip.—The engine behaved in the same manner, the maximum speed being 67 m.p.h.; but the track, which consisted of 90 lbs. F. F. rails on C. I. plates and timber sleepers (the latter at joints only on some sections), did not give as good a record of lateral oscillation as that for the previous run over $88\frac{1}{2}$ lbs. B. H. rails on D. & O. plates. Though the vertical graph was generally better, a curve near the end of the run showed up badly at 40 m.p.h. The appropriate maximum speed appeared to be about 55-60 m.p.h., except at certain places where vertical movement would become excessive, due probably to slack packing of joints.

(*e*) *First Trip.*—The two runs, with a light train, to Ranaghat and back, were made, as the track was probably in its worst condition and the banks (mostly low) were saturated after the monsoon; formation is loamy soil and water was standing for long stretches on either side of the line.

This XB engine had a six-wheeled tender and Goodall drawgear, with the hind truck at 8 ft. 0 in. centres, in which there was about one inch of movement before the Cartazzi control commenced; the bogie centre (22/70 cwt. control springs) was well oiled. It had worked 111,500 miles since heavy repairs, and 27,000 since a frame breakage, when axle boxes had also been done up. In all, the frames had been cracked and repaired nine times. Oscillation was continuous at speeds over 35 m.p.h., and the relative movement between engine and tender was 4 to 6 in.; it was so severe at about 60 m.p.h., that speed had to be reduced for safety to 55 m.p.h., and later to 50 m.p.h. This engine was very sensitive to track conditions, and lateral and vertical oscillation clearly originated therefrom; the engine seemed incapable of damping it out, except by reduction of speed. Many track defects were observable before they were reached, culverts and level crossings also being felt; this section did not appear to be fit for a speed exceeding 50 m.p.h., although rails were of 90 lbs. and 115 lbs. F. F. type.

Second Trip.—This engine was worked to the E. I. R. and another run was made on what was understood to be some of the best 115 lbs. F. F. track (wooden sleepers) on the system. The effect of better track conditions was noticeable, but at 50-55 m.p.h., there was constant lurching and nosing, though oscillation did not seriously build up as on the E. B. R. The engine required alteration and repair. The Hallade graph appeared to indicate that generally the maximum speed should not exceed 60 m.p.h., for which the engine was clearly unfit.

(*f*) This unmodified XC engine, on the other hand, had had an intermediate repair as recently as August, and was in good condition. With the exception of some oscillation on a curve at 60 m.p.h., and when passing a station at 70 m.p.h., it rode steadily up to a maximum (on the straight for a couple of miles) of 80 m.p.h. It was lifted at Gaya for the bogie to be examined; the centre plate and slide were well oiled and there was no abnormality. Having regard to the bad running just previously of the XB referred to above [(*e*) second trip] on such good track of the same class, this run illustrated the fact that maintenance of these engines is clearly a material factor in the problem of hunting. The Hallade graph showed considerable lateral oscillation, but the coach was next to the engine, and the unsatisfactory riding of the tender probably affected this vehicle. The authorised maximum permissible speed was 60 m.p.h. The track, 100 lbs. D. H. on D. & O. plates, and 115 lbs. F. F. rails on C. S. T./9 and Duplex joint sleepers, was in good condition.

(*g*) This XC engine had run 47,000 miles since general repairs in February 1938; sideplay in the bogie boxes was ½ in. on the leading wheels and 11/16 in. in the trailing wheels. It nosed continuously, although there was no building up of oscillation; the bogie tender rode badly. The running over reverse curves on either side of stations at high speeds was noticeably rough and the engine lurched badly; though vertical movements were not severe, lateral oscillations were high in amplitude. On one occasion the fireman was thrown off his feet when traversing reverse curves at 65 m.p.h. Generally this section did not appear to be fit for more than 50-55 m.p.h. There is no black cotton soil and the permanent way consists of 90 lbs. F. F. rails.

Summary.—The experiences and records, which are briefly described above, for X class Pacifics in original condition, illustrate how sensitive these engines are to track irregularities; they also show why reports of different Administrations upon performance were often contradictory and of a baffling nature, if conditions of engine and track maintenance were not given full recognition. For engines of the original design, it is evident that such conditions materially affect riding at speeds exceeding 45 m.p.h.

104. *X Class Pacifics which were fully modified in accordance with instructions of the Railway Board*, i.e., *fitted with Ferodo liners on the bogie, flat slides with Ferodo on the hind truck and German buffing gear* :—

Railway, Class and No. of engine, and date.	Routes and Miles.	Maximum Speed m. p. h.	Permanent Way.	Soil.
(a) G. I. P. R. XA No. 2211— 4th Sept. . .	Sholapur to Raichur—161 m.	65	90 lbs. F. F. on steel troughs and 82 lbs. B. H. on Pots.	Black cotton.
11th Sept. .	Wadi to Sholapur—93 m.	56	Do. .	Do.
(b) G. I. P. R. XA No. 2249. 13th Sept.	Bhusawal to Itarsi—187 m.	68	100 lbs. B. H. on Pots. 90 lbs. F. F. on C. I. plates. 82 lbs. B. H. on Pots.	Some rock. Mostly black cotton.
(c) S. I. R. XB No. 10. 7th Sept.	Shoranur to Jalarpet—227 m.	67	80 and 90 lbs. B. H. on Pots. 90 lbs. F. F. on steel troughs.	Good firm moorum.
(d) M. & S. M. R. XB No. 205. 9th Sept.	Arkonam to Madras—42 m.	80	90 lbs. B. H. on Pots and Timber.	Sandy clay and moorum.
(e) E. I. R. XB No. 1920. 12th Sept.	Akola to Shegaon—23 m.	59 and 65	100 lbs. B. H. on Pots.	Black cotton.
(f) E. I. R. XB No. 1921. 14th Sept.	Dinapore to Mokameh—60 m.	44	85 and 88½ lbs. B. H. on C. I. D. & O. plates. 90 lbs. F. F. on C. I. plates and timber.	Some black cotton. Remainder clay and sand.
(g) E. I. R. XC No. 1975. 22nd Sept.	Gaya to Moghalsarai—124 m.	72	90 lbs. F. F. on C. I. plates and Timber. 100 lbs. D. H. on C. I. & D. O. plates.	Soft yellow clay and black cotton.
(h) B., B. & C. I. R. XC No. 604. 14th Oct.	Dohad to Godhra—44 m.	60	90 lbs. F. F. on Pots and steel troughs.	Rock and hard moorum.

(*a*) This XA engine had done 12,000 miles since general repairs, and had just left the shops after modification. On both trips, it rode smoothly and steadily with little oscillation, and the driver remarked upon its improvement in this respect; also upon recent improvement in track maintenance. There was, however, some tendency to nose within clearance between wheel and rail at speeds over 45 m.p.h., with a certain amount of swaying, between 50 and 55 m.p.h. The track generally appeared to be fit for 50 m.p.h.; the Hallade record showed rough riding on both types of permanent way at speeds over 55 m.p.h. There is a considerable amount of black cotton soil on this section.

(*b*) This XA engine had a six-wheeled tender and had just left the shops, after modification and the moving back of the hind truck; it rode well up to 65 m.p.h., and was smoother than the G. I. P. R. 4-6-0 type engine No. 393, *vide* paragraph 107 (*c*). The Hallade graph indicated better gauge and alignment (though some curves were not good) than anywhere else recorded on the G. I. P. R.; but at speeds of 55 m.p.h. and over, slacks and weakness of packing showed up prominently. Appropriate maximum permissible speed during the monsoon on the 100 lbs. and 90 lbs. rails would not seem to exceed 55 m.p.h. There are long stretches of black cotton soil, except for about 50 miles of rock formation in the ghat section.

(*c*) This XB engine had just left the shops after being modified at the special request of the Railway Board; its riding was not so good as that of S. I. R. XB No. 7 (original design). It was slightly harsher, with constant nosing at the front end at 55-60 m.p.h.; but the German buffing gear held the tender steady. Part of this track had been traversed (on rising gradient) the previous day; although rainfall had been exceptional, *vide* 103 (*b*), the track generally appeared to be in good condition, and suitable for 50-55 m.p.h., and in places for 60 m.p.h. Excessive side oscillation, however, was recorded on the Hallade graph at speeds approaching 60 m.p.h.

(*d*) This XB engine had a bogie tender and had just left shops after repairs and modification. The hind truck was at 10 ft. 6 in. centres. The engine was free from long period nosing, but exceptionally rough at the back end. Reciprocating weights had been unbalanced by drilling out the crescent balance weights, and there was, as a result, fore and aft vibration, which also caused short period nosing when speed was low. This 90 lbs. B. H. track had been traversed on a previous run with XB No. 216, *vide* 103 (*a*). The C. I. Pots are packed with sand ballast and the curves are flat; a particularly good road, on which speed up to 65 m.p.h., would appear to be justified.

(*e*) This modified XB engine was ready for shops and in a very run down condition; it had about one inch play in the hind truck and coupled boxes. It had been fitted with apparatus (which will be described later) for recording flange loads and displacements. Two runs were made over this short test section. On the second test, the German buffing gear was removed. The engine was rough, felt the joints, and ran jerkily on both trials at high speed when traversing the uneven curves. With the German buffing gear in position, maximum bogie side movement was $1\frac{3}{8}$ in., and the maximum hind truck axlebox movement was $\frac{7}{8}$ in. Without the German buffing gear, these movements were $1\frac{1}{8}$ in. and $1\frac{5}{8}$ in. respectively. This is one of the worst black cotton soil sections of the G. I. P. R., and has been known to give trouble for several years. A cinder mat had been tried, many side drains had been cut, and there were a number of culverts. The track is 100 lbs. B. H. rails on C. I. Pots; the curves were out of alignment and radius varied rapidly. Apparatus had been installed on one curve to record transverse movement of the track. Gauge varied from $\frac{1}{8}$ in. tight to $\frac{1}{8}$ in slack; ballast was too big for efficient packing. The Hallade graphs showed that lateral oscillation was severe, although vertical oscillation was not bad. A speed restriction of 40 m.p.h., had been imposed, which did not affect the time-table, but prevented making-up time. It appeared that this was the justifiable speed limit under monsoon conditions.

(*f*) This XB engine was just out of the shops, and clearances were tight all round. The engine and tender rode steadily, and there was no relative movement between them; maximum speed, however, was low, and the Hallade graph was featureless.

(*g*) This XC engine had done 14,200 miles since intermediate repairs in February, and was not so steady as XC Engine 1955 [original design, *vide* 103 (*f*)] which had been through the shops as recently as August. It was running, however, on lighter track, which was more troublesome owing to black cotton soil, and the German buffers were not in contact with the slides when the engine was pulling, nor was the American draft gear central casting in contact with the rubbing plate. The tender, therefore, rode badly, and the engine appeared to oscillate more freely, even though speed was kept to a maximum of 72 m.p.h. The Hallade records indicated that considerable defects existed in packing and alignment; speed in excess of 60 m.p.h. would not seem justified. The curve at Ganjkhwaja was traversed at 50 m.p.h., and the record showed good packing, and very fair alignment. (This was the scene of the derailment in 1933.)

(*h*) This XC engine was just out of the shops and had only run 500 miles. Besides the German buffing gear, there was a plain American type drawbar with two pin fixtures. Though the riding was generally good, and appeared as steady on the straight as XC No. 614 (modified to the Committee's requirements, *vide* later paragraph 109), there seemed to be more shouldering action on curves, of which there were many in this section. The track, 90 lbs. F. F. rails on steel troughs and C. I. pots, appeared to be fit for 60 m.p.h., except on the curves.

Summary.—The experiences narrated above with X class Pacific engines, which had been modified in accordance with the instructions of the Railway Board, show that in all cases, except one, these engines were free from appreciable tendency to nose or hunt; if the sensation, therefore, on the footplate were taken as the only criterion, the modifications made could be said to have been successful in damping out oscillation. All the engines, however, were in good condition, except the one referred to, *vide* 104 (*e*), which was run down, which rode unsatisfactorily on track in bad condition, and which was fitted with the Board's test apparatus. It was proved from the records thus obtained that comparatively high flange forces occurred in such circumstances.

105. *X class Pacifics partially modified* :—

Railway, Class and No. of engine, and date.	Routes and miles.	Maximum Speed m. p. h.	Permanent way.	Soil.
(*a*) N. S. R. XA No. 48. 10th Sept.	Bibinagar to Secunderabad—19 m.	49	85 lbs. F. F. on Steel Troughs.	Black cotton.
(*b*) E. B. R. XB No. 449. 20th Sept.	Ranaghat to Sealdah—45 m.	65	90 lbs. F. F. on C. I. plates and timber. 115 lbs. F. F. on timber.	Soft loam.
(*c*) N. W. R. XC No. 1849. 26th Sept.	Ludhiana to Lahore—116 m.	70	90 lbs. F. F. on C. I. plates, timber and steel troughs. 87 lbs. F. F. on timber.	Sandy clay.

(*a*) This XA engine had a six-wheeled tender, Goodall draft gear, 25 cwts., initial spring control on the bogie, and 1 in 20 inclination on the Cartazzi slides. Axleboxes had been recently repaired, and clearances were good. Maximum speed attained was comparatively low, and the engine rode well; but it was clearly sensitive to track defects and there was slight nosing on curves. The Hallade coach was next to the engine, and the record was probably influenced by the movement of the engine and its tender. The track was well packed, but there was considerable lateral oscillation on curves.

(*b*) [illegible] this XB engine rode better than E. B. R. XB 431 [illegible] prominently on the Hallade graphs beyond 50 m.p.h. Generally the track was in good condition and appeared to be fit for 60 m.p.h.; but ballast seemed short in places, and level crossings were felt on the footplate at high speed.

Summary.—The only modification in the case of engine (*a*), which was of the latest construction, was the provision of laminated spring bogie with side bearers; the frames were also well stayed from end to end. On engine (*b*) there was Ferodo on the bogie, and German buffing gear, but the Cartazzi hind truck was unchanged. On engine (*c*) Ferodo on the bogie was the only modification made. As might be anticipated, half measures were not satisfactory, and the riding of all three engines left something to be desired, their movements being due as much to themselves as to the permanent way, at any rate in cases (*a*) and (*c*).

106. *Non-standard Pacific Type Engines*:—

Railway, and No. of Engine, and date.	Routes and Miles.	Maximum Speed m. p. h.	Permanent way.	Soil.
(*a*) M. & S. M. R. No. 901. 8th Sept.	Jalarpet to Mailpatti—27 m.	60	90 lbs. B. H. on Pots and Timber (Sand Packing).	Sandy clay.
(*b*) B. N. R. No. 796. 21st Sept.	Khargpur to Dantan—32 m.	62	85 lbs. F. F. on Pots with timber at joints. Single and stone ballast.	Sandy. Generally. firm.
(*c*) B. N. R. No. 792. 21st Sept.	Dantan to Khargpur—32 m.	60	Do.	Do.

(*a*) This engine is one of two Pacifics, designed and built by Baldwin's, and delivered in 1924. It is fitted with a swing link bogie with heart shaped links, and a swing link hind truck; it has a bar frame and American type drawgear. The engine was in a run down condition, but gave no trouble in maintenance; there was considerable sideplay in the coupled boxes and it was rough to ride on, particularly as regards vertical vibrations. The tender was, if anything, worse, as the coupling appeared to be slack. There was continuous slight nosing, but no building up, though oscillation was severe at 55 m.p.h. The track, 90 lbs. B. H. on pots, appeared to be fit for speeds up to 55-60 m.p.h.

(*b*) This 4-cylinder compound Pacific had done 54,000 miles since last repairs, and was hauling a light special train; the engine was fitted with Skefko roller bearings on the bogie and 1 in 10·6 Cartazzi slides on the hind truck. Both this, and the engine mentioned in (*c*) below, correspond to the I. R. S. XC type, and follow that design as regards the bogie (20 cwts. initial control), spring gear, and hind truck. The engine felt the joints and rode unsteadily with a continual hunting tendency, but it did not actually hunt. There was some oscillation and jerky riding on curves, the brake on one being applied at 62 m.p.h. The four-wheeled inspection coach rode well at this speed. Formation was generally on low bank with paddy fields on each side; the track was 85 lbs. F. F. rails, 40 years old, 36 ft long, recently dehogged, on 13 pots and 2 timber sleepers at joints. Gauge, where tested, was $\frac{1}{4}$ in. to $\frac{3}{8}$ in. tight, and the joints were standing up satisfactorily; suitable maximum speed appeared to be 55-60 m.p.h.

(*c*) This engine had done 71,200 miles since last repairs, and was in a modified condition with considerable clearance in the boxes. The bogie was fitted with Ferobestos liners on pivots and slides and with 37 cwts. initial control springs; the hind truck had flat slides with the same liners, and lateral movement of the radial axleboxes was reduced from 3-3/16 in. to 2-1/4 in. Instead of the German buffing gear, the B. N. R. standard had been fitted, consisting of a link and side buffers. The engine rode a little better than that mentioned in (b), but it seemed worse with steam off, and there was constant slight oscillation at high speed; it jerked somewhat round curves, and control at the front end appeared insufficient. The engine was lively, and one which might well have started hunting when traversing a bad patch of track at speed. The section of the line concerned was the same as in (*b*) above.

Summary.—It was noticeable that although the American type of Pacific rode roughly, there was no tendency for oscillation to build up; whereas, in the case of the B. N. R. Pacifics, with the bogie, spring gear and trailing truck of I. R. S. XC type, a hunting tendency was obvious, and the engines were lively enough to indicate that heavy flange forces might easily develop when traversing a bad patch of track at speed.

107. *B. E. S. A. 4-6-0 Type Engines*:—

Railway and No. of Engine, and Date.	Routes and Miles.	Maximum Speed m. p. h.	Permanent way.	Soil.
(*a*) M. & S. M. R. No. 784. 9th Sept.	Madras to Gudur —85 m.	60	90 lbs. B. H. and 90 lbs. F. F. on timber.	Deltaic silt, sandy.
(*b*) N. S. R. No. 91 11th Sept.	Secunderabad to Wadi—121 m.	60	85 lbs. F. F. on Steel Troughs.	Partly black cotton and partly moorum.
(*c*) G. I. P. R. No. 393. 11th Sept.	Sholapur to Dhond—117 m.	56	82 lbs. B. H. on pots. 90 lbs. F. F. on Steel Troughs.	Black cotton.
(*d*) E. I. R. No. 233. 23rd Sept.	Benares to Rae Bareli—143 m.	57	90 lbs. F. F. on timber and C. I. plates.	Clay, sand and Usar.
(*e*) G. I. P. R. No. 410. 25th Sept.	Agra to Delhi—121 m.	56	85 lbs. B. H. on pots and timber.	Goodfirm sandy clay.

(*a*) This engine was of an early type, had a six-wheeled tender and had done 7,200 miles since intermediate repairs. Owing to the absence of balance to reciprocating parts, it was very rough, and there was much vibration with short period nosing and shuttling; but the engine was generally free from long period nosing. The track was ballasted with shingle and stone, and there had been heavy rain a few hours previously. At one place inspected, water was standing 24 in below rail level on bank. This track did not seem so good as elsewhere on this system; the inspection coach rode steadily at 40-45 m.p.h., but there was considerable oscillation at 55 m.p.h. The Hallade record showed excessive lateral oscillation but no serious vertical defects.

(*b*) This engine was also of an early type. Clearances between axlebox and wheel boss were moderate, being about $\frac{3}{8}$ in. to $\frac{1}{2}$ in. all round; mileage since last heavy repairs was nearly 50,000. The riding was smooth and free from nosing, except for an occasional slight tendency on curves; it rode better than XB 87 which had done less mileage, *vide* 103 (*c*), since last heavy repairs, namely, 42,000, and much better than the engine referred to above in (*a*). There had been very heavy rain the night before and the Hallade record appeared to indicate that track condition justified maximum speeds of 50-55 m.p.h.

(*c*) This engine was of a recent type. It had under-hung springs with leg of mutton brackets. Clearances were good, particularly on the bogie, and the axleboxes were oil-lubricated. The engine was very lively at the back end, and rolled and nosed at speed. The track was not in first class order; badly aligned curves caused severe side blows, and lurching occurred when running off from a curve to the straight. On good portions of the track, the riding was better. There is much black cotton soil on this section, and from the Hallade record it appeared doubtful whether speed higher than 50 m.p.h., was justified, except at occasional places.

(*d*) This engine was also of recent type, and its bogie had new side control springs of 22 cwts. initial strength. There was over ½ in. sideplay in the trailing coupled boxes (after about 6,000 miles). The engine appeared to be sloppy and there was a continuous hunting action, which at times built up and died away; the sensation was not as bad as on a hunting Pacific engine. Running speed was generally about 45 m.p.h., and the track appeared to be in good condition; there had been more rain than usual, but it had been fairly well distributed, and formation was dry. The section would appear to be fit for speeds up to 55-60 m.p.h.

(*e*) This engine was of an early type, with a bogie tender. Mileage since last shopping was 56,000, and there was sideplay of about ½ in. in all boxes. The engine was rough and there was continuous nosing and hunting at 50-55 m.p.h., but without a tendency to build up, and the tender rode badly. The driver maintained a steady 50-55 m.p.h., which appeared to be the appropriate maximum, having regard to the character of the track, and to the Hallade record, which showed more vertical oscillation than lateral, indicating low joints and/or hogged rail ends.

Summary.—The above experiences indicate that the 4-6-0 type engine is little less capable of nosing or hunting than the Pacific, and that if the track is sufficiently bad in relation to the speed, rough riding can occur. On the other hand, the shorter length, lighter weight, and reduced moment of inertia of the 4-6-0 type, do not combine to cause the same amount of damage to the track or to exert the same flange forces, even when the engine is oscillating badly as might result from a Pacific behaving equally badly. Attention to the bogie side controls of 4-6-0 type engines would appear to be desirable, and might improve their running.

108. *Non-standard 4-6-0 Type Engines* :—

Railway and No. of Engine and Date.	Routes and Miles.	Maximum Speed m. p. h.	Permanent way.	Soil.
(*a*) E. I. R. No. 1105. 14th Sept.	Cheoki to Moghalsarai—86 m.	60	85 and 88½ lbs. B. H. on C. I. D. & O. plates and timber.	Clay and some black cotton.
(*b*) B.N. R. No. 684. 21st Sepr.	Khargpur to Calcutta—72 m.	65	90 lbs. F. F. on steel troughs.	Good firm deltaic

(*a*) This engine was an old 4-6-0 type of 1902. The springs were underhung and the axles uncompensated. The engine rolled and nosed with short period oscillations, but there was no building up; it was generally rough and lively at speed, with much vibration. The Hallade record showed remarkably good alignment and gauge; but vertical movements were excessive in many places, apparently indicating slack or hogged joints. In view of the latter feature, the appropriate maximum speed would seem to be not exceeding 50-55 m.p.h.

(*b*) This engine was one of the B. N. R.'s two new experimental 4-6-0's which differ from both the B. E. S. A. and I. R. S. designs. It had a bogie tender, with Goodall drawgear which appeared to permit of some oscillation of the tender. Though a little harsh, the engine rode very well and steadily up to the maximum speed attained, with a train weighing 369 tons; on one portion of the section, speed had to be reduced to 50 m.p.h., due to monsoon conditions, and the Hallade track record showed slack packing and severe lateral oscillations. Generally, however, the track appeared to be in good condition and justified speeds up to 60 m.p.h.

Summary.—The above two tests represented practically the earliest and latest 4-6-0 type engines in use on main line service in India. The B. N. R. appear to be satisfied with their new experimental engine, which, according to that Administration, met their requirements, and the Engineers apprehended less damage being done to the track than that from their Pacifics.

109. *An XC type Engine which was specially modified to this Committee's requirements*:—

Railway, Class and No. of Engine and Date.	Routes and Miles.	Maximum speed m. p. h.	Permanent ways.	Soil.
B., B. & C. I. R. XC No. 614, 13th Oct.	Kotah to Dohad—235 m.	70	75 lbs., 87 lbs. and 90 lbs. F. F. on C. I. pots, steel troughs and timber.	Rock, hard and soft moorum. Some black cotton.

This engine had done 800 miles since repairs and alterations. The bogie was of laminated spring type with roller bearings, and had new springs, giving 5 tons initial and 8 tons final control; it also had side bearers, without any friction material. The hind truck had flat slides and Ferodo. The drawgear was of American type and the German buffing gear was modified by removing the inclined slides and fitting flat buffer heads working against Ferodo faces on the tender buffer beam; distance pieces had been fitted to buffer spindles so that only one buffer was in operation at a time. Apart from the above special requirements of the Committee, this engine had also been previously fitted with diagonal diaphragm plates stiffened with angle irons from the throat plate to the cylinders, thus giving better staying between the cylinders and leading coupled wheels than was usual with the I. R. S. design. The portion of the hind truck which slides on the horns had been deepened, and there were Ferodo faces on the horn guides to reduce wear. There were Timken roller bearings on the tender and engine bogie.

The running was particularly smooth and steady at speeds up to 60 m.p.h. over a road with considerable curvature. Though there was no opportunity to record flange forces, it appeared that the use of adequate bogie centring force, without material friction, gave as steady riding as the Railway Board's modification with high friction and low centring force. The running over steel sleepers was, on the whole, better than that over pot sleepers; the highest speed, 70 m.p.h. was, however, attained over a length of pot sleepers, where the engine rode well. Generally on the pot sleeper road, joints were felt and it was noticed that some tie bars were kinked up and down. This type of pot has an old fastening which is wedge held and permits of variable gauge. On this section there is black cotton soil and the test length of 1932 was inspected. Rainfall had been about the average of 32 in., and the track was in fair condition. Speeds between 60 and 70 m.p.h. would seem to be excessive on this section, containing as it does a large number of curves which showed up badly on the Record, so far as lateral oscillations are concerned. The vertical graph is reasonably good throughout and, apart from the curves, 60 m.p.h. appeared to be the appropriate maximum.

Recommendation.—Experiments should be made with this engine to ascertain the extent of flange forces exerted on straight and curve at varying speeds.

CHAPTER VI.

Engine Maintenance.

110. *General.*—During our tour, which included visits to the 8 Workshops and 7 Running Sheds referred to in Chapter I, we were able to appreciate the general quality of maintenance, and more particularly of X class Pacific Engines, under heavy, intermediate, and light or running repairs. The question is one on which there are conflicting views, and besides the evidence which we heard and our own observations, the accounts given in Chapter II are illustrative of the differences in opinion with regard to the extent to which running conditions of engine and track may be considered to affect the problem of oscillation.

Experience in India, as elsewhere, confirms that, provided design is appropriate, the higher the standards of maintenance in respect of engine and track, the less is the incidence of oscillation and of the trouble which results therefrom, in the form of distortion of track, cracked frames, etc. Design for India must also have regard to lower standards of maintenance, and, for the same degree of oscillation and sensitivity, relatively more attention to side-clearances should be given in India than is found necessary in Great Britain, where track conditions are better.

It was represented to us that the quality of maintenance, particularly of axleboxes, is an over-riding factor in the incidence of hunting; also that the controlling force against hunting is derived from the rigidity of the coupled wheelbase, and that, therefore, wear in those boxes particularly tends to increase the amplitude of hunting. Hence, lack of maintenance in this respect was held to be a contributory factor, and some support for this view is forthcoming from the early experiences of satisfactory riding, and from the examples of cessation of hunting after clearances had been taken up during the course of repairs. On the other hand, it appears that the XB engine, which was involved in the Bihta derailment, had just previously been through the Shops, and that its axlebox clearances were normal; therefore, it seems doubtful whether engine maintenance, as such, can have had a material bearing upon the circumstances, unless, for instance, the bogie mechanism was defective in this respect.

Whichever view, however, is taken, the original design of the engine as a vehicle was such that its riding was unusually sensitive to conditions of maintenance, both of chassis and track. There is no doubt that the most important feature in the former is anything which favours the possibility of increase in the angularity of the engine to the track; but obviously care must be taken to avoid ascribing all the hunting which takes place to an insufficiently high standard of maintenance. Moreover, the general standard of maintenance which we saw in the Shops and Sheds was not on the whole unsatisfactory; nor was it inadequate, where supervision was efficient. While, therefore, the importance of engine maintenance should not be overlooked—and we make recommendations with regard to it later in this Chapter—we desire to emphasise here that he heart of the matter, namely design, would be left untouched if closer attention to maintenance was our only recommendation.

111. *Discussion of Forms of Wear and Play which affect Hunting.*—These have been dealt with in Chapter III, but for clarity will be set out again here:—

(1) Increase of clearances between :—

(*a*) Bogie pivot pin and hole in bogie centre casting.

(*b*) Bogie slide and side control spring stops.

(*c*) Axleboxes and horns.

(*d*) Bearings and Journals.

(*e*) Flanges and rails.

(*f*) Top and bottom of Cartazzi slides.

(*g*) Cartazzi slides and their casings.

(2) Play arising from lack of care in assembly, which can cause the control springs, in the standard type of bogie, to work in opposition over the beginning of their stroke.

(3) Play due to weak or unequally matched bogie control springs.

(4) Play due to flexibility in the bogie and main frames if these are not adequately stayed.

The types of wear under (1) (*a*) to (*e*) inclusive are common to all locomotives on all Railways. With normally designed engines, wear in these parts increases gradually between shoppings, but, if allowed to become excessive, an uncomfortable and rough riding engine results; hunting, however, rarely occurs in consequence, without other contributory factors relating to engine and track.

For instance, severe wear in the bogie pin and in the bogie axleboxes can bring about as much as an inch or more of uncontrolled movement; but where sufficient side control is provided, the mass of the engine is brought up against a firm resistance after the free movement is taken up. Where side control is weak and the spring has a flat load-displacement curve, the bogie frame meets a yielding resistance after clearances have been taken up; the amplitude of movement at the front end is thereby increased, throwing more of the guiding of the engine on to the leading coupled flanges, with the undesirable results already pointed out. This is one reason why X class Pacifics are especially sensitive to deterioration in maintenance, but if the side clearances in the bogie and hind truck are kept as low as possible, one of the predisposing factors towards hunting is thus suppressed.

The Cartazzi slides, referred to in (1) (*f*) and (*g*), are also susceptible to the effects of inferior maintenance. Theoretically, the slightest displacement from the centre line should cause the weight at the back end to ride up the inclined planes, and thus to exert an immediate centring force. When wear, however, in these slides takes place, free movement can occur, and this is added to play of the journals in their bearings and of the axleboxes in their horns; Cartazzi axleboxes also induce a great deal of side wear in the horns and on the journals.

112. *Additional Forms of Sideplay.*—There are two other features, Nos. (2) and (3) above, which also have the effect of increasing the uncontrolled movement of the front end of the engine, and these may be described as points in design which make good maintenance difficult. Figures 9 and 10 show diagrammatically the arrangement of the side control springs as fitted to the standard bogie on X class Pacific engines. Initial control is obtained by screwing up the plungers by means of the centre bolt and nut E. The adjustment is correct when the distance over the plungers, before assembly in the bogie frame, exactly equals the distance between the bogie frames, as shown in Figure 9. Under these conditions, the slightest displacement on either side of the centre line immediately brings in the full initial control on one or other of the springs.

In order to avoid any chance of clearance being left between the face of the buffer plungers and the frame (which would give free movement), it is usual to allow $\frac{1}{8}$ in. increase in length over the buffer plungers, so that, when in position in the frame, there is clearance between the nuts and the web in the bogie casting; this is shown on the drawings. In these circumstances, *vide* Figure 10, one spring can act against the other, largely nullifying the initial control over the distance of this clearance. It is a defect in the design of this control gear that any such clearance has to be provided. As the importance, however, of this point is not fully realised, care is not always taken in the Shops to adjust the screwing up of the plungers to close limits, and a clearance of $\frac{1}{4}$ in., and more, is not uncommon, giving an uncontrolled side movement of this amount, apart from any other features.

The second point in design which makes good maintenance difficult is the fact that the side control springs are, when in position, invisible. When there is any falling off in the standard of maintenance, weak, or even broken, springs may be assembled during repairs, and there is no means of checking this until such time as the engine returns to the Shops. Moreover, if a spring becomes weak or broken in service, the fact cannot be detected, unless the bogie is dismantled, and even the highest standard of maintenance is nullified when there are no means other than this of discovering that there are defects.

In fact, sideplay in any of the elements of the bogie or hind truck encourages a nosing tendency in any engine, and such play is a contributory factor to hunting in locomotives which are especially sensitive to maintenance conditions, such as X class Pacifics. On the other hand, sideplay in coupled wheel axleboxes is not quite in the same category. For a given amount of sideplay in bogie and hind truck, an engine with large play in the coupled wheel boxes will exert lower coupled flange forces than one with small play in those boxes; this fact has been amply demonstrated in the records of flange forces which have been taken by the Railway Board from engines in different conditions. In practice, however, undue play in these boxes is undesirable for other reasons, and good maintenance, which ensures that the coupled axlebox sideplay remains at low limits, is desirable, although less directly affecting the problem of hunting.

113. *Other Defects in Maintenance.*—If the tie at the bottom of the horn gap is not rigid, working of the frame plates will occur. While the design of horn clips is discussed later in the appropriate place, it is very important that they should be maintained in tight condition; but we did not always find this to be the case. Broken connecting and coupling rods also, of which there have been considerable numbers, are, in our opinion, closely associated with Shed maintenance. The adjustable wedge hornblock is universal in India, but, while adjustment is thus given to the coupled axleboxes, no such adjustment is provided for the coupling rod bushes. It is possible to get good service from these two features in conjunction, as is the case with many engines so fitted in other countries; but great care must be taken in the adjustment of the wedges, in order to ensure that axle centres are not moved by a greater amount than can be accommodated by the play in the coupling rod bushes. Carelessness on this point can throw great strains on to the rods, sufficient even to cause breakage.

114. *Actual Conditions of Maintenance of X Class Pacific Engines.*—The Workshops are well equipped with modern machine tools and appliances, and many of the engines, which we saw under repair, showed that maintenance work was being conscientiously performed. Most of the Shops carry out the work on a progressive system, though handicapped in respect of the type of labour and supervision; none the less, great strides have been made in recent years, and at several places new layouts and equipment, suitably organised, have allowed an improved output to be obtained.

In some Running Sheds, however, maintenance does not appear to be so good, and the incidence of hot boxes still occupies the work of a number of the staff to the detriment of general maintenance. We draw attention to the high standard now attained by the B. N. R. in respect of the incidence of hot boxes; there is no reason why other systems should not be equally successful. It is unfortunate that the sensitivity of X class Pacific engines to state of repair has not yet, in all cases, been fully realised, and certain details have not perhaps received adequate attention; such details may not be material in some designs, but they are of great importance in these particular engines.

115. *XB Engine No. 87.*—This point can be illustrated by referring to our examinations of certain engines. For example, XB No. 87 of the Nizam's State Railway was the first engine on which we experienced hunting while on its own Railway. It is an interesting case, in that the normal state of maintenance, as reflected by axlebox side clearances, was not bad, but it was unsatisfactory in other respects, which had a material effect on the riding as a vehicle. At our request, arrangements were kindly made for this engine to be transferred to the B. B. & C. I. R. where it also hunted, and we made a thorough examination of the bogie in Dohad Works.

The engine was as originally designed, and, on being lifted off the bogie, both the centre table and the slides were noticed to be well lubricated. Tried over with the straight edge, each slide on the bogie sloped towards its inner edge by about 1/16 in. Plates $\frac{5}{8}$ in. thick, had been riveted inside the frames to increase the initial spring compression from 15 cwts. to 22·6 cwts., a value which in any case is much too low for this design of engine.

At the same time, with the slide in position, the extension of the spring plungers on either side of the slide was $2\frac{1}{2}$ in. on the left, and $2\frac{1}{4}$ in. on the right. When the slide was lifted out, some release of compression was observed, and the extension of the plungers was then measured to be $2\frac{3}{4}$ in. on the left, and $2\frac{1}{2}$ in. on the right, giving $\frac{1}{2}$ in. total sideplay, over which one spring was working against the other, and the initial compression was practically ineffective. The springs were of the 50 cwt. final load type, and were of equal height, but were short to drawing.

The centre pin hole on the bogie slide measured 6·11/16 in. laterally, while the diameter of the centre pin laterally was only 6·5/16 in., giving a total play of $\frac{3}{8}$ in.; added to the self-cancelling effect of the springs, this gave a total movement of $\frac{7}{8}$ in., over which the initial compression was ineffective. Finally, the total sideplay of the bogie boxes was 5/16 in. front and 1/4 in. back. Coupled wheel total sideplays were $\frac{3}{8}$ in., $\frac{1}{2}$ in., and $\frac{1}{4}$ in. for leading, driving and trailing axles respectively.

The sideplay in the bogie boxes was not excessive, having regard to the fact that practice in Great Britain allows a maximum of $\frac{1}{2}$ in. total play at this point; but when added to the free movement due to spring adjustment and centre pin play, the total of the uncontrolled movement amounted to no less than $1\frac{1}{8}$ in., and clearly contributed to the hunting experienced.

Sufficient has been said in previous Chapters to show that hunting is not due to any one factor alone; but our examination of this particular engine showed how the effect of weak control springs was accentuated by lack of adjustment and maintenance in certain parts. This was confirmed by our observations on the road, *vide*, paragraph 103 (*c*), Chapter V. While running, the bogie could be seen to behave as if it were completely without side control for a considerable amplitude on either side of the centre line. In conjunction with loose movement in the Cartazzi slides and axleboxes, this allowed the engine to behave as if it were of the 0-6-0 type with a long overhang; hunting and high flange forces were inevitable when favoured by track conditions.

116. *XB Engine No. 1916*.—As compared with the above example, the case of E. I. R. Engine XB No. 1916, also as originally designed, may be quoted. It did not hunt while running up to a maximum of 67 m.p.h., but there was a slight nosing tendency. Admittedly it did not run on the same track as XB No. 87, but our examination in Lucknow Shops showed the relatively small differences in maintenance, which on this type of engine, make one very prone to hunt and another not so sensitive. Our observations relating to No. 1916 were as follows:—

(1) Hard patches on bogie slides where friction had been high and lubrication defective. Signs of scoring on one of the patches.

(2) Clearance of $\frac{1}{8}$ in. between bogie pin and its hole.

(3) Adjustment of control springs resulted in a total of $\frac{1}{4}$ in. free movement.

(4) Total sideplay of bogie boxes $\frac{1}{8}$ in. front and $\frac{1}{4}$ in. rear.

(5) Bogie side control springs of 90 cwt. final load type. Initial compression 31 cwt. left, and 28 cwt. right.

(6) The control springs became solid $\frac{1}{8}$ in. short of the permissible travel of the bogie slide.

(7) The Cartazzi slides were in good adjustment, with no loose movement.

Compared with Engine No. 87, it will be observed that the initial spring control was slightly greater; there was more friction on the bogie slides, possibly much more. The total of all clearances, giving uncontrolled side movement on the bogie, was only ⅝ in. as against 1⅛ in.; the Cartazzi slides were in good order. In an engine which is a border line case, these features, although each is small in itself, have, in combination a decisive influence on the sensitivity of the engine to track conditions.

117. *XB Engines Nos. 431 and 449.*—We experienced hunting on these engines on the E. B. R., but we did not have an opportunity of examining them in the Shops. The bogie and coupled axlebox clearances were not abnormal on either engine, but the side wear at the hind truck axle was considerable. This latter fact, in conjunction with the Goodall coupling, materially detracted from effective control at the back end. Total axlebox clearances were as follows :—

	431.	449.
Bogie—		
L	7/32″	9/32″
T	3/16″	11/64″
Coupled—		
L	1/4″	13/64″
D	1/4″	5/32″
T	3/8″	3/16″
Truck	3/4″	1·1/8″

The condition of axlebox maintenance was, therefore, within reasonable limits, except for the hind truck. On Engine No. 431, however, measurements were made of the amount by which the control springs were working against each other, due to lack of adjustment on the plunger bolts; there was actually a total free movement of 9/16 in., over which no effective initial spring control on the bogie existed.

118. *Further Examples, N. W. R.*—Further cases of difficulty in maintaining the original design of bogie may be quoted. During our visit to the Workshops, we had several bogies specially dismantled, and we observed the following :—

(1) The bogie of an XA engine had one of its control springs defective. Two turns of the coil were missing, and the spring had evidently been inserted in this condition; the bogie tyre flanges were worn vertical on one side, unequal pressure having forced the flanges continually against one rail. The engine had run some 90,000 miles since shopping, and there had been no means of examining the springs during that period. The unequal tyre wear was an indication of what was happening, but this was presumably not understood.

(2) The bogie of an XC engine was found to have one of its springs broken into three pieces. This had evidently happened in service, but could not be detected by ordinary examination. The broken spring, besides giving unequal control on either side, would have the effect of reducing the initial control.

(3) The bogie of an XS Pacific engine (a 4-cylinder edition of the XC) was found assembled after repairs with the wrong control springs and bolts. The springs, which had been put in, were those of an old class of 4-4-0 engine, and were similar in appearance, but not in actual dimensions. As a result, the springs would have become solid long before the maximum bogie travel was reached; in the distance in which they would have been active, the one was working against the other, so that no effective control was obtainable.

119. *Deductions from Examples.*—The above have been picked at random, as examples of engine defects which may have a marked effect on stability in running. They show that on this class of engine it is not

sufficient to keep the side clearances within normal working limits. Close attention is also necessary to the bogie control springs and slides, and to the Cartazzi trucks. Partly through difficulties, however, of adequate inspection inherent in the design, and partly through lack of appreciation that attention to these items was vital to the problem of hunting, it cannot be said that the maintenance of these parts has been of a uniformly high standard.

The nature of the design has resulted in a type of engine particularly sensitive to track conditions. The most perfect maintenance could not ensure that hunting might not be set up by sufficiently unfavourable track conditions; but a high standard of engine maintenance could considerably reduce the likelihood of hunting on normally maintained tracks. We ourselves had experience of unmodified XB and XC engines, which ran steadily even at 80 m.p.h., because the combined conditions of track and engine maintenance were such as to render innocuous the fact that the engines were insufficiently provided with side control.

120. *Organisation and Maintenance.*—Just as the behaviour of engines is affected by maintenance, so this in its turn is influenced by the way in which it is organised; indeed, we were aware on many occasions of a lack of continuity in the means of bringing to the attention of the Chief Mechanical Engineers, and of the Railway Board, what was happening on engines in service.

On some of the Railways which we visited, the C. M. E. was in direct charge of running repairs and of his staff in the Sheds. Where the Divisional System was in force, the function of the C. M. E. was more consultative and advisory, the local mechanical staff being responsible to Divisional Superintendents. We heard arguments for and against both systems, and it is not in our remit to judge between them. Whichever may be in force, however, it is of the greatest importance for the proper maintenance of locomotives, and particularly for the early location of troubles as they arise, that the C. M. E. should have prompt and accurate information as to the behaviour of engines in service. He should in turn be able to disseminate his advice to the running staff without delay. This has not always been the case.

It was noticeable at several Sheds that the help of someone who knew what should be done was missing, and the impression conveyed to our minds was that executive officers were so engaged with administrative duties that they had little or no time to attend to the practical maintenance of locomotives in the Sheds. It is unlikely that shed staff, accustomed to older and lighter types of engine, would pay particular attention to such matters as play in the bogie centre pin hole, or clearance behind the nuts of control spring bolts, or to the state of the slides, if these differed in no way from the usually accepted limits of wear. Shop staff receiving the engines for repair would not feel called upon to comment specially on wear on these parts on X class Pacifics, if it was no different from that on other classes to which they were accustomed. Accordingly, if the actual sideplay in the axleboxes was not excessive, no information in the ordinary way, on these other points, was likely to reach the C. M. E., or through him the Railway Board. Thus, one contributory factor in dealing with the problem was lost sight of.

This illustrates the necessity of someone being available in the Sheds who is able to take a wider view with regard to the various features which develop on engines in service, and to interpret them in the light of the behaviour of the engines when running. It is not, however, sufficient only to observe and to interpret. Means must be found of getting the information direct to the C. M. E. without delay, so that preventive action can be initiated. It is not enough to allow the information collected to pass through the usual channels of communication, where the matter may be delayed by Officers pre-occupied with day to day routine.

In fact, one of the principal difficulties, in a country the size of India, is that of promptly collating information. It was apparent to us that this was one of the reasons for not getting to the bottom of the trouble with X class Pacific engines earlier. We make the following recommendations in order to avoid delay in the future :—

(a) It would appear desirable to appoint young practical officers as Mechanical Inspectors, directly responsible to the Chief Mechanical Engineers. They should be free of routine work, and their duties should be to visit Sheds at any or all hours, to advise on the best methods of maintenance of locomotives, and to bring back direct to headquarters particulars of troubles experienced, either on the footplate or in Running Sheds.

(b) If adequate arrangements do not already exist, it would also be of great value, in the Divisional organisation, if a Mechanical Inspector could be attached to the Divisional Mechanical Engineer, in order to keep the latter more closely in touch with the purely mechanical side of locomotive operation; he should take the earliest opportunity for advising the Chief Mechanical Engineer of any difficulties.

(c) These young men should collaborate with motive power officers and staff; their aim should be to help in all the practical difficulties in the maintenance of locomotives required for operation. Their reports should not be interpreted as being necessarily condemnatory. It is desirable that these officers should make periodical visits to the main workshops in order that they may remain in touch with the latest practices, methods and tools used for repairing engines.

(d) Further, it is necessary for information to be supplied promptly to the Railway Board, and reference is made to this later.

CHAPTER VII.

Research and Development.

121. *Introductory Remarks.*—Conditions today have passed beyond the stage when improvements and economies in Engineering matters can be easily obtained by simple and obvious means. To initiate new lines of attack, progress demands the utilisation of science, and a continuous study of what is going on in other fields. This calls for controlled experiment, exact measurement, and logical development, matters which can conveniently be grouped under the term Research in its widest meaning.

Research will not produce fruitful results if crowded in, as a secondary consideration, among the other duties of a busy executive. Its initiation and pursuit is a full-time occupation, and the establishment of the necessary organisation was referred to by the Pope and Wedgwood (Indian Railway Enquiry) Committees. We fully endorse the recommendations made by them, and draw attention to the increasing number of industrial, as well as National, undertakings which are today making use of Research to ensure continued progress in future.

The value of such an organisation to undertakings of the size of the Indian Railways would be incalculable. Through contacts made with other bodies specialising on specific subjects outside the railway sphere, contemporary thought and experience in the engineering world can be tapped, with the assurance that no development is taking place without an opportunity being given to study its application to the Railways.

We would mention two outstanding examples. In Great Britain, the L. M. S. R. has already saved large sums of money in various fields, although its Research Department has been in operation for only a few years. Among others, one fundamental investigation has for some time been proceeding with regard to the action of a wheel on the rail. On the French Railways, Research has also produced apparatus for measuring flange pressures and track displacements. Their Engineers have been faced with the problem, comparable to that in India, of sometimes running heavy high speed engines on relatively light permanent way, and a technique for measurement has been developed which assures safety in operation under such conditions. What is being done in this respect in France and in other countries is described later in this Chapter.

122. *Central Standards Office.*—In India, up to the present, the Central Standards Office, under the Railway Board, has carried out a great deal of work on the Standardisation of details of rolling stock, permanent way material, and bridges; this has been valuable to the State in connection with the Standardisation of specifications and drawings, which have enabled Railway Administrations, and their purchasing agencies, to obtain articles to the best advantage, both in India and elsewhere. The work which has been accomplished, for example in standardising vacuum brake details, is noteworthy, and is only one of numerous fields of activity.

But though much commendable work has been done by the Central Standards Office, we feel that progress is hampered by an organisation inadequate to deal with the many problems, which affect safety, comfort and economy, and which require careful investigation, testing, and analysis. No undertaking of the size of the Indian Railways can afford to be without a properly organised and active Research Section fitted to give authoritative opinions on these matters.

Having regard, however, to their limited establishment, we would draw attention to the important research which has already been effected by the Standards Office. After investigating stresses in rails and fishplates, their officers have been dealing with the more difficult problems of disturbance in the track, as set up by X class Pacific engines; a description of their work is included in this Chapter. It will be seen from our recommendations that we consider that this essential work be continued; indeed, without it, our recommendations could not have been made so confidently, having regard to all the prevailing circumstances.

123. *Investigation in other countries.*—As a preliminary to describing and discussing the work which has been carried out in India, we think it may be of assistance to give a summary of the investigations which have been undertaken in other countries. Since the origin of Railways, the study of the reactions between engines and track has led Engineers to undertake experiments and research.

Problems have arisen from time to time, generally either after accidents, or after defects so frequently reported as to be regarded as epidemic. Special investigation has usually been suggested and put in hand, but it has sometimes happened that modifications have simultaneously been made to rolling stock or track, which have removed the causes of trouble before the investigation has been carried to any definite conclusion. In other cases, the development of suitable experimental equipment has either taken a long time, or has never been perfected, and the matter has lost its interest before the research has been carried to finality. It is for reasons such as these that experiments on track and vehicles appear from time to time in the annals of Railways as uncompleted investigations.

It is also true to say that such tests have not been carried out to an equal extent throughout the world, because some countries did not find them necessary, in view of favourable conditions in respect of rigidity of track and of design characteristics in rolling stock. Brief descriptions follow of the extent to which Research has been effected in America, Germany, France, South Africa, Great Britain and India. These refer particularly to the practical experimental work which has been undertaken. References to theoretical investigations are contained in Chapter III.

America.

124. *References.*—In America, the most important investigations into this subject have been those carried out by the Pennsylvania Railway. Through the courtesy of Mr. F. W. Hankins, Assistant Vice-President, Chief of Motive Power, on that Railway, we were provided with a description of the apparatus used, and articles on these tests have appeared in the Technical Press(10). The object was the determination of flange forces exerted by locomotives, and this was effected mainly by measurements made on the track.

In addition to the above, a special Committee on stresses in track has been set up by the American Railway Engineering Association, in co-operation with the Association of American Railroads and the American Society of Civil Engineers. Field work for this Committee included tests for rail joint and track stresses on the Pennsylvania Railway, and tests of continuous welded rails(11).

125. *Method adopted by the Pennsylvania Railway.*—Flange forces are determined by introducing a length of special track, on which, under the action of these forces, the rails are pressed laterally against strips of steel; impressions in the strips are made by Brinell balls at close intervals, and their dimensions are a measure of the magnitude of the forces involved. This method was first used as far back as 1907. With the continued increase in speed and weight of locomotives, it was subsequently adopted for investigations in 1910, 1912 and 1924 at various locations on the railway. The most comprehensive tests, however, were started in 1933 and continued for two years, the particular problem arising from the introduction of high-speed electric locomotives.

126. *Description of Apparatus.*—The special test track, which may be laid down at any point, is 440 ft. long. Existing rails are used, but they are laid for the length of the test section on 249 metal sleepers, every other one of which is fitted with apparatus to measure and record the lateral thrust against the rail. The recording apparatus uses a hardened

(10) "Railway Age", 12th September 1936, page 374; 19th September 1936, page 412.

(11) "Railway Age", 25th June, 1938, page 1042.

steel ball to make an impression in a soft steel plate. The impression made by a Brinell ball varies with the force applied; moreover, the use of this apparatus is of value, because, if the ball is subjected to repeated blows of varying magnitude, the impression is the same as it would have been under the maximum blow.

At both ends of each recording sleeper, plungers, which are free to move longitudinally in their bearings, press against the heads of the rails. A hardened steel ball, one inch in diameter, is placed at the opposite end of the plunger, and bears against a piece of annealed boiler plate supported by a suitable bracket. This impression plate is brought into contact with the ball by another plunger, which is driven up by a wedge. When a locomotive passes over the test track, the lateral blows from the wheels force the hardened steel ball into the soft steel plate, and the diameter of the impression gives a measure of the force of the maximum blow at each recording sleeper. When the test track, is not in use for trial purposes, the balls and impression plates are replaced by flat dummy plates; the plungers are then driven up against the rail, and the wedges are held in place by tightening the set screws.

At each sleeper, both recording and non-recording, the rails are supported by roller bearings, which offer negligible resistance to the lateral movement of the rail. If rail inertia and the small amount of friction of the roller bearings are disregarded, the only forces resisting the outward movement of the rail are those passing through the Brinell ball. The impression plates must, therefore, record the maximum force required to resist the outward movement of the rail when lateral blows result from the passing of a locomotive. These plates are of half-inch boiler plate, annealed after being cut to size; they are finally ground smooth on the side where the impressions are to be made. A correction is necessary for any variation in hardness in the plates themselves. Figure 11 shows this arrangement.

The speed at which the locomotive passes over the test track is measured by a chronograph. A paper drum is driven by a constant speed motor, and half second intervals are marked on the paper from a clock. The position of the engine as it passes over the track is recorded on the paper by the action of circuit breakers, which are operated by an arm attached to the locomotive severing a wire at the top of the breaker. The circuit breakers are placed 146 ft. 8 in. apart, so that at a speed of 100 m.p.h., the length between marks on the paper equals the length between second marks.

It will be noted that tests carried out with this apparatus are confined to one short piece of track. In order to extend the tests to any part of the line, the electric locomotives were fitted, in 1933, with strain gauge recorders attached to the axleboxes. These were modified so that the force between each axlebox and the locomotive frame was taken through a rigid weighbar of chrome nickel steel. The stresses in these bars were measured by electromagnetic strain gauges recording on oscillographs. A weighbar was placed at each end of the axle, which was free to move between the two bars with its normal clearance in the frame. The two strain gauges corresponding to each axle were interconnected electrically, so as to record on a single line on the oscillograph; deflection was upwards for force towards the left rail, and downwards for force towards the right. The gauges were operated on a 2000 cycle current, and were calibrated statically in a testing machine. This method of recording flange forces was developed only for electric locomotives having axleboxes and frames outside the wheels; it was not applied to steam locomotives.

127. *Results of Tests.*—In the latest series of tests, in addition to different types of electric locomotive, a standard Pennsylvania, K. 4S type, Pacific steam locomotive was tested, and, in general, the latter produced lower lateral forces on the track at high speeds than did the former

engines. The maximum thrust of the Pacific against the rail at different speeds on the straight was as follows:—

M. p. h.	Tons.
50	6·7
60	7·6
70	10·2
80	11·2
85	11·6
90	10·2
95	11·2

These forces were exerted on a track laid with 131 lbs. F. F. rails, by unidentified wheels of a Pacific engine, which weighed 138 tons, had a total wheelbase of 36 ft. 2 in. (rigid 13 ft. 10 in.), and had a swing link bogie with a hind pony truck. The results were considered to be satisfactory in relation to the weight of engine and type of track, and the whole of the two years testing was concentrated on lowering the flange forces exerted by the high-speed electric locomotives to values of approximately this order. No special tests were made with a view to reducing the forces for this particular steam locomotive.

With regard to the electric locomotives, it is interesting to note that one of the principal modifications made was to alter the side control of the bogies from the type commonly used. Instead of having a relatively small initial control, subsequently rising in direct proportion to the lateral displacement, an arrangement of control was adopted giving three times the initial value, which, after a lateral displacement of 1 in., gradually reduced in intensity with further displacement. At the same time, the rotation of the bogies was restrained by a system of radius bars. The effect of these modifications on a particular class of electric locomotive was to reduce the lateral thrust by 40 per cent. at 70 m.p.h.

128. *American Railway Engineering Association Tests.*—These track tests were carried out at speed up to 90 m.p.h., and under a variety of conditions. Magnetic strain gauges of normal type were employed for the measurement of both strains and stresses; new types were, however, developed to deal with strains of exceptional magnitude. All the tests were made on 131 lbs., F. F. rail, with fishplates of different types and conditions, representing variations in section from nearly rectangular to L shape, including those with controlled bearing surfaces and head free bearing. Observations recorded by oscillographs included stresses in the rail adjacent to the joint, stresses at different points in the fishplate, vertical and longitudinal movements between rail head and fishplate, and vertical depression of the rail between, and at, joints.

The strain gauges were of a similar kind to those on the locomotive flange force weighbars. For recording rail depression, special gauges were used; they consisted of a coil attached to a fixed reference, independent of the rail, and a core attached to the rail, moving within the coil. The change in current in the coil varied with the amount of movement of the core, this being recorded on the oscillograph film with a magnification of 4, thus permitting measurement of larger movements than is possible with other gauges. Additional tests have been carried out to ascertain the effect produced by battered rail ends, by flat wheels, by eccentrically mounted wheels, and by counterbalance of locomotives. The above brief résumé indicates the lines on which investigation is being conducted, but the tests and analyses of results have not proceeded far enough for definite findings to be published.

129. *General Remarks.*—It is noteworthy that for 30 years the American Railways have been aware of the effects of high flange forces, and have designed apparatus to measure them. Intensive use of the Brinell track equipment has been made in recent years, in connection with problems arising from high speed electric locomotive operation. It would appear that the heavy steam engines in operation in America exert flange

forces of some magnitude; but, having regard to the axle loading and the requisite weight of rail with close sleepering which is common, such forces up to 12 tons do not give rise to track distortion. The track tests which are now being carried out are more concerned with improvements in the strength of track itself, with a view to decreasing vertical deflections under load. We have found no record of tests carried out to measure the lateral resistance of track, as a whole, to given flange forces.

GERMANY.

130. As long ago as 1869, Von Weber(12) studied the reaction of the track to the passage of rolling stock by recording axle movements, amplified by suspension springs; the natural periods of the springs, however, prevented conclusions of practical importance being reached. Since that date, there have been numerous investigations, and a great deal of mathematical work has been carried out.

In 1928, owing to inability to reach definite conclusions as to the cause of certain express train derailments which had occurred during a short period, a commission was set up(13) by the German State Railways, composed of certain of their own officials, in collaboration with the Engineering Section of the Heinrich Hertz Institute, Berlin. After studying the theoretical aspects of the problem, the Commission decided that a true picture of the situation could be obtained only by practical experiment. The aspect with which they were primarily concerned was the relationship between flange forces and wheel loads, particularly on leading axles. They recognised that such forces were built up of both statical and dynamical components, and it was the impossibility of assuming any reliable value for the latter which necessitated the subsequent long series of practical trials.

The most important requirement was to make a continuous record of the amplitude of oscillation, and to measure simultaneously the magnitude of the lateral forces exerted by the leading axle and the vertical loads bearing on it. While instruments then existing were capable of measuring displacements and forces, they were unsuitable for fitting to locomotives. It was necessary, therefore, to devise special apparatus for this purpose, a process which occupied a considerable time.

For measuring pressures, use was made of carbon blocks(14); blocks of carbon have the property that, when subjected to pressure, their electrical contact resistance alters. Under constant voltage, the flow of current, recorded by a suitable device, is proportional to the pressure applied. As, however, carbon is not mechanically strong enough to stand a load greater than 400 lbs. per square inch, it is necessary for the blocks to be placed in a flexible steel housing, the top of which is in direct contact with the load to be measured (Figure 12). This has the effect of by-passing a definite proportion of the total load supplied. No amplification stage is necessary in the circuit between the carbon pressure unit and the recording element, and this method was used in preference to that of the quartz crystal (piézo-electric), owing to the fact that the latter required amplification in two stages, with much attendant complication. As the carbon elements could be made small in size, they were easy to apply without structural alteration to the parts of the engine.

For measuring displacements, an instrument was used containing an insulated resistance wire, bent into the form of a circle, contact with which was made by an arm mounted on a spindle. On the extreme end of this spindle a pulley was fixed, which was actuated by a wire from the part whose displacement was required. Any displacement, therefore, caused

(12) Die Stabilität der Eisenbahngeleise.
(Stability of Permanent Way)
by Freiherr Von Weber.

(13) Glasers Annalen, 1st and 15th December 1935.
Organ für die Fortschritte des Eisenbahnwesens, 1st Oct. 1934.

(14) Verein Deutscher Ingenieure, 1937.

the pulley to rotate and the contact arm to make contact at different points along the circumference of the resistance wire; the varying resistances so obtained were then transferred to an oscillograph.

The foregoing elements for measuring forces and displacements were mounted on the engine, but the recording apparatus and necessary oscillographs were placed in a special van immediately in rear. The recording was effected on revolving drums of paper, which were driven from the road wheel; later, it was possible to use cathode ray oscillographs for the same purpose. Accelerometers were also developed, in order to ascertain the inertia forces of the unsprung weights on the different wheels under test.

The Commission which undertook the above-mentioned investigation was dissolved in 1933, after completing work on certain definite terms of reference; but it was felt that there remained a very big field for research and that continuous experiments were still required. A new Research Section, therefore, was formed at the end of 1933, primarily to deal with the safety of vehicles at high speeds; a new recording van was specially constructed for this purpose, with instruments capable of measuring and recording simultaneously the necessary displacements and flange forces on all the axles of a locomotive.

131. Through the courtesy of Dr. Dorpmüller, Minister of Transport and General Director of the German State Railways, we have received certain information, of which the following is a translation, giving particulars of the principal tests which were carried out, and the results obtained :—

"*Briefly the present arrangement of the measuring instruments is as follows :—*

Three Siemens and 8 pen oscillographs to which are connected 24 measuring points, are accommodated in a test car. In addition there are 30 resistances for the carbon elements and 6 for displacements, ranging up to 400 mm (15¾") and from 0 to 80 mm (0 to 3⅛"). The pressure elements are suitable for loads of 5, 10, and 15 tons, and the displacement meters for large or small movements. These instruments have been built and developed by the Locomotive Research Section, and are today capable of satisfying all requirements.

For axles with outside journals, the elements for measuring vertical loads are placed between the axle-box and the bearing brass, or between the axle-box and the spring buckle; elements for measuring the side pressures are fitted between a bearing plate and the axle journal. Axles with inside journals have the vertical measuring elements placed between the spring buckle and the axle-box, while, for measuring side pressures, a distance piece, split in two halves, is fitted round the axle, and rotates on two rolling rings. The ends of this distance piece are white metalled, and a rigid pin is connected to the main frame through the intermediary of carbon measuring elements, (see Figure 12). By these methods, it is possible to measure the vertical and horizontal loads which are exerted on all the important axles. At the same time, measurements are taken of displacements such as those existing between the bogie axles and frame, and the movement between the locomotive and tender, etc. Up to now many different types of locomotives and vehicles have been tested, but I think that probably the results of the tests on the Pacific locomotives, Class 03, would be of particular interest to you. This locomotive, which is today the standard engine of the German State Railways for light and express "D" (through) trains has been fully tested; the results are of particular value, as they have given us information not previously known.

(a) Running on curves and the determination of superelevation.—*It has been the policy during the last few years to increase running speeds; and one of the first essentials of this must be a good permanent way. Critical places on the track are where the rails leave the straight, and enter curves and points; to obtain a smooth and free running, every curve must be superelevated sufficiently to take into account the centrifugal force, and it must also contain a transition curve at its commencement. The curve with the full amount of superelevation is connected to the straight track by a transition curve, which, in order to reduce side pressure, must be of a definite length. At the same time, the variation in super-elevation must not be too great, in order to avoid excessive loading and unloading of individual wheels. It was, therefore, necessary to ascertain the highest permissible speed at which running could safely take place, and numerous experimental runs have been carried out with varying curvatures, super-elevations and speeds.*

Experimental runs were also conducted over curves at a speed 40 per cent. in excess of that permitted in service, in which case the centripetal force was affected not only by the increase in superelevation of the rail, but also by the effect of flange pressures. These pressures exceeded all expectations; for instance, at a speed of 156 km/hr. (97 m.p.h.), where the permissible speed was 110 km/hr. (68 m.p.h.), the flange pressure on the leading coupled wheels was in the neighbourhood of 15 tons, vertical pressure on the outside axlebox being between approximately 9 to 10 tons, and on the inner axlebox approximately 3 tons. The results of the whole series of tests show that the leading bogie axle has practically the same side pressure at all speeds, whereas the variation in vertical bearing pressure increases with increase in speed. At low speeds, flange pressures on the leading coupled axle are obtained only on the inner wheel on curves, this being due to the force of gravity, owing to the inclination of the track. With increasing speed, this pressure is diminished until the point is reached where the pressures alternate equally between the outer and inner rails. With an increase in speed, the whole of the flange force occurs at the outer wheel, and increases rapidly as speed rises.

The vertical load on the leading coupled axle has similar characteristics; for example, at low speeds, there is decreased load on the outside wheel and increased on the inside. At the point of balance, the two loads are equalised, while, with an increase in speed there is increase of load on the outside wheel and reduction of load on the inside wheel. The best running is therefore obtained at the balancing speed where the minimum pressure changes occur. Furthermore, with an increase in speed, the pressures, and thereby the stresses in the vehicle and the track, increase the danger of derailments. For any increase in speed the superelevation must be increased correspondingly, since for high speeds the track must be satisfactory owing to the fact that any small disturbance reacts immediately on the running of the vehicle.

In order to examine the matter further, tests were conducted on curves having considerable superelevation, and also on reverse curves without a straight piece of track joining them; new ideas on the subject were ascertained from the tests which were carried out on the 03 class Pacific at the maximum permissible speed for that class of engine, i.e., *80—100 km/hr. (50—62 m.p.h.). The maximum flange pressure recorded on the leading coupled wheels was 18 tons, and the vertical* *bearing pressure 9 to 10 tons. It cannot be said that these figures afford a sufficient factor of safety; but it should be realised that such high values only occur during a fraction of a second, and the flange does not have time to react unfavourably. The flange pressure on the leading bogie wheels varied on these tests between 0 and 4 tons, and this only on the outer wheel. It was natural that with these high coupled wheel flange pressures there would be considerable changes in the vertical wheel loads; on the bogie they were of the order of ± 3 tons and on the coupled axle ± 2·5 tons.*

For the 03 class Pacific engine with the existing control spring, it can be stated that :—

(1) The bogie does not exercise sufficient controlling effect on the guiding of the engine when running on curves.

(2) The leading coupled axle is at a shorter distance from the vertical axis through the centre of gravity than is the leading bogie axle, and, for a given turning effect on the engine, a higher flange force will have to be exerted at the former than at the latter. For this reason it is the leading coupled axle, and not the leading bogie axle, which is the source of greatest danger.

(3) The flange pressures on the bogie are practically independent of speed.

(4) The friction of the slides is not sufficient to make for steady running of the bogie.

(5) To increase the guiding force of the bogie, it will be necessary to fit stronger control springs.

The most important point arising from these tests was the knowledge that this bogie, with an initial control spring load of 1750 kg. (1·72 tons) did not provide the necessary guiding force required, although it had been considered to be sufficient on purely theoretical grounds; moreover, when running over a curve, unequal reactions were obtained at the inner and outer rails. It was, therefore, decided to increase the initial load of the control springs to 3,500 kg. (3·44 tons) and the results on the same locomotive with this new spring, running on the same track, were as follows :—

(1) The displacement of the bogie in relation to the main frames was somewhat less with the strong springs than that obtained with the weak springs.

(2) The centring force and flange pressures on the leading bogie axle were correspondingly greater with the strong springs than with the weak springs.

(3) The flange pressure on the leading coupled axle at a given speed was somewhat higher on the inside rail when the stronger spring was fitted, but was noticeably lower on the outer rail. This means that, with the stronger spring, speed can be increased by 10 to 15 km/hr. (6·2 to 9·3 m. p. h.) before the flange pressures are equal to those obtained with the weak springs.

(4) The changes in vertical loads were not materially affected by the use of stronger springs.

(5) The fitting of stronger springs did not increase the hunting effect and the speed at which serious hunting commenced was definitely lifted.

It is not thought necessary to quote all the many numerical values of the test results, as the size of the loads is dependent on the varying speeds and radii of the curves. Further experiments have been conducted with the 03 class Pacific locomotive travelling over turnouts without superelevation.

(b) Travelling over points and crossings.—*The experiments were conducted over turnouts (German State Railways design 8A) having radii of 500, 300 and 190 metres respectively (1640 985 and 624 feet) and, as had previously been discovered, the highest flange pressures obtained were on the leading coupled axle. It is clear that the load changes from one wheel to the other on a reverse curve, and this transfer of load increases rapidly in value with increase in speed. It has been found that the guiding force of the bogie fitted with weaker controlling springs is very low when travelling over turnouts, and speed, could not be raised above that at present permitted, 45 km/hr. (28 m. p. h.) on curves having radii of 300 and 190 metres (985 and 624 feet).*

(c) Measurements taken on springing and compensating gear.—*You will be aware that the friction between the spring plates and the equalising links plays only a very small part. Measurements of vertical wheel loads on engines fitted with compensating gear indicate that the loads on the coupled axles are equally distributed. Tests were, however, conducted with engines having both compensated spring gear and individual wheel springing, in order that comparisons could be made between the two systems; it was found that the variations in loads were about 60 per cent. less with the former arrangement than with the latter.*

When running over rail joints, the sudden reduction of load is particularly severe with individually sprung wheels; while with compensating gear, the peaks of maximum load are flattened out considerably, owing to the fact that any change of load due to unevenness in the track is transmitted on to the other axles. It can be said that, due to vibration when running, the effect of friction in the springs and equalising links does not have any noticeable effect.

With the above conclusions and test results, the experiments conducted on the 03 class Pacific locomotives were brought to a close.

With reference to the influence of the track on the running of locomotives, it can be stated that, generally, the majority of engine types do accommodate themselves satisfactorily when the track is in good condition. Naturally, a badly laid track has a definite influence on the running of the locomotive. The experiments on the German State Railways have shown that those types of locomotives having only coupled axles, with their correspondingly heavy overhanging loads, exert high flange forces on the leading axles, and do not, therefore, run as smoothly on bad tracks (such as on secondary lines) as engines fitted with a bogie. This occurs in particular at high speeds when, of course, high stresses are set up in the track. Locomotives having a guiding axle in the form of a Bissel truck did not fully satisfy the requirements relating to the necessary guiding forces; the truck had no material effect on the guiding of such engines as originally designed. It is therefore the intention of the German State Railways to replace the Bissel trucks on those engines noted for bad running, by the Krauss-Helmholtz bogie, which has better guiding properties.

Tests conducted on an electric locomotive have also confirmed that the forces brought into play are of a similar order, and that all the results obtained depend upon the mass of the locomotive *and the arrangement of the axles. In conclusion, it should be emphasised that the testing methods described have given reliable results, and have been of assistance not only to the Chief Mechanical Engineer, but also to the Civil Engineer, in obtaining improved running of vehicles on the track."*

FRANCE.

TRACK TESTS.

132. As early as 1883, Couard (15) of the P. L. M. Railway undertook trials to measure deformation of the track under load, making use of Marey manometric bulbs. Ch. Buisson had already shown, in 1860, that they could be used for transmitting small movements of high frequency by air pressure.

The apparatus consisted of two mahometric bulbs, one, of high resistance, fitted with an actuating lever and secured to a fixed member near the part whose movement was to be recorded, the other, known as the receiving element, was much more sensitive and was connected to a stylograph which accurately followed the movements of the diaphragm, and inscribed them on the recording cylinder of an electro-magnetic chronograph. These two bulbs were inter-connected by a rubber pipe, which was 4 mm. in diameter and of sufficient length for the recording device and the operator to be at a suitable distance from the track.

These trials allowed for the study of deflections of rails and sleepers under the passage of trains, and special attention was paid to rail joints; they did not give a measure of the forces involved. An electrical pedal device marked the passage of each axle on the record, and the use of two similar pedals, 20 metres apart, permitted an exact determination of speed.

133. About 1916, the P. L. M. Railway adapted an experimental method which Rabut (16) had developed for measuring fatigue in various bridge members, using calibrated jacks to reproduce the amount of deflection caused by the passage of a locomotive on the track. In these trials, the difficulty was to establish the relation between loads applied statically and those produced dynamically, where the effect on the track was identical.

134. More recently, Blondel (17), Chief Engineer of the P. O. Railway, went further in the same direction; he sought to increase the resistance to side displacement of 46 Kg/M. (approx. 92 lbs. per yard), standard F. F. rail laid on 29 sleepers per 16½ M. rail length (about 54 ft.)

Three different kinds of ballast were employed (sand, broken granite and sharp stone), and the tests were made with (a) transverse static forces applied either with a stationary or a moving point of application, and (b) a transverse dynamic force applied in the form of a blow.

From these tests the following facts were established :—

(1) Permanent residual displacements are greater with static forces applied, with either a stationary or a moving point of application, than with dynamic forces in the form of an instantaneous blow, where the input of energy is the same.

(2) A static force acting laterally on the track, with a moving point of application, gives rise to a greater side displacement of the track than a stationary force of the same value.

(3) In all cases the resistance of track to side displacement is a function of the vertical load which presses it down on to the ballast.

(15) Revue Générale des Chemins de Fer, Oct. and Dec. 1887.
Conditions de Stabilité des voies.
(Conditions for Track Stability by Couard.)

(16) Annales des Ponts et Chausées, Oct. 1896.

(17) Revue Générale des Chemins de Fer, Dec. 1932.

(4) When track under load is transversely displaced by an amount equal to L, say, by the application of a jack, it returns by an amount equal to L/3 when the jack is removed, and by a further amount of L/3 when the vertical load is taken-off. A residual displacement of L/3 therefore remains.

(5) When a stationary static force, applied laterally to the track, gradually increases from zero, the side displacement of the track is zero at the beginning, and increases very slowly at first, then at a greater rate, and finally the displacement becomes excessive. The relation between the value of the side displacement and the force depends on the nature of the ballast and on the standard of maintenance of the track; but it should be noted that a track which has been recently repacked is weaker than one which has been undisturbed by packing, in so far as resistance to side displacement is concerned.

(6) When a lateral static force is moving along a track, and increases in value as it moves, the side displacement slowly increases at first, and then at an increased rate until a critical value is reached, beyond which a very marked side displacement suddenly takes place. This critical value also depends on the nature of the ballast and on the standard of maintenance of the track: its value has been found to be that which under the conditions set out in (5) above gave a side displacement of the track of 5/32 in. For an axle load of 19 tons on track ballasted with sharp stone after recent packing, this critical value was found to be 11 tons, but if a considerable time had elapsed since packing it increased to 15 tons. On sand ballast this force was found to be about 10 tons.

(7) A blow of about 2 in./tons (which is higher than can be produced by an axle loaded with 20 tons, even in the most violent hunting movement) did not displace the track. A blow of twice the above value gave a side displacement of only 1/32", which is a negligible amount. When blows of the same value are repeated on the same point on the track, the effect rapidly decreases, and after a few such blows, no further side displacement takes place. These blows were, however, given by a swinging weight acting on track on which a stationary vehicle was standing, and the conditions might not exactly reproduce the nature of a blow given by a vehicle during hunting. The trials were therefore amplified by reproducing irregularities of increasing magnitude at certain points on the track, in order to induce hunting of an engine running at high speed and consequent heavy lateral blows; but no further side displacement of the track could be obtained.

From the above trials it might be thought that, if hunting takes the form of exerting a series of blows on the track, it would have little effect on track distortion; but, as explained in Chapter III, the effect of hunting may be described as a more or less gradual building up and falling away of pressure on one rail and the other alternately. It can, therefore, be likened to a static force with a moving point of application, and not to a sudden blow.

Some confirmatory work has also been carried out to establish the validity of Blondel's results in actual service at high speed. A section of track of certain known type and/or condition of maintenance was selected, and pointer gauges were firmly bedded in the ground alongside, at short distances apart. These pointer gauges were arranged to record on paper drums the actual deflection of the track, and a trigger device was fitted so that the passage of each individual wheel advanced the paper drum one stage. By this means, it was possible to correlate any individual rail deflection with an individual axle on the engine. By simultaneously taking measurements of flange forces on the engine, a direct relationship was established between the known flange forces and their effect on the track at high speed. Generally, for French conditions, it was found that Blondel's conclusions, drawn from experiments made at very low speeds, held good for actual running conditions at high speed.

Further tests were made by Lanos ([18]) of the former Est. Rly. in order to determine experimentally the actual sinusoidal path traced by each pair of wheels on heavy engines when running at high speeds on curves.

ENGINE TRIALS.

135. After the War, track and rolling stock in France were found to be in bad condition as a result of the heavy traffic; when it was desired to run again at pre-war speeds before complete overhaul had been made, certain weaknesses became apparent. Billet of the P. O. Railway approached the problem by attempting to isolate the forces induced in certain locomotive parts and to determine relative displacements. To measure the forces, he employed apparatus based on the use of measuring bulbs, but the results were unreliable. To measure displacements, the following arrangement was used :—

A pick-up, consisting of a series of contacts insulated from each other, was fixed on one of the members, and a brush was secured to the other member whose displacement in relation to the first was required. This brush was pressed against the contacts, which were all electrically connected to a series of steel points resting on the recording drum, the distance between the points being the same as that between the contacts. A high tension current produced by a magneto passed through a circuit which included the brush, one of the contacts of the pick-up, and the corresponding steel point on the recorder (Figure 13). Under these conditions, a spark passed between the steel point and the metal cylinder on which the recording paper was rolled. This paper was perforated by each spark, and recording by points resulted. The accuracy of the curve obtained was a function of the number of contacts, and, therefore, of the number of points per unit of length of displacement. When, however, the points were too close, parasitical currents caused irregular sparking and the record was fogged.

To improve the record, the magneto was replaced by a low tension battery, the points rubbing on paper impregnated with ferrocyanide of potassium. By this means, current passing from a point would make a blue mark on the paper, for the ferrocyanide of potassium was transformed into ferric-ferrocyanide of iron, *i.e.*, Prussian blue, at the point of contact. This apparatus was heavy, its points and contacts wore away rapidly, and it was not found suitable for general application.

136. *Mauzin's Apparatus for Track Measurements.*—A few years later, Mauzin made use of Bowden cables to record, in a continuous manner, the exact position of engines in relation to the track, as well as the variations in curvature. The casing of the cable was fixed at one end to a rigid part of the engine frame, and at the other end to the casing of the recorder. One end of the cable itself was fixed on a moveable contact held against the rail by a spring; its other end was secured to the pencil of the recorder. By this means, also, bogie movement in relation to the mainframe could be measured.

For linear displacements, another method used was a potentiometer wire secured to the fixed member. A sliding contact, fixed to the moving member of the engine, could traverse the length of the potentiometer wire which was fed by a low voltage direct current. The variations in current picked up by the sliding contact were indicated and recorded by means of an oscillograph. Care was necessary in the arrangement of the potentiometer to ensure that the voltage variations in the oscillograph circuit were proportional to the linear displacement of the contact. For measuring in a

(18) Revue Générale des Chemins de Fer, 1st Feb. 1939.
(Experimental and theoretical study of the nosing movement of locomotives on curves.)

continuous manner the exact curvature of the track under load, three contacts were fixed to the engine mainframe, each bearing against the rail. The value of the versine was thus obtained for a chord whose length was equal to the distance separating the outer contacts. In practice, however, records taken in this way could be falsified by horizontal deflection in the engine frame.

In the earlier apparatus recording cylinders were driven by clockwork, and, as cables or rods were used to transmit the displacements, the apparatus had to be mounted on the engine itself. Later, in order to superimpose diagrams taken at different speeds, the drums of the recorders were driven from an axle in order to correlate the diagram movement with the distance run. When the potentiometers were introduced, however, for the measurement of the relative movements, and when electrical apparatus was subsequently developed for measurement of forces, it became possible to mount the recording apparatus in a special van hauled by the test locomotive. This has the advantage of reducing to a minimum the number of parts which have to be fitted on the engine, and also allows successive tests on different engines to be rapidly carried out. Moreover, delicate instruments and their operators can function better in a van than on the footplate. There are in France at present five or six such vans specially fitted for this work.

137. *Mauzin's Apparatus for measuring Flange Forces.*—Measurement of flange forces exerted by an engine on track is a more difficult matter than the measurement of engine displacements. At first, Mauzin (19) used relatively large deflections of crank axles as a dynamometer for measuring continuously the variations in distance between the tyres (6 ft. 6 in. diameter) under lateral load in the horizontal plane of rolling. Variations in this distance were transmitted by a Bowden cable from spring loaded contact wheels bearing against the inside faces of the tyres on a given axle. In France, the crank axle generally leads, and as, in this position, it affects the guiding of the engine when bogie control is insufficient or track is imperfect, records of some value were obtained, although calibration of a dynamometer, which consisted of a wheel and axle assembly, was difficult in practice.

Direct measurement, however, of the lateral forces was desirable, and this could be made only by devices fitted between the engine frame and the axleboxes. Almost at the same time, apparatus of this nature was also developed in America and Germany. In France, use was made of the piézo-electric properties of quartz (20), which had already proved useful in other spheres. The use of quartz has an advantage over all other methods; it enables forces to be measured directly without the intermediary of any other dynamometric element.

When a disc of quartz (Figure 14), suitably mounted, is subjected to a compressive force, it becomes electrically charged on its opposite surfaces like a condenser, and two equal quantities of electricity are produced of opposite polarity, the value of which is proportional to the force applied. A special electrometric valve of high resistance is mounted as near as possible to the quartz to avoid loss; in this valve, variations of potential in the quartz are transformed into variations of current, which are, in turn, amplified by a double stage valve amplifier. The measuring device was originally a Dubois oscillograph, but now a Cathode ray oscillograph is used. The first quartz apparatus was fitted, in June 1933, on a B-B type electric locomotive. In March 1934, it was first used on a steam locomotive of the 4-8-2 type.

The measurements of flange forces, by this apparatus, have been the means of determining the most suitable values for bogie side control on certain steam engines, and of suppressing individual hunting of the bogies on electric locomotives. The measurements have also been used in connection with increase in speed of streamlined locomotives; the flange forces exerted

(19) Revue Générale des Chemins de Fer, March 1934.

(20) Revue Générale des Chemins de Fer, Jan. 1938.

by streamlined 4-4-2 type engines at 140 km. per hour (87 m. p. h.) have been proved to be no higher than those of normal Pacific type engines at 120 km. per hour (74 m. p. h.) (21). It has also been shown that lateral movements of locomotives are usually initiated by variations in curvature and defects in alignment or level.

138. *Accelerometers.*—Due to the deflection of the track under load, it has long been recognised that visual examination of unloaded track does not reveal all defects, and recourse is often had to accelerometers, placed either on engine or train, to check the state of the track in loaded condition. The original apparatus of this kind is the Hallade Track Recorder, which simultaneously gives vertical, longitudinal, and lateral accelerations of the vehicle in which it is located. More recent instruments, such as the Puica-Keraval, Huguenard-Magnan-Planiol, and, later, one of quartz type, measure accelerations in one direction only; but their indications are more reliable, because their own natural period is very small, especially in the case of the quartz type.

Since, however, the relation between the acceleration measure—which varies even from one position to another in the same vehicle—and the lateral force exerted by a vehicle at the rail, is constantly varying, the use of an accelerometer is not able to give absolute values of the forces exerted. On the other hand, accelerometers are useful for comparative purposes in connection with the state of maintenance of the track and comfort of travel in coaches.

139. *Measurement of Truck Defects.*—In seeking to remedy defects in curvature, or in line and level, it is essential to give their exact positions and relative importance to the gangs responsible for maintenance, and the following apparatus has recently been introduced in France for this purpose:—

(1) *Vehicle for measuring rail depressions* (22).—The depression of one rail in relation to the other is measured by the distance between the point of contact of one wheel on the rail, and the plane of the points of contact of the three other wheels of a bogie. When the variation in depression exceeds a certain value a jet of paint can be automatically thrown out to mark the spot. Where one rail is superelevated in relation to the other, the value of this at any given point is obtained by integrating the variation in the level of the two rails in relation to the bogie wheelbase of the measuring coach.

This vehicle will detect low joints in the track, while an arrangement of three rail contacts, as already described, gives variations in curvature by measuring continuously the versine on a given wheelbase. Variations in gauge can also be recorded by special pedals touching the inside of both rails. When these devices are rigidly calibrated, the accuracy of the records is independent of the speed at which they are taken, and this vehicle can be used in normal trains without any particular speed restriction.

(2) *Vehicle for measuring curvature* (23).—This is a 3-axle vehicle which measures the versine on a base of 20 metres, by directly recording the transverse displacement of the centre axle in relation to the rigid frame joining the two outer axles. The versines are measured full size, and the simplicity of the device in conjunction with the high degree of rigidity in the transmitting elements between the axles and the recording table, guarantees extreme accuracy. In addition, the device measures the gauge of the track; also the superelevation, by means of a damped pendulum.

(21) Revue Générale des Chemins de Fer, June 1937.

(22) Revue Générale des Chemins de Fer, Jan. 1933.

(23) Revue Générale des Chemins de Fer, Dec. 1937.

Because of the desire to give direct transmission of the relative movements, it has been found preferable to mount this vehicle without bearing springs. This limits the maximum speed at which the vehicle can be used to 20 km. per hour (12½ m. p. h.). On the other hand, there is the advantage that, due to the practically negligible centrifugal force at this speed, it has been possible to use the simple pendulum for measuring superelevation.

In connection with the above apparatus, it is of interest to note that, in 1934, a Committee (24) was appointed, consisting of an Engineer from each of the Railways, in order to consider the results so far obtained by the different French Companies regarding the stability of rolling stock on the track.

140. *Side Control provided.*—Representative values for the amount of side control provided in France are as follows:—

Type.	Railway.	Weight on Bogie.		Bogie Control Spring Load.		Hind Truck Control Spring Load.	
		T.	C.	Initial. Tons.	Final. Tons.	Initial. Tons.	Final. Tons.
4-6-0	Est.	24	15	1·75	5·6	No truck fitted.	
4-6-2	P. O.	27	10	5·6	10·0	Radial box with flat slides.	
4-8-2	Est.	26	16	7·8	11·8	0·8	1·5

South Africa.

141. Publicity has recently been given to a comprehensive series of tests carried out by the South African Railways in connection with derailments on curves. A description of these has been given in The Engineer of 25th November 1938, page 581, and this information has been kindly supplemented by Mr. W. A. G. Day, Chief Mechanical Engineer of the South African Railways.

The origin of the tests was several derailments which had occurred on curves in different parts of the 3′ 6″ gauge system; although they were shown on enquiry to be due to excessive speed, they had some effect on public confidence. It was decided, therefore, to investigate the whole matter, in order to prove that the theoretically calculated maximum permissible speeds were well within the limits of safety. The trials were carried out between April and November 1937. In the first place, single vehicles, then an engine and tender, and finally a whole train were run round a curve at increasing velocities until derailment took place. Careful records of speed and distance were kept, and still and moving pictures were taken with high speed cameras.

Each unit was hauled up a gradient of 1 in 30 to 1 in 40 and then released to run down under the effect of gravity alone. The curve at the bottom was of 300 ft. radius, and the vehicles either negotiated the curve safely, in which case they were brought to rest by an automatic braking device, or they derailed. The speed at which the test curve was traversed was obtained by direct calculation from simultaneous records of distance and time, made on a revolving chart. Points for distance were inscribed through specially designed track contacts, situated at intervals of 40 ft. round the curve, and operated whenever a copper contact plate on the vehicle struck the flexible phosphor bronze strips of the fixed track contacts. Time was marked by electric impulses from a clock giving 10 strokes per second. The units tested were a 4-8-0 type engine and tender and representative goods wagons.

The results confirmed the formulae used for overturning speeds, and these speeds were in all cases higher in practice by several miles per hour than the calculated figures. This was held to indicate that hammer blow and lurching do not play so great a part as was anticipated. With regard

(24) Revue Générale des Chemins de Fer, 1st Jan. 1938.

to the former, it had been assumed that the locomotive hammer blow reaction on the low rail side could be sustained long enough at the top of its stroke to enable it to assist in capsizing the engine. Cinematograph studies, however, showed that the capsize was gradual over a distance of 100 to 150 ft., and as the wheels revolve many times in the interval, it would indicate that hammer blow is not a factor of first importance in this respect.

These tests were made for a special purpose, and did not deal with more than one class of engine, which was not running under its own steam; they were, however, an interesting approach to the subject of derailment at speed on curves, and the educational effect of showing the films to the staff has impressed the need for strict adherence to speed regulations.

Some particulars were also supplied by Mr. Day of the type of bogie used on the engine, and this is of interest, as being a combination of swing link and spring side control. The single point swing links, of themselves, afford no initial control; this is provided by laminated springs. As there are no sliding surfaces, the friction in the system is reduced to a small amount in the swing link pins. The 4-8-0 type engine which was used in these tests weighed 58 tons on a wheelbase of 23 ft. 3 in. The initial side control was 1·42 tons.

GREAT BRITAIN.

142. Until recent developments in high speed services emphasised the importance of research, no connected experimental work has been carried out in Great Britain on flange forces and their effect on track. There are two reasons for this. First, the standard of track construction and maintenance has been generous in relation to the probable transverse forces to be resisted, coupled with the fact that adverse natural features such as undue heat, torrential rain and unstable subsoil are rarely met with. Secondly, the locomotive in general use on high speed services has, until recent years, been of the 4-6-0 type, which gives lower flange forces for a given degree of bogie control than does, say, a Pacific. Moreover, engines of the latter class, which might have brought the problem into prominance have, where introduced, been mainly confined to running on important main lines, the track of which is generally acknowledged to be amongst the best in the world.

Track distortions have only occurred at rare intervals, but, as a result of gauge spreading, certain Railways are carrying out practical trials with bolted track, the general use of which is confined to the G. W. R. Generally speaking, radical alteration in the type of engine has been made whenever necessary, without a systematic investigation into the whole subject as affecting both track and engine. There have, therefore, been no trials at high speed of the kind undertaken in America, Germany, France and India. A certain amount of investigation has, however, been initiated on the broad subject of vehicles on rails, of which the following examples will give some idea:—

(1) Work has been proceeding in the Research Department of the L. M. S. R. for a number of years on the subject of rail and tyre wear. As a necessary feature of this, the motion of a pair of wheels on the rail has been considered, the main objects being to reduce the rate of wear, and to investigate the riding of 4-wheel bogies, particularly from the point of view of obtaining comfortable riding in passenger coaches. Mathematical investigations have been undertaken ([25]), trials have been made with models, and high speed cinematograph films taken of the action of full size wheels on the track; this has resulted in recommendations for the degree of tyre coning and for the materials used.

(2) In the last two years, a mathematical investigation has also been undertaken by Professor Inglis of Cambridge ([26]) into the vertical path of

(25) Some experiments on the lateral oscillation of railway vehicles.
By R. D. Davies.
Proc. Inst. C. E. 1939.

(26) The vertical path of a wheel moving along a railway track, by Prof. C. E. Inglis.
Proc. Inst. C. E. 1939.

a wheel moving along a straight railway track. The object of this is to study the manner in which the running of a pair of wheels and axle may be effected by characteristics such as the elastic compression of the ballast, the stiffness of the rail, lack of continuity at the rail joint, wheel loads and speed. Experimental verification is in hand, on the track of the L. M. S. R.

(3) On the G. W. R., a series of preliminary tests, with various types of bogies on passenger vehicles, were first made, the effect of permanent way being temporarily ignored; these were later supplemented by the use of the Hallade Instrument to obtain records of the various movements of vehicles. These tests soon showed that it was impossible to ignore the effect of the permanent way, or even to make allowance for it without further data. A standard stretch of road was then selected, and was maintained, so far as was practicable, in a uniform condition; over this portion of the line comparative tests of various bogies were made, the same special vehicle being used, attached to the rear of a train with adjacent buffers just in contact. To ensure that speeds when passing over the standard track were as uniform as possible, the same train was selected for each test.

Elsewhere, valuable information was obtained of the influence of track defects on the running of vehicles, and, to assist the permanent way staff in locating these defects, an observer in the special vehicle released whitewash from a container at points where excessive movements were observed. As a modification of this, when various types of bogies were being tested, washes of different colours were used (one for each type). If all bogies reacted unfavourably, it was evident that the track was at fault; if, however, only some of the colour washes were found on the track, it was concluded that the corresponding types of bogies were more sensitive to track defects than others.

The next step eliminated the human element, and the coach movement itself was used to operate the whitewash valve. For this purpose, a bogie was selected which had shown itself to be most suitable; this was permanently installed under the coach thereafter being maintained to the highest possible standard. In this way, effects due to worn tyres, etc., were eliminated, and the dropping or withholding of white-wash was made increasingly dependent on the condition of the permanent way. The apparatus [27] has proved to be so successful that, in conjunction with the Hallade Recorder, it is now used on the G. W. R. on all track-marking trials. It is important to note that the white-wash dropping apparatus is controlled only by the relative speed of lateral movement of the bogie in relation to the coach body, and not by the amplitude of such movement, and is entirely unaffected by vertical oscillation.

(4) In the course of an investigation on the L. M. S. R. into certain derailments at low speeds, a hydraulic flange force recorder has also been developed. In this arrangement, the plungers of small hydraulic cylinders, which are attached to the frame, bear against a ring welded to the wheel spokes. A force at the wheel flange exerts a pressure on the plungers, which is recorded by an adaptation of a steam engine indicator. Accurate readings can be obtained at very low speeds and over short periods of time, and the apparatus has been found to be successful within its limited range. It is not considered to be capable of use at higher speeds, because. leakage and inertia effects are liable to reduce the sensitivity of the apparatus and the accuracy of the diagram obtained.

143. *Side Control.*—The above examples are quoted to show that work so far done has only had a partial bearing on the matter we are considering. In India until the advent of Pacific engines, as in England until now, it is true to say that lateral forces on rails have not presented an urgent problem. The subject, however, must increase in importance with the present day trend towards increased speeds. The amount of side control at present provided

(27) Proc. Inst. Mech. E. Vol. 121, page 465.

on bogies and trucks in British practice is given by the following examples taken from the L. M. S. R. :—

Type.	Weight of Engine. Tons.	Wheel-base. Ft. in.	Bogie Control Spring Load.		Truck Control Spring Load.	
			Initial. Tons.	Final. Tons.	Initial. Tons.	Final. Tons.
4-6-2	100	37 0	4	5	1·44	3
4-6-0	79½	27 7	2	2·83	..	..
4-4-0	54	22 8	1·56	2·6	..	..

INDIA.

B. B. and C. I. Railway Research.

144. *Scope of the Investigations.*—Research work has been undertaken by the B., B. and C. I. Railway and by the Railway Board, acting independently. The investigations of the former involved :—

(a) Designing a recording mechanical oscillograph for bogie movement.

(b) Making a series of records for engines in different conditions of bogie and hind truck control, and in different conditions of maintenance.

(c) Exploring the relation between packing of the track and engine oscillation, making use of white-wash to record track defects.

The work was initiated in 1930 following displacement of the track by XC engines during the monsoon. The recording apparatus for bogie movement in relation to the main frame was first adopted in January 1931, and it has since been used at intervals to investigate riding problems as they arise.

145. *Description of Ocillograph.*—The recording instrument is carried on a bracket attached to the bogie centre frame stretcher on the engine; it consists of an arrangement by which a roll of tracing cloth about 5 in. wide is driven by suitable gearing from one of the bogie wheels. The tracing cloth passes under three pencils, the outer two of which record time and distance (mile posts), whilst the central one, which is operated from a bracket fixed to the bogie stretcher plate, records displacement.

The drive is effected by means of a belt between a pulley, which is bolted to the outside of one of the bogie wheels, and a countershaft running across the top of the engine framing, from which a second belt leads down to drive the oscillograph. The point from which the displacement is taken is about 1 ft. 9 in. ahead of the bogie centre, so that the movement recorded is compounded of bogie rotation and displacement of slides. The apparatus is robust, and, by scribing the record of the movement directly on to tracing cloth, copies of the record can be simply taken after inking.

146. *Deductions from Use of Oscillograph.*—As displacements only are recorded, and no means of measuring flange forces had been developed, the series of graphs obtained show a continuous reduction in relative movement between bogie and main frame, as more friction is added to bogie and hind truck; the deductions made were the same as those reached by the Railway Board, namely, that the troubles experienced with these Pacific engines can best be cured by retaining a light bogie control spring, lining the bogie slides with friction material, fitting a flat Ferodo faced slide to the hind truck, and adopting German draft gear.

Previous to these final deductions, trials had been made by increasing the bogie control within the limits of the original design, increasing the inclination of the Cartazzi slides, and cutting out sections of the compensating gear; none of these materially effected improvement. In 1934, a complete bogie was obtained having roller bearing axle-boxes and laminated spring side control; the centring force was 3 tons initial and 4½ tons final. Used in conjunction with the Cartazzi slides, no improvement resulted.

During our visit, new laminated springs were, at our request made and fitted to this special bogie, having an initial load of 5 tons and a final load of 8 tons. The engine was also fitted with flat Ferodo hind truck slides, and with modified German draft gear, in which flat side buffer faces were provided rubbing on Ferodo. The buffers were fitted with collars to their spindles, so that when the engine traversed a curve, only one buffer at a time came into action. The oscillograph was fitted up on this bogie on XC No. 614, and a very smooth graph was obtained over a portion of the main line between Kotah and Dohad, which had considerable curvature (*vide* also paragraph 109, Chapter V).

147. *Relation between Packing of the Track and Engine Oscillation.*—In 1932, some interesting and valuable trials were carried out on a stretch of line one-quarter of a mile long, over which oscillation had been experienced with XC class engines. At intervals of approximately 20 ft., the following measurements were taken :—

Vertical alignment,

Horizontal alignment,

Gauge,

Unloaded cross levels,

Deflection under engine at 60 m. p. h.

Cross levels under engine load at 60 m. p. h.

Throughout these trials, the engine used was one known to hunt at speed on this particular section, and its condition was not varied; but with the object of discovering the effect of track conditions on hunting, the track was repacked after each test. It was also desired to ascertain whether hunting could be damped out if the track were more efficiently packed. The measure of hunting corresponded with the amount of white-wash which was ejected by a special fitting carried on the engine. Figure 15 shows a portion of the chart, from which it will be observed that successive packing of the track gradually reduced the tendency to hunt.

These investigations, which to the best of our knowledge were original, are of value because they show that the B., B. and C. I. R. authorities were thinking on the right lines, so far as the interdependence of track and engines is concerned; it was thus demonstrated that hunting can be practically cured if intensive attention is paid to the track, and this confirms what we have set out in Chapter III on this subject.

The fact, however, that this desirable result for these particular engines requires a standard of track maintenance financially impracticable does not detract from the value of the experiments, which establish an important relationship between track maintenance and engine hunting. One beneficial effect of these trials was that attention was focussed on track, and the B., B. and C. I. R. accelerated their programme of renewal of some 200 miles of wooden sleepers with steel troughs on 90 lbs. F. F. rails. Since these measures, the XC engines on this Railway, even in original condition, are reported to have given no further trouble in this respect.

Railway Board Research.

148. *Origin.*—In continuation of the experimental work in connection with X class Pacifics, which has been described in Chapter II, the field of research was extended in 1935. The matter was approached from two complementary angles, first to determine the actual flange forces exerted, and, secondly, to ascertain the resistance of different tracks to those forces. It is intended in this section to deal with the locomotive first, as it is to this that most attention has so far been given. Track Research will be described and discussed in the latter part of the section.

Two Officers from the Civil Engineering Staff were placed on special duty, and the following extract from their Report describes the apparatus used so far as the locomotive is concerned:—

"*We were instructed to undertake a research into the permissible axle loads and speeds on various types of Railway track existing in India. We commenced our investigations in the winter of 1935 with the following terms of reference:—*

(1) To verify or otherwise the speed allowance formula vide *item D (4) of Technical Paper No. 245 for the increment of rail stress due to the passage of a wheel load on a rail at speed due to the elastic character of the support.*

(2) To investigate the increment of stress over and above the static effect that may be expected to arise under normal conditions from defects in the track such as low points, rail joints or non-uniformity in the support offered by adjacent sleepers.

(3) To investigate the conditions of support at rail joints with a view to determining what reliance can be placed on the rail continuity effect of fish plates both new and worn, and the effect of closer sleeper spacing.

(4) To investigate the conditions of stability in the ballast of various types and designs of sleepers including recent designs of the Central Standards Office from the point of view of reducing maintenance and preserving a level track surface.

(5) To investigate the effects on rails and sleepers of the lateral forces on rails arising from the hunting movement of locomotives at speed both on straight track and on curves.

By the summer of 1937, our investigations covering the first four items were completed, and the results indicated that so far as a vertical axle load is concerned, axle loads of 19 tons could be run safely on almost any weight of rail on Broad Gauge tracks at speeds of 60 m. p. h. There remained, however, the investigation of the important matter covered by item (5) and it was evident that no reliable conclusions could be drawn unless due account was taken of the lateral forces which tracks are called upon to bear.

The expermental investigation of the effects on rails and sleepers of the lateral forces arising from the hunting movement of locomotives at speed presented a problem of some difficulty and complexity. One of the handicaps with which we were confronted was the absence of any standard type of apparatus suitable for our investigations, and it was necessary for us to design and manufacture the special apparatus required. The apparatus which was completed by the summer of 1937 was so designed that, when fitted between the axle boxes of locomotive axles, the flange pressures imposed on the rails could be electrically recorded whilst the locomotives were travelling at speed. In addition, arrangements were made to record the lateral movements of the front and rear of engines by means of electric telemeters of the type used in our earlier investigations with the necessary adaptations to suit the purpose in view.

It was decided to start experimental investigations on the East Indian Railway, and the work was about to commence on that system when the Bihta accident occurred. As a result of this, we were directed to concentrate the investigations practically exclusively on the matter of the running of XB class engines and their effect on the track. With periods of intermission, 14 months in all was spent in testing XB class engines. During *this period, some 180 engine runs were made under varying conditions and on different sections of line, and records were electrically taken of the engine movements and flange forces.*

Objects of Investigation.—*The objects of the investigation were :—*

(i) *To ascertain the characteristics of XB engines when hauling passenger trains on the Indian permanent way at express speeds.*

(ii) *To determine the inter-relation between the engines and the track to ensure safety.*

During the investigation, tests were carried out on the following Railways :—

East Indian,

North Western,

Madras & Southern Mahratta,

South Indian,

Great Indian Peninsula.

The scope of the tests covered classes of tracks with rails of medium weight such as 82 lbs. B. H. on the Great Indian Peninsula Railway and 88½ lbs. B. H. on the East Indian Railway. Tests on the other Railways were carried out on track upon which the engines have hitherto normally operated at unrestricted speed, i.e., *60 m.p.h.*

Description of Apparatus used on Locomotives.—*The general character of the apparatus used on the locomotives has already been indicated. In addition, an optical recording seismograph was used for testing lurch movements. This instrument is described in a paper read by one of the writers before the Institution of Civil Engineers and published in the Proceedings of that Institution in Vol. 237, pages 354-355, and in the 11th Report of the Indian Bridge Standards Committee. The equipment on the locomotive also included scribers and 'scratch-plates' for indicating maximum amplitudes of the bogie slide and of the hind truck axlebox movement.*

For the purpose of electrical recording, a five element electromagnetic strain gauge recorder was employed. Of the five elements, three were adapted to record movements relative to the engine frame such as those of the bogie slide, bogie pivot, coupled axlebox, hind truck axlebox and hind truck axle. The remaining two elements were designed to record flange pressures.

Measurement of relative Movements or Deflections.—*The principle adopted is shown diagrammatically in Figure 16. The bracket A carrying a cantilevered spring steel strip is securely bolted to the first member in such a direction that the relative movement of the second member will be normal to the cantilevered strip. An operating bracket B incorporating two rollers is bolted to the second member so that relative movement results in bending strain in the strip closely proportional to the relative movement between the two members. The electro-magnetic strain gauge detector E is attached at a position along the cantilever strip where the range of strain is of a suitable magnitude for recording. The electromagnetic principle in both movement or deflection and flange pressure detectors is the same, but in the former case they take the form of separate units.*

The elements for recording lateral forces consist of weighbars in the form of tubular struts illustrated in Figure 17, fixed in pairs between the axleboxes, the channel liners of which are planed down at X to give sufficient clearances to ensure proper functioning of the weighbars, which requires that the path of the lateral forces between the flanges and the locomotive frame shall be via *the weighbars or struts. The thickness of metal of the tubular struts is reduced to 0·19 in. over the length GG and strain on this length is detected by an electro-magnetic strain detector assembly. In the assembly are three wound laminated cores of Rhometal separated by air gaps of ·020 in. The central core, on which is wound the energising coil, is rigidly connected to one end of the gauge length by means of a duralumin forked plug. The two outer cores, with their windings connected in opposed series to give the difference of the voltages induced in them, are rigidly connected together and to the other end of the gauge length by means of duralumin frame plates and plug. When a load is applied to the weighbar, the strain on the gauge length closes the air gap on one side of the central core and opens it on the other, thus increasing and reducing the induced voltages in the respective outer core windings. As arranged for use, the number of turns on each of the outer coils is different so that under no load the difference of the induced voltages is 5 volts decreasing with load. Up to the maximum load the variation of voltage is very closely linear. The weighbars are made in matched pairs and are retained between the axleboxes by means of hemispherical sockets. The nett induced voltages from each of a pair of weighbars is added so that the total of the two nett induced voltages varies linearly with the total load on the pair of weighbars, and is independent of the actual distribution of the load between weighbars.*

The energising power is obtained from an oscillator-amplifier delivering about 6-7 watts at 6000 c.p.s. The whole of the electro-magnetic strain detector assemblies are connected in parallel with each other. This parallel group is connected in series to a condenser to form a series resonant circuit which presents a load of pure resistance to the amplifier. The impedence of each assembly is practically constant for the working variations of the air gaps.

From each pair of weighbars and each deflection meter the nett induced voltage is applied to the grids of a pair of valves arranged for rectification. The anode current from each pair of valves is filtered and passed through an adjustable resistance to a Duddell type oscillograph tube. The filters are designed to cut off at about 60 c.p.s. in the case of the weighbars and 20 c.p.s. in the case of movement or deflection-meters.

The battery of oscillograph tubes with their electro-magnetic D. C. field coils are arranged at one end of a light-tight box which forms the 'bellows' of a camera. The film box is set at the other end but not touching the 'bellows' box, the connection being made by means of a labryinth light trap. Images of a straight filament are thrown on to a cylindrical lens in front of the film by the oscillograph mirrors. The cylindrical lens reduces this line image to a point image on the film. A slit 0·010 in. wide is placed across the film to protect it from stray images and dispersion. The film is wound past the slip at any required speed by a small motor. The 'bellows' box is mounted on a sponge rubber mat one inch thick to protect the oscillograph tubes from possible vibration from this motor.

The whole group consisting of oscillator-amplifier, rectifying valves and camera oscillograph is mounted on a board and slung from the roof of a bogie vehicle by rubber ropes. In practice, the suspension is satisfactory and no influence of train motion can be detected on the records.

Method of Calibration.—

(a) Deflection Meters.—*A direct calibration is obtained by moving the free end of the spring steel cantilever strips through a measured distance and adjusting the oscillograph by the variable attenuators to give a convenient scale. The scale adopted is 1 cm. = 1 inch.*

(b) Weighbars.—*A direct calibration is obtained by applying known loads in a calibration assembly and adjusting the weighbar oscillographs to a convenient scale. The scale usually adopted is 1 cm. = 5 tons. The calibration can vary about 5 per cent. due to heating up of the oscillograph tubes by the field current. To minimise errors due to such variations calibrations were taken before and after each day's tests.*"

149. *Nature of Tests.*—For the first time in India, apparatus having been devised, which was capable of giving quantitative results as regards flange forces, an intensive programme of testing was put in hand from the end of 1937 up to the time of our visit. These tests covered a wide range of variables in engine fittings and maintenance, and in track, and the following is a summary of the principal variations :—

A. *Locality.*—By far the largest number of these test runs were made either between Arrah and Bihta on the E. I. R., or between Bhusawal and Nagpur on the G. I. P. R., the latter containing sections of track on black cotton soil notably difficult to maintain. Individual runs were also made on certain portions of the M. & S. M. R., S. I. R., and N. W. R.

B. *Engines.*—

(1) *Type.*—About 75 per cent. of the trials were made with XB engines, the remainder being divided between XA, XP, HPS and XC classes in that order of numbers.

(2) *Side Control Springs.*—On X class Pacifics, coil springs varying from 15 to 31 cwts. initial loading were tried, as well as laminated springs with 15 to 90 cwts. initial loading.

(3) *Bogie Slides.*—Cast iron or bronze were tried, with oil lubrication.

Five different friction materials of the Ferodo type were also employed on slides, lubricated and unlubricated.

An arrangement of needle roller bearings was fitted on the slides, to explore the effect of absence of friction at this point.

(4) *Hind Truck.*—The following variations were tried :—Cartazzi slides with different inclinations. Flat slides, cast iron on steel, lubricated. Flat slides, lined with two different friction materials of the Ferodo type, unlubricated. Pony truck.

(5) *Draft Gear.*—The Goodall type, and the link type, with and without German buffing gear, were tried; also the Mestre type.

(6) *Condition.*—Engines were tried in different conditions of maintenance as regards axlebox side clearances, varying from new out of Shops to very sloppy. Two E. I. R. XB engines, on which a large number of tests were made, were specially

chosen to represent the extremes of maintenance in this respect. The sideplay in the boxes was as follows :—

	XB 1920.	*XB 1921.*
Bogie leading	0·4″	0·2″
,, trailing	0·4″	0·2″
Coupled leading	0·646″	0·188″
,, driving	0·246″	0·188″
,, trailing	0·879″	0·188″
Hind truck	0·8″	0·125″

C. *Speeds.*—These trials were generally conducted at speeds of about 60 m.p.h., except when travelling over turnouts.

D. *Track.*—E. I. R.	88½ lbs.	B. H., D. & O. Plate, and wooden sleepers.	
G. I. P. R.	82 lbs.	B. H.	C. I. Pots.
	100 lbs.	B. H.	
M. S. M. R.	80 lbs.	B. H.	C. I. Pots.
	90 lbs.	B. H.	
S. I. R.	90 lbs.	B. H.	C. I. Pots.
N. W. R.	90 lbs.	F. F.	C. I. Plates.

E. *General.*—Out of 95 high speed runs, of which we were given detailed graphs and particulars, only 16 were taken on curved track, the remainder being on the straight. In addition, a large number of tests were made on 1 in 12 turnouts at varying locations and speeds. On each run, records were taken of bogie and hind truck displacements, and in some cases also of the bogie rotation in degrees. Flange forces were usually recorded at the same time for leading and trailing coupled wheels, but were not taken in all cases. Figure 25 illustrates extracts from typical charts, diagram A showing a graph for an engine behaving normally, and diagram B for an engine in the process of hunting.

150. *Results of Tests on Engines and Deductions drawn by the Railway Board.*—Amongst the numerous variables in operation, one fact stood out. As friction was introduced into the side controlling elements on bogie and track, so the amplitude of oscillation was reduced. Figure 18, diagram A, is a copy of a chart prepared by the Railway Board showing the relation between the two, as established by numerous tests. Moreover, from a study of the recorded flange forces, there appeared to be a definite tendency for coupled wheel flange force to vary with amplitude of bogie slide movement, at any rate on the straight. Diagram B on Figure 19 shows points plotted from different trials, with a trend line running through them.

These observed facts were supported by mathematical investigations based on theoretical work by Cain, Langer and Shamberger, and Carter; the Board's calculations showed that the critical speed of hunting increased with the coefficient of friction in the slides. Apart, however, from the foregoing, normal footplate observation also confirmed how hunting and undue oscillation disappeared when engines were fitted with friction damping on the slides fore and aft; the Railway Board, therefore, considered that they had justification for putting forward the recommendation that all X class Pacifics should be so dealt with, as a final cure for the trouble which had been experienced.

In addition to the above, which sets out briefly the major conclusion, certain other inferences which the Railway Board drew from these trials are of interest :—

(a) That increasing the amount of initial side control successively up to 3¼ tons on an XB engine showed no reduction in oscillation or flange forces.

(b) That an increase in centring force on the bogie alone increased the amplitude of movement at the back end, if no alteration was made to the hind truck slides.

(c) That an engine with side clearances tight gives less oscillation than one with big side clearances; but that the flange forces with tight clearances on the coupled wheels may be higher than those with ample side clearances, should the engine be oscillating due to the combined effect of the bogie and hind truck clearances.

151. *Comments on the Railway Board's Conclusions.*—To some extent, therefore, on our arrival in India, we were presented with a *fait accompli.* Research, theory, and ordinary observation appeared to indicate that the problem was solved. Instructions had already been issued by the Board for all X class Pacifics to be altered, and numbers of them had already been dealt with. On the other hand, the method of curing the trouble was at variance with the fundamental considerations which we have set out in Chapter III, and it was, therefore, necessary for us to make a very close study of all the records taken, in order to throw some further light on the problem.

Two considerations emerged. Amplitudes of oscillation had been regarded as a more important indication than flange forces, and the behaviour of the engine on straight track had been the main pre-occupation. There is perhaps some justification for the latter in that the Bihta derailment, and most of the others, occurred on the straight. It is, however, the flange force alone which can damage and displace track, and any remedial measures taken on an engine must be equally effective on curved as on straight track.

Accordingly we concentrated on flange forces and on curved track; from an inspection of the records, we found that, whilst flange forces were reduced to small values on the straight by the Railway Board's modifications, on curves these forces remained equally as high for the modified engine as for the original engine on the straight. From the relatively small number of tests taken on curved track, it was possible to pick out examples confirming this. The following table, for instance, gives maximum flange forces recorded on XB No. 1920 :—

Test No. and date.	Condition of Engine.	Speed m. p. h.	Track.	Maximum Flange Forces L. Coupled. Tons.	Maximum Flange Forces T. Coupled. Tons.
98 16/9/38	Needle rollers on bogie slides. Cartazzi hind truck. Goodall coupling.	60	Straight . .	13	7·5
21 7/2/38	In original condition, *i.e.*, metal to metal bogie slides lubricated. Otherwise as above.	62	Straight . .	6·5	6·0
65	Modified. Ferodo bogie slides. Flat truck slides with Ferodo. German buffing gear.	65	Straight . .	3·85	3·0
81 1/8/38.	Same as 65 above . .	63	Curved 2640 ft. rad.	14	4·0

Bogie control springs, initial load 25 cwts. final load 50 cwts.

Figure 25 sets out the relevant portions of the graphs of flange forces recorded, as summarised above. It shows that it is possible for a modified engine, exemplary in its behaviour on straight track, to exert flange forces on curves greater even than those exerted on the straight when the engine is deliberately fitted with special needle roller bearings in the slides, to obtain experimentally the worst hunting conditions.

In answer to objections that the dates of the above tests are too far apart to be comparable, and that test No. 81 on the curve was carried out at the height of the monsoon when the track was in its worst condition, we give a further table on similar lines in which all the tests concerned were made within a week. The table below refers to XB No. 1921 which, as already stated, had tight clearances in its axleboxes.

Figure 26 shows the relevant portions of the graphs in this case.

Test No. and date.	Condition of Engine.	Speed m. p. h.	Track.	Maximum Flange L. coupled. Tons.	Forces T. Coupled. Tons.
62 27/6/38.	Needle rollers on bogie slides. Cartazzi hind truck. Goodall coupling.	61	Straight . .	12	7·5
..	In original condition .	No tests made with this engine as built.			
55 22/6/38	Modified. Ferodo bogie slides. Flat truck slides with Ferodo. German buffing gear.	62	Straight . .	6	5
58 25/6/38.	Same as 55 above . .	68	Curved 2,640 ft. rad.	10	7·5

Bogie control springs initial load 22·5 cwts. final load 50 cwts.

The above, taken from the Railway Board's test results, provides an indication that the use of high friction and low spring control values on bogies and hind trucks is not a satisfactory solution of the problem in all its aspects. Further confirmation of our views is found in a diagram prepared by the Board on the same lines as Figure 19. This shows flange forces on the leading coupled wheels in relation to bogie slide displacement on curves of 2,640 ft. radius, the progressive reduction in movement being due to the introduction of friction damping. Figure 20 illustrates points obtained on various tests, and it will be noticed that the trend line, which we have added, indicates that there is little, if any, reduction in flange force as friction increases and the bogie slide movement in consequence decreases. It should be carefully noted that the conditions shown are very different from those for straight track in Figure 19.

The effect of stronger bogie side control springs was investigated by the Board, but records made with initial values rising from $1\frac{1}{4}$ to $3\frac{1}{4}$ tons gave no indication of any improvement in flange forces or displacements. An examination of the records in question, however, shows that:—

(a) Friction liners were fitted on the bogie slides, and the true effect of the control springs was masked.

(b) The Cartazzi slides were retained on the hind truck which had considerable sideplay, so that stiffening up the control at the front end was discounted by free movement at the rear.

(c) The tests were made on XB No. 1920 which had very large bogie and hind truck axlebox side clearances, about $\frac{1}{2}$ in. in the former and $\frac{3}{4}$ in. in the latter. This gave a great deal of free movement, irrespective of the degree of control provided.

(d) The tests stopped short at an initial value of $3\frac{1}{4}$ tons for the bogie side control. More positive results might have been obtained from a higher value.

It is not surprising, therefore, that the Railway Board received no clear lead as to the value of increasing the initial side control on bogies. An opportunity might have been taken for ascertaining the effect of a bogie with metal to metal slides, with 3 tons initial side control and a pony truck at the back end, as in the tests with the experimental

XP Pacific engine No. 3100. Displacements only were recorded and no flange force values were taken either on the straight or on curves.

Credit is due to the Officers of the Railway Board for formulating a test programme covering so wide a field, and for developing and perfecting the measuring apparatus for displacements and flange forces. The full diagrams taken on over 100 separate runs, which were placed at our disposal, have been of great value in our consideration of this matter, and if the calibration of the apparatus is correct, we have no reason to doubt the reliability of the indications. The fact that the Board had, prior to our arrival, drawn differing conclusions from these test results is due, as already mentioned, mainly to their concentration on the aspect of hunting which concerns straight track alone; also to the fact that the choice and combination of variables on the engines tested were such as to prevent in many cases the emergence of clear and definite tendencies.

152. *General Research on Track.*—In paragraph 148 are set out the Railway Board's terms of reference which initiated the test work on track and engine, items 1 to 4 of which refer to research carried out on the track alone. This work was commenced in November 1935 and completed in the summer of 1937. It was necessary to be able to measure stresses in rails and fishplates, and, for this purpose, electro-magnetic strain gauges were obtained from the Baldwin Southwark Corporation. Optical deflectometers, for use in conjunction with the strain gauges, were designed and constructed by the two Officers on special duty. Similar equipment, which was developed from the original track apparatus, was afterwards used in the research on locomotives.

153. *Application of Blondel's Tests to India.*—It was desired to investigate the effects of flange forces on rails and sleepers, and, following the pioneer work carried out by Blondel in France, tests on similar lines were undertaken in India. These were made under varying conditions of rail, sleepers, and ballast, and took the form of:—

(1) Pulling sideways on the rail under static vertical load, using a hydraulic jack anchored alongside.

(2) Running two wagons on adjacent tracks, and introducing between them a means of applying a known load on the axle ends, thus exerting a flange force on the rails under moving conditions.

(3) Making similar tests with two engines, in this case applying the load to the bogie and leading coupled wheels.

We were given an opportunity of seeing the last named tests in operation at Moghalsarai with two XB engines. In the case of (1), the apparatus was simple. For (2) and (3) the equipment is illustrated in Figure 21, which shows its application to engines, in order to produce a known flange force. The effect of that force on the track was measured by a series of simple telescopic deflection gauges, mounted on long bars which were in turn secured to lengths of rail embedded vertically in the ground clear of the ballast on either side of the track. By these instruments, the elastic and permanent deformation of the track at the rail head was measured.

The object of tests (2) and (3) was to find the limiting flange force which different kinds of track could stand without distortion. The speed at which these experiments were carried out was very low. It has, however, been found in France that the values so obtained hold good at high speed, but this should be verified so far as India is concerned.

Owing to the attention which has been given in the last two years to locomotive flange force recording, only a limited amount of work has been carried out with this particular form of track testing, and the results so far obtained are different from those obtained by Blondel in similar tests in France. This requires some further investigation, in our opinion, and the following points should be noted:—

(1) There is no continuous record of the force exerted by the spring separating the two engines, and although a certain tonnage is applied there is no guarantee that this remains constant

throughout the duration of a run, owing to the strength and stiffness of the springs used. This may possibly be the cause of the difference by which Blondel finds that the same flange force causes less displacement of the road when stationary than when moving; the Indian tests, however, appear to show the opposite, and careful verification of this point is essential.

(2) Owing mainly to the effect of the coning of the tyres, the bogie was noticed to pursue a sinuous motion along the track within the clearances between wheel and rail. This requires investigation to ensure that such motion does not interfere with the flange forces which are assumed to be present.

(3) It is desirable that the different elements making up the total displacement of the track should be split up, and deflection gauges should be applied to the head and foot of the rail separately, and to the sleepers.

154. *Conclusions reached by the Research Officers from the above Tests.*—In so far as our terms of reference are concerned, the Research Officers have summarised the conclusions which they have drawn from the investigations so far made. Extracts from these are as follows :—

"(*1*) *The lateral strength of track depends on the time it has had to consolidate after being laid or re-packed.*

(*2*) *The type of rail has no appreciable effect on the lateral strength of the track.*

(*3*) *88½ lbs. D. & O. plate track shows superior lateral strength to 90 lbs. R. track with hardwood sleepers. This applies even to D. & O. track freshly laid or re-packed.*

(*4*) *Under ordinary conditions of maintenance CST/9 type and steel trough sleeper (90R rail) tracks show higher lateral strength, even after re-packing, than either D. & O. (88½ lbs.) or timber sleeper (90R) tracks.*

(*5*) *The D. & O. plate track shows a rate of growth of lateral strength due to consolidation inferior to both steel trough and CST/9 type sleepers, but superior to hardwood sleeper track.*

(*6*) *88½ lbs. D. & O. track is superior to timber sleeper track in its ability to hold gauge and is almost as efficient as CST/9 and steel trough tracks in this respect.*

(*7*) *Comparative tests with steel trough sleepers N+3 and N+6 sleepers per rail have shown that the lateral strength of the track may be taken to vary inversely as* $\sqrt[4]{l^3}$ *where l equals the sleeper spacing, with a substantial margin of safety.*

(*8*) *Under conditions of good maintenance and when consolidated, the D. & O. track affords excellent lateral stiffness, and it may be said to be capable of withstanding lateral thrusts of the coupled wheels up to 10 tons under 17 ton axle Pacific engines with an adequate margin of safety and without appreciable permanent distortions.*

(*9*) *The capacity of track to retain good surface and alignment is an important feature. If one type of track due to features of the sleeper, ballast or subsoil is prone to run down more quickly than another, it will have to resist greater horizontal disturbing forces even though it may have greater lateral resistance. Our experiments, confined as they have been to observations of lateral effects, do not enable us to report upon the susceptibility of any given track to 'running down'.*"

It will be noted that the 88½ lbs. track on D. & O. plate sleepers is considered to be satisfactory. In another section of this Report we have discussed this type of track, and venture to suggest that statements so definite as are made in the conclusions quoted above are hardly justified by the extent to which the research into the track has yet been carried; indeed, the phraseology of Conclusion (8) may well be misleading, and, in any case, the flange force which the 88½ lbs. D. & O. track is said to be capable of withstanding safely is given as 10 tons for the 17 ton axle load of the XB engine, *viz.*, 60 per cent. Flange forces considerably higher than this have been recorded in the trials on XB engines; our recommendations with regard to the replacement of this track are referred to in Chapters IV and IX.

PROPOSALS FOR FURTHER RESEARCH WORK IN INDIA.

155. *Engine.*—Throughout our Report indications are given of matters which require further investigation and research. It is only intended to mention here the more important work which should be undertaken. This may be divided into research which will establish certain values, and repeated testing to verify the continuance of those values.

We are satisfied that the Railway Board now possess an apparatus which, in principle, affords an accurate means of recording locomotive flange forces. The immediate object of further research should be to verify what modifications on existing engines will effect the largest reduction in flange forces, both on straight and curved track; this matter is referred to again in Chapter IX, paragraph 206.

Our proposals are as follows :—

(1) That two engines of each class (XA, XB, XC) should be modified as recommended, and flange forces on leading and trailing coupled and on guiding wheels recorded on both straight and curved track. The effect is required of speed, type of track, and type of formation. Trials should be carried out both in the dry weather, and under monsoon conditions.

(2) That, during the life of engines, spot checks should be made under different conditions of track, weather, and maintenance, to ensure that in no circumstances are excessive flange forces attained.

In principle, no modification, whether contained in this Report or subsequently decided upon, should be adopted until flange force records of trial engines show that, under no conditions of reasonable railway operation, are such forces excessive.

Tests should always be carried out under similar conditions of adhesion (dry, damp or wet rail) and under similar conditions of traction (with or without train, regulator open or shut). These conditions are much more important than straining to obtain equal speed on all tests, which may give rise to acceleration and deceleration, and falsify results. It is also desirable that a comparison between two different arrangements on an engine should be made at short intervals, so that the state of the track does not have time to alter. If tests have to be repeated after a length of time, one or more of the tests already made should be repeated; this will serve as a calibration, because of possible differences in the state of the track.

Track.—The work which has been commenced with two moving engines on adjacent tracks should be continued. Attention should be given to the points referred to in paragraph 153, to ensure accurate results. A suggestion in this connection is that electro-magnetic flange force recorders might be mounted on one of the trial engines, to verify the forces which are thought to be given by the spring separating them.

On completion of these low speed tests, it is very important for Indian conditions that the values obtained should be verified by high speed tests. This can be done by fitting a series of deflection recording gauges to a given piece of track, the gauges being so arranged that the passage of each wheel will advance the recording paper one stage, thus allowing the axle producing the worst deflection to be identified. These deflection recorders should be fitted to both the head and the foot of the rail and to the sleepers. The form of the apparatus may well be similar to that which has been described in the French section of this Chapter.

Tests on these lines should be conducted with engines up to the highest speeds allowable and under the worst track conditions. Tests might usefully be carried out on two successive lengths of track, one being in condition as found, and the other put into the best practicable condition. It should be pointed out, however, that it is possible to examine only a relatively short length of track by means of deflection recording gauges fixed in the formation.

We have recommended the extended use of the Hallade track recorder, or some such accelerometer, and the limitations of this instrument have been referred to in paragraphs 101 and 138. It is, however, necessary to verify and record in a continuous manner the line, level and versine of track under load, and we recommend that consideration should be given to the provision of high and low speed track testing cars such as are described in paragraph 139. The former is of use in co-ordinating measurements of flange forces and track irregularities when coupled to a locomotive which is under test (27A). The latter is of assistance to the Civil Engineer in giving quantitative particulars of track defects. We have no doubt that the introduction of such special test vehicles on Indian Railways would be of great benefit.

Knowledge of the limiting lateral resistance of various classes of track is of equal importance to knowledge of the extent of flange forces themselves, and, although investigation into the former is likely to be more laborious and protracted than into the latter, complete security cannot be ensured until reliable information, affecting both engine and track, is obtained. Close research into the 88½ lbs. D. & O. track is a matter of first importance.

Organisation.

156. *Central Standards Office.*—There are many other fields of activity which can be profitably developed by a permanent central organisation such as the Central Standards Office. They can initiate investigations which can well be carried out by the various Administrations, but, to enable results to be properly analysed and interpreted, the staff must consist of persons who are free from ordinary routine work of the Administrations and who can be sent to watch and follow up research in the field. We consider that this work is so closely associated with that at present being undertaken by the Standards Office that it would be desirable for it to form an integral part of it. The Office already controls the testing of engines with a dynamometer car, and collaborates with the Government Test House and with the Metallurgical Inspectorate on various matters.

The details of such an organisation must be left to the Government of India; we can only generally recommend that its aim should be permanency of record, continuity of staff and work, and co-ordination with other Technical, Scientific and Research Departments in the country, in order to avoid waste of effort in covering the same ground. Care will have to be taken in the choice of staff; only workers with the necessary inclination, temperament, and training are likely to be suitable, and the number and type should be adequate. Suitable publicity should be given to such work, to stimulate interest among the Railways and to enlist popular support; this is an essential factor to success in the changing conditions in India. The Technical Bulletin issued by the Railway Board might well be enlarged, and its scope extended to embrace work of this kind; although it is not an official publication, it should in time become a useful mouthpiece of the Research Organisation.

We hope that, before long, the Board will find it possible to include a Member (Technical), who should have under his control the Directors for Civil and Mechanical Engineering, and a Director in charge of an enlarged Research and Standards Organisation. These Directors should be adequately assisted by deputies and technical assistants. We feel that suitable officers should be forthcoming from the existing Railway Cadre. It would

27A. Revue Générale des Chemins de Fer, March 1939.

be the duty of this Organisation to initiate research, to be carried out either by individual Administrations, or by the Board itself, as may be found most suitable. Of equal importance to the initiation of research is the following up and development of the work, and the staff should be adequate to cover this latter phase. On the Development side, it is essential that any work which may be allocated to Administrations should be independently supervised by observers sent from the Board to co-ordinate results, and to ensure that full advantage is obtained from what is being done.

In this connection, there should be the closest association between the technical sections of the Board, the Research and Standards Organisation, and the Chief Mechanical and Civil Engineers of the various Railway Administrations. For instance, when some trouble, such as defective tube plates, is brought to notice, one of the Administrations should be nominated to report for all Railways. The Chief Mechanical Engineer concerned should send out questionnaires to ascertain the experience of other Railways, and their suggestions as to how the problem can be met; thereafter, the nominated officer should report to the Board. Research and experiment may then be initiated, to be carried out by the reporting Chief Mechanical Engineer on his own Railway, in close contact with the Research and Standards Organisation; the results, after suitable development, would then be available for all Railways.

157. *Finance*.—We appreciate that at the present time difficulties may be experienced in financing Research and Development; it has even been suggested to us that this should not be a charge against ordinary budget. We consider that budgets should be confined to definite allocation of expenditure for regular maintenance, and that the cost of any research undertaken with the authority of the Board should be kept separate. A special order number should be issued to which all the work in the latter category should be charged. If this is done, not only will the Finance Department know the cost of all research work going on at any given time, but there will be a sound basis for estimating the cost of any recommendation for a resulting alteration applicable to all Railways. Administrations can then in turn include in their estimates a definite sum of money for carrying out the necessary alterations concerned on their Railway.

The continuity and prompt performance of research work is so important that we strongly recommend that a definite annual grant be allocated to cover the expenditure, and that a separate Report should be prepared annually by the Research and Standards Section. Similar reports in England are regarded as of great importance. It should be realised that research is, by its very nature, incapable of showing immediate financial results in all cases. It is often necessary to make lengthy investigations into certain problems before it can be definitely ascertained that a return will be forthcoming; it is also inevitable that sometimes there will be negative results. It is, therefore, not always possible to demonstrate in advance what results are likely to be obtained, and it is essential that a long view should be taken.

It should be made possible to allocate increased expenditure, and to select and depute additional staff in consultation with the Administration concerned, if any investigation shows promise of success. Indeed, this may be so important that the Railways may actually be losing money while being deprived of the benefit of a particular improvement. Again, money savings, although important, are not the sole criterion. Safety and reliability are of equal, if not greater, importance, and research which enhances these makes for public confidence and in the long run works for the benefit of the Railways. Mistakes are doubtless inevitable in scientific investigation, but discouragement, which is apt to arise from uninformed criticism, should be avoided so long as good results, in the majority of cases, are being obtained from the experimental work. The importance of a bolder policy in this respect has already been emphasised both by the Pope and Wedgwood (Indian Railway Enquiry) Committees.

With regard to the subject matter of this Report, our recommendations relating to improvement in the riding qualities of X class Pacific engines cannot be implemented without a continuance of the research which has already been so ably commenced. Although there is little likelihood of immediate return in revenue, definite knowledge and measurement are being substituted for rule of thumb, and the resulting standard of safety should be considerably enhanced. In the wider field, experience all over the world proves that progressive continuance of savings can only be ensured by invoking the aid of science to an increasing degree. This is of the utmost importance to India, to assist her in attaining self-sufficiency.

CHAPTER VIII.

TERMS OF REFERENCE NOS. 1, 2 AND 3.

1. *The suitability of the XA, XB and XC designs as originally framed, and as subsequently modified, for the type of work for which the engines were intended.*

158. *The suitability of the original Design as a Power Unit.*—First, we will deal with the suitability of the designs as originally framed; this can be divided under two heads, the designs as power units and the designs as vehicles.

As power units, the engines appear to have been justified, and the selection of the Pacific wheel arrangement was a logical development from the conditions laid down. Two of the items in the remit from the Railway Board to the Locomotive Standards Committee in 1924 were:—

(*g*) adequate boiler power;

(*h*) largely increased grate areas to permit the more extended use of inferior coals.

The considerations leading up to these requirements have already been dealt with in Chapter II. In these circumstances, the Locomotive Standards Committee had justification in adopting the Pacific type, because it has a suitable wheel arrangement on which a boiler of "adequate power" can be mounted, having a grate area sufficient to burn low grade fuel containing a high percentage of ash.

159. *Firebox Width.*—It has been suggested that these requirements could have been met by engines of the 4-6-0 type, since the Indian gauge allows a wider grate to be placed between the frames than is possible on Railways with 4 ft. 8½ in. gauge. Some reflection, however, will show that this is not free from difficulty. The XA class has a grate area of 32 sq. ft. and it is true to say that a grate of this size can be acconmmodated inside the frames without undue length, so that a 4-6-0 type engine can carry a grate of this size. Indeed, the B. E. S. A. standard 4-6-0 type engines have a grate area of 32 sq. ft., but their axle load is 17½ tons. The XA type was intended for use on lightly laid branch lines and has an axle load of 13 tons. It would be impracticable to provide 32 sq. ft., of grate area on a broad gauge 4-6-0 type engine having an axle load of only 13 tons, without so reducing the boiler size as to make it entirely inadequate for the sustained tractive effort required. In order to provide "adequate boiler power", therefore, a trailing truck to carry some of the weight was essential.

With regard to the XB and XC engines, grate areas of 45 and 51 sq. ft., if provided inside the frames, would require lengths of grate of 10 ft. 0 in. and 12 ft. 6 in. respectively. These lengths were no doubt considered to be too long for efficient firing, and, indeed, they are longer than those employed in England. Hence the necessity for widening the grate beyond the frames, which, in turn generally calls for the firebox to be behind the coupled wheels with a trailing truck to carry its weight.

160. *Grate Area.*—Some criticism has also been made that the grate areas chosen were too large, but our observations do not confirm this. Where the size of the grate was particularly criticised, it was found that this arose because coal consumption was high. This, however, depends on other things besides grate area. Pacific class engines in England with a 50 sq. ft. grate can, with light high-speed trains, burn as little as 30 lbs. of coal per mile; even allowing for the difference in quality of coal, it cannot be said that a large grate area of itself is wasteful of fuel. Having regard to the quantity of ash present in Indian coals, 15 per cent. to 20 per cent., we are of the opinion that generally the grate areas of XB and XC type engines are suitable for their working conditions, *viz.*, the haulage of heavy express passenger trains, in some places over severe gradients.

161. *Wheel Arrangement.*—The choice of the Pacific wheel arrangement was, therefore, logical, and there is nothing in this choice which conflicts with good modern practice. This type of engine has been running in the U. S. A. since 1904, and has been the standard passenger type in that country until quite recently, when a trailing bogie was introduced to carry the still larger grate areas being called for. In France there were no less than 500 Pacifics in use before the War, and the type has multiplied since; some 1,300 are now in service. In Germany, Italy, Poland and other European countries, it is a standard type for heavy passenger traffic, as in South Africa, South America and Japan. In fact, the Pacific is the most widely adopted passenger type in the world, and no criticism can justly be levelled at its employment in India on appropriate services.

With few exceptions, the representatives of the Administrations visited informed us that X class Pacific engines were useful to them as traction machines and filled a definite need. They certainly had, in varying degrees, been exasperated at the mechanical defects which had been encountered, and the general consensus of opinion with regard to the XB class was that in its present form it gives so much trouble that the 4-6-0 type is to be preferred, although the latter may not have the same capacity for peak conditions, low grade fuel etc. But few were found to say that engines of the capacity of the XB and XC classes were not required when loads exceeded 9 bogie vehicles, whilst the usefulness of XA engines, for both branch and main line work, was generally acknowledged.

162. *The Suitability of the Original Designs as Vehicles.*—With regard to the original designs, from the point of view of the riding qualities of the engines as vehicles, we consider that they were not suitable for high-speed service, as they were over-sensitive to certain conditions of track and engine maintenance prevailing in India. In our opinion, the selected types of bogie, hind truck, and coupling between engine and tender, were unsuitable, and the amount of side control provided was inadequate.

163. *The Bogie.*—No particular type of bogie was specified in the Reports of the Locomotive Standards Committee, nor was anything said about the amount of side control. It was only, therefore, when the detailed designs were being prepared by the Builders, under the supervision of the Consulting Engineers, that the question of the type and design of the bogie came into prominence. The B. E. S. A. 4-6-0 engines, and the earlier 4-4-0 engines before them were, from the outset, equipped with a type of bogie having two small side control springs, working independently, and enclosed in buffer plungers on either side of the bogie centre casting. This design of bogie has been used on British Railways on older and small engines, for instance, certain 4-4-0 types, and, while the side control is severely limited by the nature of the arrangement, it has always given satisfactory results on the engines to which it has been applied. In India, in the case of the B. E. S. A. 4-6-0 type, it has also proved itself to have been satisfactory from the point of view of track disturbances.

None the less, as some trouble with hot boxes had been experienced, the Railway Board, in correspondence in 1926, expressed their disapproval of this particular type of bogie for X class engines. They stated that they preferred one of swing link type, which was in use on the only Pacific engines, in England, then operating on the L. & N. E. R., and had, up to that time, been widely used abroad. For seven months the matter was the subject of corespondence between the Board, the Consulting Engineers and the Builders; but in March 1927, it was finally decided to adopt the design which existed on the B. E. S. A. 4-6-0 type engines. The objections raised were countered by the desire to retain something which was standard for the B. E. S. A. engines, and was well known and tried; moreover, this type of bogie had been provided on the four experimental Pacifics on the B., B. & C. I. R., and on the E. I. R. Accordingly, the X class Pacifics were constructed with bogies of generally similar design and with the same control springs.

It has been indicated in Chapter III that if a spring having 15 cwts. initial compression was suitable for a 4-6-0 type engine weighing 67 tons, an initial control of 5 tons was necessary to obtain comparable centring forces on a 4-6-2 type engine weighing 90 tons. It follows that the provision of only 15 cwts. initial side control on the X class Pacifics was quite inadequate. We desire, however, to point out that when this design was being prepared, 12 years ago, much less was known than is known today about the action of locomotives as vehicles on the track.

Although it is easy to be wise after the event, it will be seen from Chapter VII that reliable information in this respect was not really available to designers and builders until 1934. Indeed, with such information as existed, which, mainly coming from abroad, was of conflicting character, it seems unlikely that the design was looked upon in England at the time as anything but conventional and orthodox. At the same time, we cannot but express surprise that it was at least not deemed prudent to provide engines of this character—particularly after the Railway Board's suggestion—with a bogie of such design that the controls could be altered to suit prevailing track conditions in India. Even when defects became apparent, as disclosed by the correspondence and opinions expressed in India as early as 1929, no serious attempt seems to have been made to modify the design of the bogie to enable springs of much larger capacity to be fitted.

164. *The Hind Truck.*—This was of the radial type with Cartazzi slides; it obtains side control from lubricated inclined planes, and was copied from that in successful use on the L. & N. E. R. Pacific engines, which have a world-wide reputation for high-speed running. In their case, however, they have the advantage of operating over excellent permanent way and in conjunction with a swing link bogie. On the other hand, this form of hind truck is little used, in conjunction with spring controlled bogies, on Pacifics elsewhere, and, under certain prevailing conditions of track and engine maintenance, it is now generally accepted in India that the design is unsuitable. We agree with this, and, from the investigations which we have made, we certainly consider that the arrangement should not be perpetuated.

165. *Coupling between Engine and Tender.*—The "Goodall" coupling permitted of the utmost freedom of movement between engine and tender, and was expensive to maintain under conditions in India; moreover, it did not enable the tender to assist in controlling the engine, which itself lacked effective control. While no engine should have to depend on being tied to its tender to make it run steadily, some other type of coupling, which uses the mass of the tender for this purpose, would have been preferable. A measure of rotational control on the bogies (where used) of the tender would also have promoted steadiness in running.

166. *Realisation of Defective Design.*—We examined the characteristics of the bogie and hind truck controls of the first four experimental Pacifics on the E. I. R. and the B., B. & C. I. R.; we find that the original X class Pacifics were almost identical in this respect. The XB and XC engines, however, are somewhat heavier than the comparable experimental engines, and their moments of inertia are greater. We consider that this may account for the fact that they have given more trouble, though we understand that no investigation has been made of the displacements and flange forces relating to the four earlier engines. Our recommendations, however, should be applied to them also.

Although there is no doubt today with regard to the extent of the defects, as described above, we are satisfied that all concerned had confidence in the suitability of the engines at the time they were built. After they were put into service, however little doubt can have been left in the minds of those operating the engines that the design required modification. On each of the eight Administrations to which the engines had been sent, there is correspondence to show that, without exception, abnormal oscillation occurred, and in many cases it was accompanied by track spreading or distortion to a greater or less extent, as set out in Chapter II. Having regard to the fact that the 18 M class engines on the B. N. R. had also been provided with I. R. S. bogies and hind trucks, this Administration may be included as one where track was also affected.

The first X class Pacific engines were delivered in January 1928 to the E. I. R.; in May the same year, the first report was received of undue oscillation, and, in June, of track distortion. In undertaking widespread experiments later, the Railway Board may be said to have recognised that there were defects to be remedied. The engines were, therefore, not suitable as vehicles for high speed operation.

167. *Variability in behaviour*.—It is necessary here to refer to a feature which from the beginning was of a particularly baffling nature, *viz.*, the variability in the behaviour of the engines in different localities, or even of the same engine at various times in the same locality. It was this more than anything which retarded the finding of a lasting solution, and which more than once gave the impression in the last 10 years that the trouble was solved, only for it to break out again in another place or in different circumstances. In the light of present knowledge, however, a rational explanation of this may be attempted.

The engines were what might be termed border line cases. The degree of side control provided was not of such a value that all the engines hunted all the time. Its value was such that if the bogie and engine generally were maintained in good order, and if the track was rigid and in good line and level, an engine might run satisfactorily for long periods. On the other hand, because of the border line nature of the engines as designed, they were extraordinarily sensitive to track irregularities; although track might appear satisfactory when examined in the usual way, it may, when the load is applied, provide differences in gauge and level sufficient to initiate hunting as was proved by experiment on the B., B. & C. I. R.

Moreover, there are certain features in the design of the bogie which can materially vary the degree of control provided, without it being possible to observe this by external examination. First, the control springs, being of small capacity and totally enclosed, can break or lose strength; as they act independently, in equalizing compression on both sides, they would maintain the pin out of centre. Secondly, the way in which the springs are mounted allows a varying amount of movement on each side of the centre; one spring may act against the other, and the effective initial control may be practically nil. Thirdly, the large metal to metal surfaces of the bogie slides are particularly difficult to lubricate and keep clean; the friction of the bogie slides, and consequently the degree of control, may vary widely on the same engine, depending on whether the surfaces are smooth, lineable and perfectly lubricated, or whether they are dry, scored, and on the point of seizing. We have seen slides in both categories and in various intermediate stages; we are satisfied that these considerations alone are sufficient to account for the varying reports which have been constantly received about the engines as originally built. Our detailed criticisms with regard to the design of the bogie, from the constructional point of view, are given later.

168. *The Suitability of the Engines as Modified*.—Between March 1929 and March 1938, 28 major modifications were tried, which may be divided into two sections, *viz.*, those tried before there were any means of measuring accurately the effect in terms of flange forces, and those made after such means were available. The following is a list of the modifications made in the former category :—

(1) 1929-30 .	Increase in initial side control with existing bogie design from 15 cwts. to 22·6 cwts., and subsequently to 24, 31 and 34 cwts.
(2) 1930-32 .	Alteration in inclination of Cartazzi slides on hind truck from 1 in 10·25 to 1 in 7, 1 in 5, and 1 in 20 ; finally flat oil lubricated slides were also tried.
(3) 1930-32 .	Setting back of hind truck by distances up to 2 ft. 6 in.
(4) 1930 . .	Compensation eliminated between leading and driving wheels.
(5) 1931 . .	Ballasting front and then back end of engine to find effect of altering position of centre of gravity.
(6) 1930 . .	Cartazzi slides on bogie.

(7) 1931 . . Goodall drawbar replaced by American type drawgear with side buffers.

(8) 1932 . . Axlebox horncheeks bevelled top and bottom.

(9) 1931 . . Hydraulic dampers on bogie slides.

(10) 1931 . . Ferodo disc liners on bogie pivot.

(11) 1932 . . Bogie with laminated spring control. Initial control variable from 2½ to 4 tons.

(12) 1934 . . Flat hind truck slides faced with Ferodo.

It will be seen that the very first modification was in the right direction, *viz.*, the increasing of the bogie side control. But the design of bogie was so unsuitable that it was possible to obtain only a trifling increase in the value of the control within the existing design, and, in view of the small increases in value attempted, no clear lead emerged that this was the right direction in which to proceed. Even when the radical step was taken in 1932 of trying out a completely new bogie with side bearers, and laminated springs having 4 tons initial control, the lead which this should have given was masked by the unsatisfactory nature of the Cartazzi hind truck.

Because of the difficulty and cost of reconstructing the back end of the engine to take a spring-controlled pony truck, the radial box with Cartazzi control was persisted in, and several variations in the inclination of the slides were tried. The setting back of the trailing wheels, which was another major modification, had actually an adverse influence on curves, and, in these circumstances, the already weak effect of the bogie side control was still further weakened. This effect, however, was only slight.

To sum up, the modifications introduced during this period had little effect. Some of them were in the right direction, but were not co-ordinated. For example, an engine fitted with modifications Nos. 7, 8, 10, 11 and 12 simultaneously, had its initial bogie control not been below 4 tons, would have contained the substance of the recommendations which we are now making, and should have proved satisfactory in running. But the proper combination of the different alterations was not understood, and, in consequence, no clear indication emerged as to what was to be done; their effect could be evaluated in no better way than by the personal impression gained when riding on the footplate on various occasions, without regard to time and place, and this can be very misleading. Even as modified in this period, the engines could not be said to be satisfactory as carriages for high speed.

169. *Later modifications.*—As soon as means became available for taking records of bogie and axle displacements, and further, of making accurate records of flange forces, it became possible to obtain a picture of what was happening and to pursue a logical course. The development and nature of these means, worked out independently both by the Chief Mechanical Engineer of the B., B. & C. I. R., and by the Railway Board, have been described in Chapter VII.

It began to be clear that material reductions in the amplitude of nosing were obtainable mainly by the application of friction material to the bogie and hind truck slides, and by providing some degree of steadying force between engine and tender by means of an adaptation of the German buffing gear. Up to the time of our arrival in India, therefore, the final modifications recommended by the Railway Board, supported by nearly 100 tests carried out by their Research Officers, as well as by oscillograph tests carried out on the B., B. & C. I. R., were as follows :—

(1) Bogie pivots and slides to have friction liners.

(2) Original control springs to be used with packing plates, in order to give 22 cwt. initial compression, with a final load of 50 cwt.

(3) Cartazzi inclined slides to be removed, and replaced by flat slides having a Ferodo face.

(4) German type buffing gear to be fitted between engine and tender; either the "Goodall" or American type drawbar to be used.

170. *Summary of Performance of Engines as finally modified by the Railway Board.*—We rode at high speeds (maximum 80 m.p.h.) on eight different engines of the three classes which had been fully modified in accordance with the recommendations referred to above; we also examined all the graphs of the tests which had been made. The improvement in riding was marked, and in no case did we experience material oscillation or hunting. Examination of the test charts also indicated that this problem had apparently been solved in respect of straight track, and that flange forces had been reduced to moderate values.

With regard to curved track, however, examination of these charts confirmed what has been indicated in Chapters III and VII, namely, that the application of high friction, with a low centring force does not reduce the coupled wheel flange forces on curved track. Indeed, the records taken on curved track, with fully modified engines, revealed a tendency to high flange forces on the coupled wheels, at least equal to the highest attained with unmodified engines on the straight.

We are of opinion that the tests carried out confirm that it is necessary to provide adequate control on the carrying wheels of an engine, in order to keep the flange forces within reasonable limits. They also indicate that whereas a control, in which friction plays the principal part, may accomplish this on straight track, very high flange forces can still be attained on curves, although the riding of the engine may appear steady and smooth to the footplate observer. So long as this is the case, the possibility of track distortion or derailment cannot be dismissed. The engines, therefore, even if modified in the manner described, would not appear to be suitable for unrestricted running in the type of work for which they were designed and over the tracks of the country in which they must travel.

Other modifications are evidently required, which will be discussed later.

2. *The suitability of the procedure followed in preparing and approving the designs for these engines.*

171. *Preparation of designs.*—The procedure followed in preparing the designs has been fully described in Chapter II, but it would be well to summarise the sequence of events. The Railway Board's policy of Standardisation, to which there had apparently been some opposition until 1923, was brought up again about that time, and was finally accepted by the Locomotive and Carriage Superintendents' Committee, and supported by the Indian Railway Conference Association. Various aspects of the question are dealt with later in this Chapter.

The requirements of future locomotive power for Railways in India were laid down by the Board in 1923, and are given in detail in paragraph 26 of Chapter II. It thus became essential for the Board to set up a Technical Committee to prepare the necessary specifications and particulars of the classes of engines required. This constituted a departure from the practice, which had been adhered to for many years, of allowing individual Administrations to make their own arrangements within the limits of the B. E. S. A. standards, in direct communication with Consulting Engineers.

In making this change, the Board probably anticipated the addition in 1925 of the E. I. R. and the G. I. P. R. to the State-managed systems, which up to that time comprised only the N. W. R., the E. B. R., and the O. & R. R. After 1925, the Board had complete control of the largest Railways in India, and in our view the initiation of new standards was a necessary and prudent measure. Further, in the case of Company-managed systems, the Board exercised in no small measure a general financial control. It followed, therefore, that all Administrations were expected generally to conform with the prescribed standards, so far as was practicable.

172. *First and Second Reports of the Locomotive Standards Committee.*—The duty of this Committee was to "*prepare diagrams and general specifications for new types of engines required on Broad and Metre Gauge systems*". The first steps taken were to send out a questionnaire, to visit

each Administration, and to consult with the Chief Mechanical Engineers. The First Report was prepared on the information thus obtained and was published in May 1924; this contained the Committee's tentative specifications for new types of standard engines, which had been drawn up to conform with the Railway Board's instructions and to try and meet the views expressed by the various Administrations. This Report was circulated to all Administrations, and their remarks were invited. No notes of the discussions with the Railways have been preserved, and this seems regrettable, particularly as the matters under discussion must have been of considerable importance; further, it is difficult now to say to what extent the diagrams and specifications in the Report represented the combined opinion of the Chief Mechanical Engineers.

The Consulting Engineers were asked to prepare the necessary drawings and specifications, in consultation with the British Engineering Standards Association and with Manufacturers; the Consulting Engineers informed us that they considered this matter so important that they deputed a partner to visit India in the winter of 1924-25 to discuss it with the Locomotive Standards Committee, the individual Railways, and the Railway Board, and to obtain general information with regard to requirements. Many alterations in the original specifications resulted from these discussions, and were included in a Second Report by the Locomotive Standards Committee in March 1925.

This Second Report was not circulated to the Railways for comment, and they were merely asked to report which types of new engines they could best utilise; but, so far as we could ascertain, with the exception of the B., B. & C. I. R. (who suggested deferring the design of the new Pacifics, pending further experience with the two experimental engines which had then been running for a few months), no Administration appears to have criticised the proposals, and, in any case, no question was raised as to the advisability of introducing Pacific type engines. On the other hand, it is difficult to resist the conclusions (a) that the Administrations were not as fully consulted on the final proposals as they should have been, and (b) that the business of Standardisation was concentrated in the hands of too small a Committee, which did not adequately represent mechanical engineering opinion on the Railways of India.

Up to this point, it appears that the Railway Board decided for themselves the outlines and preliminary specifications for the new types of locomotive, and the matter was then referred to the Consulting Engineers in London who had been regularly dealing with previous locomotive design work for the Indian Government Railways. Our only criticism, therefore, at this stage of design is to the effect that the Railways were not given an opportunity to comment on the final proposals put forward in the Second Report; but, in fairness to the Board, with regard to the issue in question, it must be repeated that the design of the engines *as vehicles* was hardly mentioned in that Report.

The next stage in the procedure may be divided into two parts. First, there was the invitation to the Builders of the experimental P. & P. S. class Pacifics for the B., B. & C. I. R. and E. I. R. respectively, to prepare preliminary drawings amplifying the engine diagrams supplied by the Railway Board; secondly, there was the procedure after these preliminary drawing had been taken to India by one of the partners of the Consulting Engineers at the end of 1924. These matters have been described chronologically in Chapter II, and, as regards the first, it must be remembered that at this time (early 1924) the experimental engines had not been delivered in India, so there was no assurance that a satisfactory design was being followed. On the other hand, there was no reason at the time to suspect that the designs were in any way defective. Since the required dimensions of the new XB and XC classes corresponded fairly closely with the PS and P classes respectively, adherence to these designs was to be expected. After, therefore, the partner of the Consulting Engineers had returned to England, and the modifications agreed on with the Board had been embodied in the 1925 Report of the Locomotive Standards Committee, the Consulting Engineers themselves prepared the necessary final drawings for tendering.

173. *Preliminary and Completed Drawings.*—The Consulting Engineers informed us that the drawings for tendering purposes were only carried sufficiently far to obtain reliable competitive quotations, and that the contract conditions provided for their approval of detail drawings, which were to be prepared by the Builders during the course of constructions, with *as-made* sets of drawings for use in connection with repetition orders. The Consulting Engineers gave us every facility for examining typical sets of drawings in the various stages concerned. They informed us that they consider it to be no part of their functions to prepare detail drawings, but prefer to draw on the experience of Locomotive Builders, who are in constant practical touch with manufacturing methods. They undertake the duty of scrutinising and checking these drawings, in the light of their general experience of locomotive design throughout the world. We are satisfied that this procedure was sound in principle. On the other hand, from the evidence before us, we have gathered the impression that, on account of the divided responsibility between the Builders and the Consulting Engineers, there was a possibility that certain details of design were not given sufficient consideration, owing to some feeling that each party considered the other primarily responsible for what should be done.

Further, with regard to the approval of completed drawings, attention is drawn to paragraph 34, Chapter II, and to the part played by the Railway Board's representative in the Consulting Engineers' office. In view of the long time taken in those days for correspondence between England and India, we consider that the original proposal, by which all drawings were to have been submitted to India for approval, was impracticable, however desirable it may have been; the procedure adopted was in our opinion a business like arrangement. It had the result, however, of placing upon the Consulting Engineers a degree of divided responsibility in the preparation of the designs, in view of the presence of a representative of the Railway Board in their offices; but they assured us that the collaboration was helpful, friendly and satisfactory to all parties concerned, and it appears to have been the only practicable course between considerable delay on the one hand, and India having had no share in the development of the design on the other. We therefore make no criticism of the procedure up to this point. The shortcomings in the X Class Pacifics as delivered to India were shortcomings of design only.

We questioned the Consulting Engineers and Builders at some length on the origin of the particular features of design which have since proved defective; apparently, the situation simply was that the importance of the degree of side control, and the limitation of lateral wear, were not then appreciated as they are to-day. As pointed out in Chapter II paragraph 35, out of 57 recommendations contained in the 1924 Report of the Locomotive Standards Committee, and 18 further recommendations in their 1925 Report, none had any direct bearing on these subjects. Again, in all the correspondence which subsequently passed (during a period of 7 months) concerning the design of the bogie, the arguments related to the type of bogie, for example, as between slide and swing link; but we find no reference to values of side control. The same applied to the correspondence relating to the hind trucks. Moreover, we have been unable to find evidence in the technical press, that degree of side control was considered at that time to be a matter of first importance. Chapter VII shows how inconclusive the results of investigation all over the world had been even up to 1934. It is true that trials had been carried out, but decisive recommendations had not been formulated. We are of the opinion that there was no failure on the part of the Consulting Engineers to solve a problem; it was a case of lack of appreciation that a problem existed.

174. *The trial before purchase policy.*—Further comments appear to be necessary on the relations of the Consulting Engineers with the trial before purchase policy, and with the subsequent behaviour of the engines. While these matters are fully dealt with later in this Chapter, certain aspects of them concern design.

The original proposals clearly envisaged the building of two engines of each type for each Administration which required them, and these engines were to be thoroughly tried out for at least two years. This was prudent and coincided with the Board's earlier policy in connection with the purchase of the six preliminary Pacifics for the B., B. & C. I. R., E. I. R., and M. & S. M. R. It was the intention that during the trial period of the X class Pacifics, careful records should be maintained of running and maintenance costs, and these, together with any recommendations for such modifications as might be necessary, were to be submitted to the Locomotive Standards Committee; this pooled experience was then to be considered, and the resulting modifications incorporated in the final design, for the approval of the Railway Board, before large orders for new types were placed. But for various reasons, no records of running and of maintenance costs were kept, and, unfortunately, the Board's policy of trial before extended purchase was abandoned.

As already stated, it would appear that the design of the X class Pacifics was largely based on that of the first four British built Pacifics. In the case of these latter engines, the Board had refused to allow the Railways concerned to purchase more than two pending thorough trial for at least a year. In view of this, there appears to be a strange inconsistency on the part of the Board in framing diagrams and specifications for yet a further type of Pacific following generally the lines of an experimental engine, the performance of which, up to that time, was an unknown quantity. Even if, as is claimed, the need for the new engines was urgent, we cannot but think that the preparation of the diagrams and specifications displayed some degree of incautious precipitancy.

175. *Demi-official Correspondence.*—There is another point, which we think is open to criticism. We have said in Chapter II that much of the correspondence to which we have referred was of a demi-official character; and some of this was not confined to details of design, but touched on important matters of policy, as will be shown later in this Chapter. While we do not suppose that the points dealt with in such letters were treated less formally than they would have been had the communications been official, we cannot help thinking that, had the correspondence been official, the decisions given would have been reached on a wider basis of responsibility.

176. *Reconsideration of design.*—There remains the question as to why the troubles experienced with the first engines did not require a reconsideration of the design of the subsequent batches. Apart from the long delay on the part of the Indian Authorities to recognise the nature of the problem, the Consulting Engineers have pointed out that it was no part of their functions to follow up of their own initiative the behaviour of the engines in service. India had a large and experienced staff already engaged in the operation of the locomotives, and the Consulting Engineers could only investigate defective running, either by information supplied by the Railway Board, or by themselves sending out representatives unasked.

In the former case, there are certain inconsistencies. On the one hand, the Consulting Engineers were supplied from India with voluminous demi-official correspondence dealing with points which had been found defective on the engines, with a view to modifications being incorporated in later designs. On the other hand, the information received does not appear to have assisted them in arriving at a real solution of the troubles. Indeed, this could hardly have been expected, since, as already pointed out, the Board themselves had no clear lead as to the nature of the problem prior to 1935.

The role of the Consulting Engineers, therefore, after delivery of the first engines has, in practice, been confined to incorporating in subsequent orders such modifications as were requested from India; although it is true that they were generally kept informed and so became possessed of many of the facts, they do not appear to have been called in to formal consultation on this difficult problem. Had they been asked to examine and report on this matter, it would have been necessary, in our opinion, for them to send a deputation to India. As late as 1932, when they offered their services to advise the Railway Board with regard to oscillation, they were informed that if a solution could not be found in India, the offer would be accepted; the offer was not made use of, and there was little further correspondence on the subject of hunting after 1934, by which time it appears that reports of complaints had more or less ceased. We cannot help feeling, however, that the Consulting Engineers should have realised earlier, from the information being received from India, that there was a problem to be solved in connection with the riding of these engines; we are of opinion that, with their world-wide contacts, they should have been able to obtain a valuable lead from the experience of other countries.

177. *Relationship with the British Engineering Standards Association.*—In Chapter II it was pointed out that the Consulting Engineers were to prepare working drawings in consultation with the Association, and we have endeavoured to ascertain what contribution the Association made to the designs of the engines. Neither in India nor in England have we been able to trace that the Association was consulted step by step during the evolution of the designs, as appears to have been the original intention; but we have been shown certain unconfirmed minutes of an informal meeting of the Locomotive Conference of the Association, held just before one of the partners of the Consulting Engineers visited India in the cold weather of 1924-25.

This meeting was convened, apparently, with the object of discussing the First Report of the Locomotive Standards Committee, of May 1924, and no comments were raised which could materially have affected the riding of these engines as vehicles. There is also on record the Note, (Appendix V), addressed to the Railway Board by the partner of the Consulting Engineers who visited India in 1924-25, which explains the functions and valuable services of the Association to Indian Railways. He sent a copy of this Note to the Association; but though no further meetings were held to consider the design, we can find no evidence that this had any effect on the particular questions with which we are concerned.

178. *Suitability of Procedure.*—The Consulting Engineers were responsible for the work outside India, in connection with the design and construction of the engines in question. The Railway Board, who prepared the original outline sketches and specifications, and the Builders concerned, also shared in the design. The whole responsibility, however, for the operation and maintenance of the engines was borne by India.

The merits of the problem must be gauged by the standard of locomotive design existing at the time, and not in the light of present day experience. The advance which has taken place during the subsequent 12 years, and the knowledge gained by the behaviour of these locomotives under widely varying conditions, have indicated the need for radical alterations.

In connection with a procedure which follows from the obtaining of engines from another country, Consulting Engineers employed to develop the design may be expected to assume a certain standard of maintenance of track and engines. Modification of design to suit local conditions can best be done progressively, and the fewer the engines to be dealt with the easier this becomes. The Railway Board, by their decision to purchase large numbers of engines of a new type, took the risk that the new designs would fulfil requirements on the many differing conditions of track in India.

The Board had decided on Standardisation, and had outlined the types of engines; they had specified their many features, and had collaborated in, and approved in some detail, the work done by the Consulting Engineers in London when developing the design. The Board were responsible for the testing, operation, and maintenance of the engines, and, what is just as important, for the maintenance of the track on which they ran. Had the engines proved to be an unqualified success, due credit would rightly have belonged to the Board; and they must, we feel, equally accept a full share of responsibility for the troubles which ensued.

So far as the procedure was concerned between India and England in dealing with the design and manufacture of these engines, it appears to have conformed generally to accepted practice in the supply of engines to other countries. Moreover, we are satisfied that the Consulting Engineers impressed upon the Board the desirability of adhering to a cautious policy of thorough trial before commitment to extended purchase. The trials could only have been made in India, and the Consulting Engineers were entirely dependent upon the Board for information thus obtained.

179. *Summary.*—Our views on the suitability of the procedure followed are summarised below :—

(1) The procedure, though modified from previous standards, was sound and practical, but involved divided responsibility.

(2) The various Railways in India were not so fully consulted as they should have been in the preparation of the new designs; but there was generally no criticism of the designs from that source.

(3) The original intention to obtain the collaboration of the B. E. S. A. in preparation of the designs was not entirely fulfilled; but we consider that this had no bearing on what followed.

(4) The preparation of drawings and specifications for the X class Pacifics should have awaited more definite results of the performance of the six preliminary Pacifics.

(5) The Consulting Engineers failed to appreciate the importance of correct side control, the responsibility for which they share with the Railway Board.

(6) The Consulting Engineers should have been able to obtain a valuable lead from the experience of other countries.

(7) The Consulting Engineers were not asked formally to collaborate in solving the problem of oscillation, but they were generally kept informed.

(8) While the closest contact between India and London is highly desirable, and may well be encouraged by demi-official correspondence, we consider that important decisions should not be taken by such communications.

3. *The circumstances attending, and the justification for, the initial and subsequent purchases of these engines.*

180. *Reasons for Purchase.*—In Chapter II, we have already described the circumstances leading up to the inception of the engines in question, and we need not repeat the facts here. It remains, however, to examine the Railway Board's reasons for introducing them, and for their continued purchase. We understand that they were threefold :—

1. Anticipation of greatly increased traffic;
2. Need for curtailing the fuel bill; and
3. Standardisation as a measure of economy.

181. *Anticipation of greatly increased Traffic.*—There is no doubt that the financial outlook when the engines were originally planned was very different from that obtaining during their first years of service. Their purchase should not be judged against the background of the economic depression, which began to be felt in 1930, but which no one in India foresaw when the idea of introducing the engines was first mooted. It is desirable to recapture, so far as we can, a fair impression of opinions and conditions prevailing at the time; for, what country in the world anticipated such a set-back in trade, and yet what country was so criticised for having so obsolete a railway machine as India by the Acworth Committee.

Besides the evidence of witness after witness before that Committee, prominent persons in commercial and industrial circles felt that a trade boom was then imminent, and that it was only held up by inadequate railway facilities. While optimism at that time was not peculiar to India as a country, it was certainly not the monopoly of the Railway Board. One firm of steel manufacturers alone informed the Acworth Committee that they contemplated giving the Railways a ton-mileage which would require over 7,000 wagons and 139 engines (28). Another group of firms, engaged in metallurgical and allied industries, anticipated that by 1926 their annual freight movement would have increased from two to fifteen millions of tons (29). It is also significant that even the Inchcape Committee did not recommend postponement of the Board's Rs. 150 crore programme, but suggested that capital allocated to unremunerative lines should be diverted to profitable projects (30).

To deal with the anticipated increase in goods traffic, it is perhaps not surprising that the Railways may have aimed at emulating the characteristics of other countries; heavier goods traffic was naturally expected to induce heavier passenger traffic, and the latter service was already deficient. The Agent of the E. I. R. informed the Acworth Committee that, though his passenger trains were overcrowded, he could not run more without reducing goods services (31). Hence, it seems that there were good reasons for thinking that, not only were new engines needed in large numbers, but that increased power was necessary to handle heavier trains. We were informed that higher maximum speeds were not the object in view.

It may also be noted that in the five years 1920-21 to 1924-25 the gross receipts for the State-owned Railways substantially increased from Rs. 80 to 100 crores. There was a slight set-back in the years 1925-26 and 1926-27, but recovery took place in the two following years; and though the year 1929-30 showed a slight drop compared with the previous year, earnings were still higher than in 1924-25, and it was not until 1930-31 that the serious decline commenced.

It appears that the demand for Rs. 30 crores included in the figures given to the Finance Committee of the Legislature contemplated an addition of some 600 locomotives each year for five years. The Board freely admit that, in the light of subsequent events, even 400 engines and 400 boilers per annum, given officially to the Indian Peninsular Locomotive Company as the anticipated requirements, was an overestimate. But, although the Board shared the general optimism and overestimated their requirements in common with many business firms at the time, they did not, having regard to the operating methods then in vogue, apparently commit the Railways to a stock of engines materially larger than was required. Though a sum of Rs. 30 crores was asked for, to be spent in the five years 1923-24 to 1927-28, there was actually spent in a period of fourteen years, from 1923 to 1937, less than Rs. 6 crores on capital account, and about Rs. 14½ crores on depreciation account.

Having regard to the foregoing facts, we are led to conclude that, in being unduly sanguine regarding the prospects of railway traffic, the Board merely shared feelings that were generally prevalent; in deciding to purchase modern powerful Pacific engines in large numbers, they were satisfied that this was the best type to handle the growing passenger traffic which was then expected. As already stated, we have no grounds for thinking that anything but efficiency of operation was the actuating motive.

Even with the traffic now offering on a number of the Indian Railways, the use of the Pacific type of engine is desirable. We were shown data on the E. I. R. relating to the operating difficulties which arose when express trains of over nine coaches had to be hauled by 4-6-0 B. E. S. A. type engines having 17 ton axle loading; it was said that the temporary withdrawal of XB and XC types from express service was detrimental to the efficient handling of the passenger traffic on this system. Similarly, such trains as the Karachi mail on the N. W. R., and the Frontier mail on the B., B. & C. I. R., cannot be satisfactorily worked with engines of 4-6-0 B. E. S. A. type.

(28) Acworth Committee Report, page 10.
(29) Acworth Committee Report, page 9.
(30) Inchcape Committee Report, page 77.
(31) Acworth Committee Report, page 8.

182. *Need of curtailing the Fuel Bill.*—No criticism can be raised against the Board's desire to reduce the fuel bill; indeed, it is much to their credit that they developed Railway collieries and acquired others with a view to reducing and stabilising coal prices. That this policy has succeeded is shown by the fact that control of prices and supply has been consistently effective since 1927.

The effect of the use of lower grade coal on engine design has already been discussed under Terms of Reference 1, and it has been shown why the Pacific wheel arrangement was adopted. But it is true that the burning of this fuel on 4-6-0 type engines has subsequently been found to be practicable, as, for instance, on the latest engines on the B. N. R., which are not of I. R. S. design, and have a 4-6-0 wheel arrangement with a tractive effort of 27,797 lbs. We understand that they adequately meet the needs of fast passenger traffic on that Railway, and, because a rocking grate is fitted, they are able to burn second grade coal efficiently on a grate area of 36 sq. ft.

So far as moderate power outputs were required, therefore, there does not appear to have been any urgent need for the Board to have introduced Pacifics in large numbers, as was pointed out by the Consulting Engineers in their letter quoted hereafter; but, here again, we hesitate to be critical after the event. Had traffic developed to the extent anticipated without adequate power to cope with it, the Board would have been rightly criticised for want of enterprise and foresight.

183. *Standardisation as a Measure of Economy.*—But, even allowing that the Railway Board's decision to acquire new and powerful engines was justified, in view of possible traffic developments, we still have to consider their policy of standardising such engines for all the State-owned Railways in India.

There are many sound general arguments for such a policy; but it is with the more practical effects that we are concerned. The Board informed us that since 1903-05, when the earliest efforts were directed towards Standardisation of locomotives, the Company-managed Railways had freedom of action in design; though they adopted the standards on general lines, they did not accept them in detail, and "*the advantages of complete Standardisation were not fully obtained*". If, however, there were material advantages in Standardisation, it might be assumed that the Company-managed Railways would have co-operated for their own benefit; but the fact that they did not support the policy to the full was less connected with any inherent disadvantage in Standardisation than with a natural reluctance to part with their own initiative in the matter of design. This is one of the reasons why it is never possible to obtain unanimity on this subject, and why some measure of compulsion is almost invariably necessary when such schemes are introduced.

We have already referred in Chapter II to the criticisms of a former Chief Mechanical Engineer of the B., B & C. I. R. (*vide* Appendix VI). In furnishing us with a copy of this note, the Board informed us that, so far as they could trace, it contained the only reasoned objections to their policy. But, although there may be no record of similar objections, we think, from what we heard, that this one Chief Mechanical Engineer was not alone in his opinion. If delays are to be avoided and decisive action is to be taken, it is certainly desirable that questions of design should be concentrated in the hands of a committee such as that appointed by the Railway Board; but it appears to be essential that the opinions and experience of those officers on the Railways, who are necessarily responsible for maintenance and safe running, should be given full weight. Most of the criticisms which we heard were obviously due to a feeling that there had been shortcomings in this respect.

Actually, up to the introduction of the I. R. S. locomotives, administrations diverged from standards according to their local needs, and, though the Locomotive and Carriage Superintendents' Committee of the Indian Railway Conference Association finally supported the policy in 1923, the same body was opposed to it in 1921. We have heard, too that some other Administrations considered that the Standardisation policy was much too rigid, particularly in respect of the small number of engine types which were available; further, that more adaptability was needed to meet the varying conditions on different Railways. But we are concerned not so much with opinions as with the practical effects of the Board's policy of fifteen years ago; it can, perhaps, be summarised as follows:—

(1) They were convinced that a large number of new and more powerful engines were needed;

(2) These engines had to be capable of burning low grade coal, to reduce the fuel bill.

(3) For reasons of economy, designs had to be standardised for all State-owned Railways; and

(4) Existing designs, which could not burn low grade coal, had to be treated as obsolete, and were not to be perpetuated.

Since the available number of new standard designs was very small, strict adherence to the above policy has resulted in certain Railways being equipped with locomotives of power in excess of requirements where density of traffic is less than the average. This arises, so far as passenger engines are concerned, from the big gap in capacity which was left between the XA and XB class Pacifics. There are Railways which appear to require engines of lesser capacity than the XB class; the Railway Board, in collaboration with the Consulting Engineers, have designed a new WL class Pacific with a 16 ton axle load, and four of these engines are now under construction for trial purposes. There may be other classes required to meet special traffic conditions, and the Board should accordingly give consideration to increasing the range of standards.

184. *Railway Board's change of Policy.*—In Chapter II statements are given showing dates and other details of the contracts of the 284 X class Pacific engines, the subject of our Inquiry, and these statements indicate that orders for the engines had been placed in quick succession. This being the case, the first point which naturally arises is that the Railway Board, for some reason or other, discarded their policy of trial before bulk purchase. They had notified the Railways in 1923 that only two engines of each type should be obtained for each system, and that exhaustive trials were to be made with these for at least two years before further orders were placed. The Consulting Engineers had also pointed out that a considerable period of running experience would be necessary to eliminate any defects which might develop in the first of the new standard engines.

The statements alluded to show that, although only two XA engines were originally authorised for the N. W. R., G. I. P. R., and E. I. R. in December 1925, no less than 20 were authorised only 22 months later, and further large orders followed annually for the next three years. But, as regards the XB engines, 28 were authorised for three Railways in December 1925, only nine months after the Locomotive Standards Committee had submitted their Second Report, and only about 18 months after the four experimental Pacific engines had been placed in service on the B., B. & C. I. R., and E. I. R. Moreover, by December 1925, the Board do not appear to have received any report on the performance of these engines, as the memorandum of the Chief Mechanical Engineer, B., B. & C. I. R. is dated January 1926. Even in the case of these engines the Board had prescribed at least a year's trial before further purchases were made, and yet they persisted in their precipitate policy, notwithstanding the protest from the Consulting Engineers, one of whose Partners wrote in May 1926 as follows:—

> *"I urge most strongly, that the Railway Board will not order more of these new types till the first have been made and tried out. This trying-out process has always been insisted on in the Railway Board's instructions, and should be adhered to. The first lots will take, in my opinion, a year to construct.*

Meanwhile, next year's programme will come on, and there will be a temptation to order more of the new untried types. This happened when the first Standard Locomotives were got out with unsatisfactory results to all concerned. The existing standard types (brought up to date to the Committee's requirements) will in most cases do, and do well, all the work required of them for the present.".

The relevant extract from the Railway Board's reply of June 1926 is as follows :—

"*The Board have considered your suggestion that no more orders should be placed for new Standard Locomotives until the trial engines have been tried out, but are unable to agree to placing any further orders for narrow firebox engines, which, in their opinion, are an obsolete type and should not be perpetuated. They are, therefore, of opinion that it would be preferable to order only wide firebox engines in future, but the demands will be reduced to an absolute minimum until such time that we have sufficient experience of the new trial engines to justify orders being placed.*"

It would appear that, in such circumstances, the Consulting Engineers could do no more than obey instructions; they had advised on the point as strongly as they could, and had received a reply giving reasons of policy for not ordering engines of the older type. And, although the Board intimated that demands for the engines would be reduced to a minimum pending thorough trial, the first bulk order had already been placed for 46 engines six months previously, and bulk orders followed in October 1927 for 20 XA, 24 XB, and 28 XC engines before any of those originally authorised had even arrived in the country.

Further, before these latter large purchases were authorised the Consulting Engineers had written to the Board in May 1927 as follows :—

"*At the same time, we would most strongly urge that no more orders should be placed for these New Standard Locomotives until the first lots have been completed and the actual detailed working drawings (which are far more numerous than have hitherto been attempted) are completed.*"

The Consulting Engineers referred again to the subject in August 1927, and the following is a relevant extract from their letter to the Board : —

"*Thanks for the advance copy of the proposed design of the XH 28 ton 2-8-2 4-cylinder locomotive, which we have also received officially through the High Commissioner. We will give this our attention as soon as possible, but at the moment we are unable to proceed owing to pressure of work on the other new standards. In addition to the above type we have on hand to date the preparation of no less than 24 designs for new standard engines, and also the conversion of 6 types of old standard engines to superheat.*

The number, however, of locomotives of these new standard types which is being ordered appears to us to be becoming somewhat of a serious matter. You will recall that in the memorandum for the Locomotive Standards Committee (vide *L. S. C. Report 1924, Page 6, Para. 8), it was stated that "Arrangements would be made for two engines of each type, or class of a type, to be built for each Administration requiring them, and these engines should be thoroughly tried out for a period of at least two years". Up to the present, however, we have had indents for no less than 167 new standard engines, covering 14 types. A complete statement of the position to date is shown on the enclosed list, from which you will note, for instance, that the first Combined Call, 1926, contained an order for 28 of the XB type alone for only three Administrations, and also* *that in the case of the YD type, we have to date orders for as many as 50 spread over five Administrations.*"

185. *Reasons for Change in Policy.*—So marked a change in policy requires explanation, and we have been at some pains to ascertain the reasons; there appears, however, to be little recorded on the subject. We are satisfied that had the Board not been confident, as were the Consulting Engineers, that the general design of the new engines was sound and in conformity with established practice at the time, such large orders would not have been placed. It should be borne in mind that previous instances were not lacking of bulk purchases of new types of locomotives for India without previous trials; there is also the recent example of the L. M. S. R. having placed much larger orders for entirely successful engines, but in that case they already had wide experience of the wheel arrangement adopted.

One reason which appears to have induced the Board to depart so substantially from their declared policy of 1923 was the urgent need for rehabilitating the Railways, and for providing power to meet existing and anticipated traffic. There was also the unsuccessful attempt to establish a company in India to build locomotives; this proposal, which has already been mentioned, was based on an optimistic outlook, which was unfortunately shattered by later events, including the fall in prices from 25 per cent. to 40 per cent. between 1922 and 1925 and the subsequent financial crisis. Thus, the Board were deprived of a source of manufacture in the country.

But more important still, apparently, as a determining factor in the rapidity of the Board's purchases of these engines, was their anxiety to reduce the coal bill by extending the use of low grade fuel, a point with which we have fully dealt in Chapter II. There can be little doubt that this consideration was allowed to outweigh all others, for in their reply to the Consulting Engineers already quoted, the Board stressed their wish to purchase in future only engines with wide fireboxes. It was explained to us that to have continued purchasing existing types of engine with narrow fireboxes would have committed the Railways to what the Board then considered were obsolete types for a further 35 years (the estimated life of a locomotive under the Depreciation Fund Rules).

The Board further informed us that, when the original proposal was made to purchase only two trial engines of each type for each Railway, one Administration pointed out that two would be of little use for experimental purposes, and that for adequate trial, sufficient engines to form a link were needed. Yet another consideration, which appears to have influenced the decision at the time, was the delay of about four years which the more cautious policy would have involved, namely, one year for construction of the experimental engines, two years for trials, and another year for construction of the approved engines. In view of the urgent need for extra power, it was considered that such delay could not be entertained.

Such then are the reasons given us for the Board's change of Policy, and, while we cannot say that they had no justification, we feel that in view of the warnings conveyed by the Consulting Engineers, the wiser course would certainly have been to have continued purchasing a further number of the well tried B. E. S. A. type engines (suitably modernised as necessary), pending thorough trial of the new Pacific classes. In our view, the Board's action in this matter was regrettable; but, in making this criticism, it should be recognised that had the trials and alterations been conducted on no more searching lines than those carried out after the first X class Pacifics were delivered, it seems unlikely that the policy of trial before purchase would have assured immunity from the troubles which followed. Its principal effect would have been that a smaller total number of Pacific engines might be running at the present time. While, therefore, it appears that the Board laid themselves open to criticism for abandoning their declared policy, it can hardly be said, in view of what we now know to be the state of knowledge at that time, that adherence to their policy would have materially altered the conditions of operation which have led to this Inquiry

CHAPTER IX.

TERMS OF REFERENCE NO. 4—THE CONDITIONS SUBJECT TO WHICH THESE ENGINES CAN BE USED WITH SAFETY WITH PARTICULAR REFERENCE TO THEIR SUITABILITY FOR THE TRACK ON WHICH THEY ARE REQUIRED TO RUN AND CONVERSELY THE SUITABILITY OF THE TRACK FOR THESE TYPES OF ENGINE.

186. *Introductory Remarks.*—It is now over 10 years since the first case of hunting and track distortion by an X class Pacific was experienced. This is a long time, and, it is, therefore, necessary to consider in some detail :—

(a) What preventive action was taken by the Administrations and by the Railway Board.

(b) What improvements were effected to the engines.

(c) Whether the measures adopted were reasonably sufficient.

The history of these engines is dealt with in Chapter II, and shows that the first was put into service on the E. I. R. in January 1928, while the first cases of hunting and of track distortion were reported in the following May and June, respectively. Subsequently, every Broad Gauge Railway in India using Pacifics experienced cases of hunting and track displacement to a greater or lesser degree, and the first derailment occurred in February 1929.

187. *Reasons for time taken on investigation.*—So far as was practicable, we have considered the circumstances in which the various derailments took place, and it appears that they were mainly the outcome of excessive oscillation at considerable speed. There was evidence of occasional disagreement with the opinions of Government Inspectors; there also appear to have been instances of failure to face the issues, and to avoid an all-too-common tendency to shift blame from the engine to the track and *vice versa*. Personal responsibility, and even departmental responsibility, are minor considerations, compared with prompt preventive action, when the cause of an accident has been made clear as the result of Inquiry; we refer to this later in paragraph 210. We feel that harm has been done by a too rigid departmental outlook, which must have reached to the detriment of the best interests of railway working; in this case, it seems to have retarded an earlier appreciation of where the trouble lay and what were the necessary remedial measures.

As we have pointed out, however, the case was a baffling one from an engineering point of view, owing to the border line nature of the design which renders these engines so sensitive to certain track conditions. The real cause, therefore, of the trouble did not reveal itself either to the Administrations using the engines or to the Railway Board; coupled with this, there appears to have been no systematic method of collecting data and submitting it to the Board and to the Consulting Engineers. It was largely due to these factors that the problem has remained unsolved; but, generally, there is no doubt that safeguarding measures were under constant consideration and application. It must also be remembered that reports to the Board from some Administrations disclosed no grounds for criticism; this has apparently tended to conceal the importance of the issues, and has resulted in a condition of uncertainty and indecision as to fundamental requirements.

PREVENTIVE ACTION TAKEN.

188. In an endeavour to overcome the clearly demonstrated bad riding tendencies of these locomotives, the preventive action, which was taken, involved limitations of speed, initiation of research, and alterations to the engines.

Speed.—Wherever track distortions have occurred, Civil Engineers and Government Inspectors have been prompt to impose speed limits of 45 m.p.h. or less; these have been removed as the various engine alterations appeared to show promise of improvement, only to be re-imposed in many cases following further distortions. On the other hand, on some Railways, notably the M. & S. M. R. and N. W. R., it was not considered necessary to impose such restrictions. Subsequent to the Bihta accident, however, the Railway Board instructed the Administrations to restrict X class Pacifics to a maximum of 45 m.p.h. over any section where track distortion attributable to hunting, or tendency to hunt, had been experienced within the previous 12 months.

Generally, at the time of our visit, this limit had been adopted, irrespective of whether or not distortions had occurred, and had been taken as applying to unmodified X class Pacifics, as well as to those which had been modified to the Railway Board's instructions. An exception, however, has been made in respect of XA engines on the G. I. P. R.; after full modification, and with the Government Inspector's approval, they are being allowed to run at a maximum of 60 m.p.h. instead of 45 m.p.h.

189. *Research.*—For the first time, research, which enabled accurate measurements to be made of the forces, as well as the displacements involved, was initiated in India only two or three years ago; its great value, in allowing a rational attack to be made on the problem, has been set out in Chapter VII. Although work had commenced in other countries before it was taken up in India, each country was occupied in perfecting its own apparatus, and few of the published results were helpful.

190. *Alterations to Engines.*—The alterations and improvements which were made to the engines have been set out under Terms of Reference 1 in Chapter VIII. As already explained, the majority of those carried out in the earlier years had apparently no effective bearing on the riding of the engines, and were not, therefore, sufficient to enhance safety of operation. In this Chapter, it is proposed to consider only the effect of improvements, resulting from the Railway Board's final instructions, which, in turn, largely resulted from the research work to which reference has already been made. These were contained in a letter of April 1938 to all Railways, and are briefly repeated here :—

(i) Bogie pivot and bogie slides to be fitted with friction liners.

(ii) Bogie control springs to be fitted having an initial load of 22 cwts. and 50 cwts. final.

(iii) Cartazzi inclined slides to be removed and replaced by flat faced with Ferodo.

(iv) German buffing gear to be fitted.

At the time of our arrival, the position on the individual Railways, with regard to the above instructions was as follows :—

G. I. P. R.	Proceeding with the fitting of all XA engines.
B. B. & C. I. R.	Proceeding with the fitting of all XC engines.
E. I. R.	Several XB and XC engines already fitted for trial. Orders issued for further 35 engines to be fitted.
S. I. R. M. & S. M. R.	Only one engine on each line altered for experiment.
N. W. R. E. B. R.	Only partial modifications on one or two engines.
N. S. R.	No engines fitted.

CONDITIONS UNDER WHICH ENGINES CAN AT PRESENT BE USED WITH SAFETY.

191. *Original Condition.*—Consideration will first be given to engines which are fitted with the original type bogie, hind truck, and drawgear. These engines are not safe to run at unrestricted speed in all circumstances. There are many locomotives in this condition which have not been known to hunt on specific routes; we ourselves travelled on unmodified XB and XC engines at even 80 m.p.h. with comparative steadiness. Given, however, adverse engine and track conditions, whether individually or in combination, there is possibility of undue oscillation being set up, followed by hunting and excessive flange forces, and even by subsequent derailment when speed is high and/or conditions are particularly unfavourable.

In Chapter IV we have already discussed the relations which the different types of track, formation and weights of rail bear to the running qualities of these engines; while the weight of rail is an important factor, it is not necessarily the decisive one. Heavier rails, such as 90 lbs. and 115 lbs. F.F. have a greater moment of transverse resistance, and, when used in conjunction with a more generous provision of sleepers, afford a substantial track. Nonetheless they are capable of deflections sufficient to initiate the hunting of engines so sensitive as X class Pacifics unless suitable control is provided. This is especially so if the track is in an inferior condition both in alignment and level, such as sometimes prevails during the monsoon and on black cotton and water-logged formation.

As an alternative to altering the engines, they can be safely used either by restricting speed to 45 m.p.h., as has already been done, or by raising the standard of track maintenance to levels which may become uneconomic. The experiments on the B., B. & C. I. R. (*vide* paragraph 147, Chapter VII) have shown that, given sufficient and continuous attention to packing of sleepers, the oscillations even of highly sensitive engines damp out. The cost of such treatment, however, might be prohibitive and, even so, some degree of softening of the formation must be expected under monsoon conditions. For safety in operation at unrestricted speed, therefore, alterations are required to the engine and the maintenance of appropriate standards are necessary on the track; these matters are discussed later. In the meantime, we recommend a continuance of the existing 45 m.p.h. maximum speed restriction.

192. *Partial Modification.*—This has usually taken the form of fitting friction material to the bogie, but of retaining the Cartazzi hind truck. It has been explained, however, that engines so modified are, in fact, little better than those which have remained unmodified; this was demonstrated to us by the violent hunting which we experienced on a partially modified engine on the E. B. R. The remarks which have been made regarding unmodified engines, therefore apply equally in this case.

193. *Full Modification.*—It has already been stated that, on the straight, engines modified to the Board's full requirements ride without undue oscillation, and with much reduced coupled wheel flange pressure, If confined to straight track, therefore, they could be worked with safety at unrestricted speed, over permanent way which is suitably designed and adequately maintained. On curved track, however, it has been demonstrated that the high friction of the bogie slides, combined with the low value, of the control spring centring force, can give rise to undesirably high flange forces, and the position in these circumstances is no different from that of unmodified engines on the straight.

It is true that most of the hunting and derailments in the past have occurred on the straight, and that no accident has occurred on curved track with a modified engine. Nevertheless, so long as it is possible to obtain high flange forces when passing round curves, complete assurance of safety is absent. Provided a sufficiently unfavourable combination of circumstances exists, there must remain a latent possibility of track distortion under the action of high flange forces; so long as this continues, however remote the eventuality even engines as modified cannot be said to be free from the liability to derailment at high speed. We recommend, therefore, that the restrictions at present in force, which limit the maximum speed to 45 m.p.h. should continue to apply also to the engines which have been modified in the manner referred to above.

TRACK CONDITIONS REQUIRED TO ENSURE THE UNRESTRICTED USE OF THESE ENGINES.

194. *Permanent Way.*—We have emphasised in this Report that safety in riding is a joint matter between engine and track; it is necessary, therefore, to consider measures to be taken with regard to both. Track has already been dealt with in Chapter IV, and it remains to summarise our views and to make recommendations. There is little doubt that, when X class engines were introduced, they immediately brought to notice weaknesses in

the permanent way, and we are satisfied that, generally, suitable action by speed restriction and strengthening has been taken during the last 10 years to meet the situation.

We are aware that a heavy standard F. F. rail of 115 lbs. per yard was introduced some years ago when traffic and other conditions appeared to warrant its use; also that the attention of the Railway Board was drawn by the E. I. R. (Company) to the advantages of adopting 100 lbs. F. F. rails as a standard for that line. We feel, however, that it would be unjustified financially, unless traffic or other conditions are exceptional, to depart from the standard of 90 lbs. F. F. rail, which has been in general use for many years and appears to be satisfactory for the main lines of the country. We draw attention to the advantages of longer rails, from both the aspects of maintenance and of comfort in running; also to the value of continuance of research regarding the strength of fishplates.

In our observations, we took particular note of those features of the track which might contribute to lateral instability of the engine, namely, features which can give rise to undue elastic deformation under load. The following points, some of which are not confined to India, may be mentioned in this respect :—

(a) In the case of flat footed rails and wooden sleepers, square section spikes are used; there is a tendency for the wood to shrink and for the spikes to start working, which results in play between the rail foot and the spike head.

(b) In the case of bull headed rails and wooden sleepers, the chairs are fixed by spikes, which are subject to the same tendency.

(c) Plate and pot sleepers which are cross-tied below the bottom of the rail, have a tendency to deflect outwards, under the effect of flange pressure, when the play in the tiebar is excessive and its moment of inertia is insufficient.

(d) With plate or pot sleepers the inclination of 1 in 20 of the rail tends to vary.

(e) Wooden keys are liable to become loose, and steel keys to flex.

(f) The provision of sleepers is sometimes inadequate, and reference to this is made below.

It may be claimed that permanent distortion of track was unknown with the 4-6-0 engines previously operating; also that if the flange forces of the Pacific type engines were reduced to the same value, by the measures which are recommended for the engine later in this Report, no further attention to the track would be necessary. This may be a sound enough argument, but, in our opinion, it is desirable to aim at a higher margin of safety in India, and to this end, a degree of betterment in the track is indispensable. It is necessary, therefore, that, irrespective of the weight of rail and spacing of sleepers, attention should be given to the points enumerated above, as well as to the following :—

(i) In the case of pot and plate sleepers, the design should allow of the tiebars being fixed as near as possible to the foot of the rail, in order to avoid deflection by rotation of the rails about their base.

(ii) In the case of steel trough sleepers, the arrangement of four wedges per sleeper is preferable, in order to allow of easy gauge adjustment, while ensuring a high degree of rigidity.

(iii) The design of steel trough sleepers should ensure that a transverse moment of inertia is provided sufficient to resist bending under the maximum flange forces encountered.

It has been found that the lateral resistance of track can be considered sufficient if a transverse static load of 10 tons does not produce a deflection greater than 1/8 in. In France, this has been determined by the use of calibrated hydraulic jacks. This figure should be verified, and modified as necessary, for Indian conditions.

195. *Sleeper Spacing.*—As already stated, we feel that sufficient attention has not been paid to the appropriate spacing of sleepers, which should be provided to withstand the lateral forces tending to spread the gauge and to distort the track as a whole, and to distribute the weight on the formation. The present minimum sleeper spacing prescribed in the Schedule of Standard Dimensions is N + 1 up to 17 tons axle loading, N+2 up to 18½ tons, and N + 3 up to 22½ tons, where N is the length of the rail in yards and relates to the 36 ft. rail. We would remark that this standard is no higher than that adopted on British Railways, where conditions are so much more favourable to better standards of maintenance, and is much lower than that generally adopted in France and Germany.

We recommend that the aim should be for all main lines to be sleepered to a minimum of N+3, increased as found necessary even up to N+8, on weak formation and on curves. We noticed on some Railways that, with certain types of sleepers, their spacing was graduated for a distance of 3 or 4 sleepers on either side of the joints; we recommend that this practice also should be generally followed, where practicable.

While referring generally to the question of strengthening the permanent way by increasing the number of sleepers per rail, we would stress the necessity for research into the bearing capacity of different kinds of soil encountered in India under varying conditions of moisture; we consider that investigation of this nature would be of great value in determining the number of sleepers which should be used for a particular soil in a given locality. In this connection, the greater use of blanketing under ballast should be encouraged; and renewal and recoupment of ballast, to ensure adequacy of section, may be as important as the renewal of track itself.

196. *Recommendations.*—We are aware that there is a considerable mileage of track on the main trunk routes where the rail weighs less than 90 lbs. per yard, and it is probable that in some cases the type and size of sleeper will not permit even an N+5 spacing. The Railway Board must decide, after the further research which we recommend, whether retention of the lighter rails is justifiable, even with added sleeper strength, or whether it is necessary to expedite complete renewal. In the latter case, we consider that it would be advisable to prepare a renewal programme for completion within a limited period of, say, 5 to 10 years, and to include special and exceptional maintenance of existing old type material, pending replacement.

While lighter section track continues to exist in main trunk lines, it would obviously be unwise to suggest that the XB and XC engines should be permitted to run over it at unrestricted speeds. In such cases, it will be necessary for Chief Engineers to regulate speed of operation in accordance with the condition of formation, standard of maintenance, and age of material. After modification of the engines as suggested later in this Chapter, and when the foregoing measures have been taken regarding permanent way, we anticipate that it will be possible to relax these speed restrictions. Our recommendations on the use of Hallade instruments, training of staff, and observation of rail joints under load, have been set out in Chapter IV.

FEATURES OF X CLASS PACIFIC ENGINES AS ORIGINALLY DESIGNED.

197. Before making recommendations for alterations to the engines, we will examine their guiding elements as originally designed. Figure 27 shows a drawing of the original bogie; Figure 28 illustrates a Cartazzi hind truck, and Figure 22 the Goodall drawgear. Examination of these drawings and inspection of the parts in India, lead us to make the following criticisms and remarks:—

(a) *Bogie*:—

(1) The sliding member is controlled by two independent springs on either end of the transverse centre line, arranged inside a form of buffer plunger. The free length or coil spring is 10⅜ in., and this allows only a very limited range of control.

(2) As these springs are totally enclosed in the centre casting and the buffer plungers, it is impossible to see them without complete dismantling; there is, therefore, no ready means of checking whether they have broken in service, or were defective even when assembled in the first place.

(3) In service, there is the possibility of one spring breaking or becoming weaker than the other without being seen.

(4) As the control springs are necessarily of small dimensions, the limitation of diameter in relation to section tends to give rise to overstressing; in some cases it has been found that the spring becomes solid before the total side displacement is taken up.

(5) The initial compression is obtained by a bolt, the head of which is let into the buffer plunger, and the shank of which passes through a web in the cross slide casting. The amount of initial compression is regulated by screwing up the nut, and, theoretically, the width over the two buffer plungers should exactly equal the distance between the bogie frames, when the correct initial compression has been provided. In practice, it is impossible to realise this, and to ensure that there is no gap between the buffer face and the frame, clearance is left between the face of the nut and the web in the casting. Any clearance, whether between the plunger face and the frame, or between the face of the nut and the web, allows one spring to act against the other, and reduces the initial control over the distance represented by the clearance. This is shown in Fig. 10.

(6) As this type of bogie is common on older B. E. S. A. engines, it is easy for their parts to be confused with those of X class bogies. As, however, the springs are different in size, this would result in incorrect control, and we noted one such case.

(7) The centre plate and sliding casting are difficult to lubricate properly, and to keep free from dust and ashes; this results in variable friction conditions.

(8) The design of bogie is such that the main transverse castings, which form the slides are in two separate sections, each bolted independently to the frame. It is possible for these two unconnected castings to give rise to inequalities in level, causing high spots and friction in the slides.

(9) The spring cradle bars bear on the axleboxes through a cross rib which has a flat top. Contact between the cradle bar and the axlebox top was noted to be unsatisfactory, allowing the load to come on one end or the other of the bearings; this gives bad weight distribution, which is one cause of hot boxes.

(10) The passage of a bogie over track, which has superelevation or differences in level, necessitates all parts being free to move in any direction. In this connection, it is noted that the horn guides on the axleboxes are neither barrelled nor veed.

(11) Having regard to the guiding function of the bogie, it is essential that the wheel hub and axlebox faces should have large bearing surfaces. It was noted that these faces were too small, and excessive wear took place.

(12) The bogie has heavy centre castings, which extend well towards the horn gaps. On the other hand, the outer ends of the frame are stayed with only small round struts. This is likely to give rise to concentration of stress at the point where the casting terminates.

(b) *Coupled Wheel Springing.*—The flexibility of the coupled wheel springs as measured by their deflection per ton is 0·2 in. in the case of the XA, 0·18 in. for the XB, and 0·16 in. for the XC. Corresponding values in British practice range from 0·15 in. to 0·2 in., while in France 0·35 in.

per ton is a representative value on the more important express passenger engines. No modification has at any time been made to the flexibility of the bearing springs on X class Pacifics, which it will be noted, conform in this respect to normal British practice.

(c) *Clearance between Flange and Rail.*—When wheel flanges and rails are new the side clearance between them in India (gauge 5 ft. 6 in.) standard locomotive designs is 9/32 in. for all wheels. In Great Britain (gauge 4 ft. 8½ in.), it is 5/16 in. for full tyre sections, but for certain high speed locomotives this dimension has recently been reduced to ¼ in. on the bogie and hind truck wheels. In France, 3/16 in. is the standard clearance, which has come about in recent years as the result of 3/16 in. reduction in track gauge (now 4 ft. 8½ in.). Figure 23 illustrates this point.

(d) *Engine Frames.*—Owing to the presence of large vacuum cylinders between the frames immediately behind the smokebox, it has been found difficult to provide sufficiently stiff frame staying at this point, with the result that frame fractures have been epidemic. The original designs had no continuous longitudinal stays, but, in later engines, such staying was provided, and many of the original engines have been altered in this way. While however, the frames were thus made more rigid from the region of the leading coupled axle backwards, the continued presence of the vacuum cylinders prevented any stiffening of the staying where it was most needed, *viz.*, between the leading coupled axle and the bogie centre. Flexing of the frame was, therefore, likely and this can affect the riding of the engines as described in Chapter III; the incidence of frame fracture is dealt with in Chapter X.

(e) *Hind Truck.*—It is now generally accepted that Cartazzi control on radial axleboxes is unsuitable, having regard to the conditions and types of track in India. The disadvantages are:—

(1) The engine tends to curve in a series of jerks, because the lubricated slides are continually riding up the inclined planes under the influence of the displacement, and slipping back under the influence of the engine weight. If lubrication of the slides is defective, this action is irregular.

(2) Wear is very severe in horns and guides.

(3) The value of the centring force obtained is uncertain.

(f) *Drawgear.*—A well designed engine should not have to derive any centring force from the mass of its tender, but if its side control is very weak, some useful steadying effect can be exerted by a suitable coupling between engine and tender. The Goodall drawgear is particularly unsuitable for engines with the characteristics of X class Pacifics as originally designed; it allows freedom of relative movement in all directions, other than the longitudinal.

FEATURES OF X CLASS PACIFIC ENGINES AS SUBSEQUENTLY MODIFIED.

198. Fig. 29 shows the application of friction liners to the bogie; Fig. 22 illustrates the American type of drawgear, and Fig. 24 the German buffing gear. With regard to the principal modifications which have been made since the engines were first built, we offer the following comments :—

(1) *Increasing the strength of bogie control springs.*—The increases which were made within the limitations imposed by the original designs were inadequate. An initial load of 1½ tons and a final load of 4½ tons were the utmost which could be provided with single springs.

An effort was made on one Railway to improve the control. within the existing limitations, by fitting two concentric springs into the original housing in the bogie casting. Even by this means, however, initial load is not more than 2 tons.

In 1932, some experimental bogies were built with laminated side control springs and side bearing pads. In this case, trials were made with initial side control values of from $2\frac{1}{2}$ to 4 tons, but the retention of the Cartazzi slides on the hind truck and of the Goodall drawgear masked the improvement which such an increase in bogie side control should have given.

(2) *Altering the Inclination of the Cartazzi Slides.*—Steepening the slides would provide a measure of increased controlling force on the straight, but on curves it has the effect of diminishing the effective control of the bogie, as outlined in Chapter III. Moreover, the action of steeply inclined slides gives very rough curving.

3. *Setting back of the hind truck wheels by amounts up to 2′ 6″.*—If the amount of the bogie and hind truck control remains constant setting back of the hind truck, by increasing the arm at which the trailing control force acts, will increase the value of its moment. As in (2), the effective control of the bogie will be reduced on curves. The setting back of the trailing wheels, however, was usually accompanied by a substitution of bogie control springs, which had 90 cwts. final compression in place of the original 50 cwts., and the alteration probably made no material difference.

(4) *Replacement of Goodall drawgear by American type of drawgear with side buffers.*—The latter type of drawgear provides for a plain link coupling with radial rubbing blocks, side buffers being used at the same time. This was a move in the right direction.

(5) *Introduction of friction material to bogie slides.*—This was the principal contribution made by the Railway Board to the solution of the hunting trouble on X class Pacifics. As gradually developed, and as finally applied, after recording of actual flange forces became available, this measure cured hunting and undue oscillation on the straight. It has the merit of achieving this with the minimum alteration to existing engines; but it has a serious drawback which can be appreciated only by close study of flange force diagrams, As already explained, a high degree of friction in the slides reduces the effectiveness of the side control springs on curves; this is particularly the case if the springs are weak, as they continued to be after this modification was made. In consequence, high flange forces may be experienced on curves, and it cannot, therefore, be considered that this modification affords a satisfactory solution.

(6) *Replacement of Cartazzi slides on hind truck by flat slide slined with friction material.*—This measure was adopted in conjunction with (5) above, and has considerably assisted in steadying the engines and avoiding the building up of oscillation. Although the flat slides remove all centring force from the trailing wheels, they are satisfactory in practice when the engine is running forward. When running backwards, however, the absence of centring control may lead to derailment at any considerable speed. In India, travelling tender first is restricted to 15 m.p.h., and no trouble in this respect appears to have been experienced. Lip brasses fitted to the hind truck axleboxes have proved valuable in reducing the amount of lateral wear.

(7) *German Buffing Gear between engine and tender.*—The particular application made is not an adaptation of the German draw and buffing gear in its entirety, but makes use of the buffer plungers acting on inclined planes, as a means of steadying the

back end of the engine, when the side control at the hind truck (Cartazzi slides) has been removed. The effect of this buffing gear has been described in Chapter III.

Two practical objections are, first, that the mechanical arrangement of inclined planes and buffer spindle guides is such that severe transverse forces are brought to bear on the buffer spindles; secondly, that the arrangement usually has to work in a mixture of water and coal dust under the tender footplate. Abnormal and rapid wear may be expected in consequence. Where adequate control is provided on an engine, the use of such a device should be unnecessary, but, where a hind truck is provided without spring control, the arrangement is of some assistance. Its advantages, however, cannot, in our opinion, outweigh the high cost of maintenance.

(8) *Discs of friction material on bogie centre to increase resistance to rotation.*—This is a valuable measure, as it prevents the bogie from setting up self-induced nosing movements.

RECOMMENDATIONS FOR IMPROVEMENTS ON X CLASS PACIFIC ENGINES.

199. In order to obviate the defects referred to in the last section, and to improve safety in operation, the main items requiring alteration are the bogie, the hind truck, and the connection between engine and tender. We recommend as follows :—

Bogie.—(a) The amount of spring control, both initial and final, should be considerably increased. The control must have sufficient initial value to avoid lateral displacement of the bogie on the straight, and must have a load-deflection curve sufficiently inclined to avoid undue flange forces at the leading coupled wheels, when traversing curves of minimum radius without speed restriction. We recommend the following values :—

	Tons.		Tons.
XA Initial	$3\frac{1}{4}$	Final	5
XB Initial	5	Final	7
XC Initial . .	$5\frac{3}{4}$	Final	7

These values should be verified by test as described later (*vide* paragraph 206), slight upward and downward variations being tried.

It is impossible to provide springs giving these values within the limitations of the original design; if, therefore, the bogie slide and centre castings are not to be scrapped, it is necessary to alter them by incorporating a new arrangement of coil springs. Figures 30 and 31 show a means by which such improvement can be applied to an existing bogie, and it will be noted that this avoids the defects which are referred to earlier in this Chapter.

(b) The surfaces of the bogie slides should have as low and constant a coefficient of friction as possible. This may be achieved by metal-to-metal surfaces, if adequate lubrication can be maintained. Owing to their position, however, these slides are always difficult to lubricate, and if the oil supply were to be interrupted, partial seizing and very high coefficients of friction can result. We recommend, therefore, that a trial should also be made with a suitable fabric material on the slides which is lubricated from an external source; this will provide a low coefficient of friction (0·1) in normal use, and will limit the upper coefficient (0·25) should the supply of lubrication fail. In time, it may be possible to obtain material with a coefficient of friction below 0·15 when dry, which would be the ideal solution.

(c) The slides themselves should be reduced in area, and should be ground to a smooth finish, level, as well as true, in both directions and with each other. To ensure this, it will be necessary to mount the bogie as a whole on the grinding machine, or alternatively to take out the separate slide castings and join them with a stirrup as shown in Figure 31; by these means they can be ground and subsequently assembled as one unit. The upper slides should also overlap the lower in all positions, in order to give grit and dirt no opportunity to lodge.

(d) To reduce the nosing tendency of the bogie, in so far as it behaves as an independent vehicle of very short wheelbase, the circular pivot plate, on which the bogie centre casting rotates, should be faced with friction material. The fitting of such discs to the tender bogie centres would improve the riding of the tender.

(e) To decrease the side clearance between bogie flanges and rails, certain relationships must be observed as between wheel flanges and check rails and crossing noses. An increase in thickness of 3/32 in. on each side of the flange is suggested, but the actual amount of sideplay for Indian conditions must be determined jointly by the Chief Civil and Mechanical Engineers.

(f) All bogie maintenance should be of a high standard, and side-play should be reduced to a minimum. In this connection, we draw particular attention to the proper adjustment of side control spring gear, to the clearance between bogie centre pin and its hole, and to the side-play in the axleboxes. The rate of development of the last named can be materially reduced by the provision of more ample bearing surface between axlebox face and wheel boss. But, in addition, limits of wear for these surfaces should be prescribed and rigidly enforced in sheds and shops. The value of these limits can be determined only in India, but they should obviously be as close as possible from a practical point of view.

(g) The freedom of the bogie boxes to find their own position should be improved, and, incidentally, their liability to heating would be reduced, by substituting a ball end for the flat knife edge arrangement, where the spring cradle bars rest on the crown of the axlebox. At the same time, the axlebox horn cheeks should be tapered outwards, top and bottom, to allow some freedom in the guides when one wheel on an axle is lower than the other. An alternative design of bogie, having laminated side control springs and side bearers, has been developed by the Railway Board, and is fitted to a few X class Pacifics. This is a much better design than the original standard, and, by substituting a stronger laminated spring, an increase in the centring force can be obtained without any alteration to the bogie. Such a substitution was satisfactorily carried out at our request on XC engine No. 614 on the B., B. and C. I. R.

(h) Special attention should be paid to the rigidity of the bogie frame between horn gaps and centre castings. The greater the flexibility of the frames, the less is the efficiency of the side control provided.

200. *Hind Truck.*—It has already been pointed out that the Cartazzi slides, as distinct from the radial type of axlebox, are unsuitable for Indian conditions. Owing to the axleboxes being outside the wheels it is impracticable to substitute a spring control whilst retaining the radial arrangement. Control can only be obtained by one of two alternatives. The first is entirely to reconstruct the back end of the engine to permit of the fitting of a spring controlled pony truck; the second is to retain the existing radial axleboxes, and to replace the Cartazzi slides by flat slides lined with friction material, following the Railway Board's proposals.

The relative effects of spring and friction control have been discussed in Chapter III, and there is no doubt that the spring controlled pony truck gives a more satisfactory arrangement. We recommend this for new construction in the next section of this Chapter, and this has already been recognised by the Board in the design of the new WL class Pacifics now under construction. We consider, however, that we are not justified in recommending so large an alteration on the existing X class engines for the following reasons :—

(i) As outlined in Chapter III, an initial control made up entirely of friction can give the same practical effect as a pony truck in a forwards direction of running.

(ii) Although unsuitable for backwards running at any considerable speed, the arrangement of radial boxes and flat slides faced with friction material, appears suitable for running at 15 m. p. h. and under, provided a form of tender drawgear is selected which has a centring effect. No trouble has been reported with such an arrangement in India under these conditions, although a number of engines so fitted are in service.

(iii) The cost of the extensive alteration involved in fitting a pony truck would be some £400 per engine, which is out of proportion to the small advantage likely to be gained by such a change.

(iv) There is also the possibility that this alteration which was not provided for in the original design, might give rise to new troubles, as the result of the difficulty of obtaining sufficient clearances and adequate anchorage to the existing frame.

(v) There are a considerable number of Pacifics in service in France which have radial trucks with uncontrolled flat slides. This arrangement is used in conjunction with a bogie having a strong spring control (*vide* paragraph 140, Chapter VII).

We recommend, therefore, that all existing X class Pacifics should have their hind trucks modified according to the Railway Board's instruction, namely, that the Cartazzi slides should be removed, and should have flat slides faced with unlubricated friction material. Engines so dealt with already should remain unaltered. At the same time, the following improvements in details are recommended :—

(1) The use of the lip type bearing, already approved by the Railway Board, should be standardised as an effective means of reducing side wear.

(2) The guiding surfaces which work in the hornblocks should be increased and fitted with renewable sections as on the XC class engines on the B., B. and C. I. R.

(3) Recommendations (e) and (f) for the bogie should apply also to the hind truck.

201. *Drawgear.*—The Goodall drawgear should be eliminated and a simpler plain bar type of drawbar introduced, in conjunction with rubbing blocks and independent side buffers. An arrangement on these lines has already been developed by the Railway Board, and can easily be applied to the existing castings. The proposed gear should be cheaper to maintain, and may be expected to give more satisfactory service than the present equipment. Further, it would have a steadying effect at the rear end of the engine. Where German buffing gear has already been fitted, we recommend its retention with the following modifications :—

(1) Inclined plane rubbing blocks should be removed, and plain blocks faced with friction material substituted.

(2) Buffer heads should be made flat, instead of V shape.

(3) Collars should be fitted on the buffer spindles, so that only one buffer at a time acts on curves.

These modifications are recommended with the object of obtaining an increased centring effect at the back end of the engine on curves, to compensate, in some measure, for the absence of control springs on the hind truck. The arrangement has the further advantage that it comes into action immediately, and is not affected by any clearances that may exist. It was tried on XC engine No. 614 on the B., B. and C. I. R., as described in Chapter V.

Where German buffing gear has not yet been provided, the effect outlined above can be obtained by fitting on the tender simple side buffers having coil springs, an arrangement likely to be less costly than the German type. An initial load of 4 tons on each buffer is suitable.

202. *Engine Main Frames.*—The present arrangement leaves a weak section of frame between the bogie pin and the leading coupled wheels. The existing staying of the frames between the cylinders and the first cross stay requires stiffening; it has been considerably weakened to provide space for the two vacuum cylinders, and the effect is to reduce the degree of control provided. Serious consideration should be given to finding another position for the brake cylinders, so that adequate stiffening may be provided in this part of the frames.

203. *Tender.*—Discs of friction material should be fitted at the centre of each bogie, in order to damp out separate nosing of the bogie on its own wheelbase. Brasses of the lipped type should be fitted to all journals of both bogie and 6-wheeled tenders.

204. *Engines to be altered.*—We recommend that, in the first place, two engines of each of the XA, XB and XC classes be altered according to the foregoing proposals, and a full series of trials should then be carried out with each, as set out later in this Chapter.

RECOMMENDATIONS FOR NEW PACIFIC ENGINES.

205. In the event of engines of Pacific type being required for India in future, the above recommendations should be embodied, with the following additions and qualifications:—

Bogie.—Either the coil or laminated spring type may be used, provided they are arranged to work in parallel. All cross stretchers should be designed to avoid twist and misalignment. The main centre castings should be in one piece, to ensure that the surfaces on which the slide rests can be machined and maintained in one plane. Axleboxes should have adequate bearing surfaces on journals and between face and wheel boss.

Hind Truck.—Spring controlled pony trucks should be provided. The value of the initial side control should be appropriate to the amount of bogie control, and the load-displacement characteristic should be flatter than that of the former.

Carrying Springs.—Spring and compensating gear in stable equilibrium should be provided. Springs should be arranged under the axleboxes, and the latter should be so designed that the keeps can be withdrawn for repacking, without interfering with the spring gear.

Frames.—As having a direct bearing on the riding of the engine (*vide* Chapter III), the main frames between the bogie and the leading coupled wheels must be sufficiently rigid, to withstand the forces which tend to deflect them in the horizontal plane. As already mentioned, an alternative position should be found for the vacuum brake cylinders, in order to allow adequate crossbracing.

OTHER RECOMMENDATIONS.

206. *Testing and Research.*—It is not sufficient merely to adopt the measures outlined above. It will also be necessary to carry out extended trials with the two engines of each class, altered to our recommendations, to ensure that they do not exert forces higher than the track can safely resist under all the varying circumstances of Indian climate and maintenance. The remaining 278 engines should be altered only after the Railway Board are satisfied from the results of the trials that the modifications introduced have definitely reduced flange forces to a permissible limit under representative conditions both on straight and curved track.

It is of the highest importance that these conditions should include the worst; the tests should therefore preferably be carried out during the monsoon, and should be made with an engine having the maximum permissible clearances (specially fitted up, if necessary). Should, however, satisfactory results be obtained in dry weather, alteration of other engines need not be delayed, provided that further tests are made during the following monsoon. After engines have been altered, confirmatory trials should also be carried out at intervals, and, in any case, the Chief Civil and Mechanical Engineers should determine for all circumstances the maximum permissible speeds.

The form which the trials should take has been indicated in Chapter VII, and it is recommended that alternative sets of springs should be prepared for each class of engine as follows:—

	Tons.		Tons.
XA One set initial	2¾	Final	4½
One set initial	3¼	Final	5
One set initial	3¾	Final	5½
One set initial	2¾	Final	5½
XB One set initial	4½	Final	6½
One set initial	5	Final	7
One set initial	5½	Final	7½
One set initial	4½	Final	7½
XC One set initial	5¼	Final	6½
One set initial	5¾	Final	7
One set initial	6¼	Final	7½
One set initial	5¼	Final	7½

The strengths of these springs are suggested, assuming that the weight on the bogie is as shown in the diagram; we recommend that careful check should be made from time to time to ensure correct distribution of weights on the axles throughout the engine.

The object of recommending continued trials is to ensure that in no circumstances of maintenance will the engine exert more than a certain flange force on either straight or curved track. As this value is so intimately connected with track conditions, research is equally necessary on the track to ascertain flange forces which a given track will resist under varying conditions of weather and maintenance; it is also important to study the influence of a yielding track on flange forces, quite apart from the condition of the engine.

The highest degree of safety will have been attained when:—

(a) The track is so substantially constructed and maintained that it will not initiate and assist in building up oscillations.

(b) The engine is designed and maintained in such a way that any lateral oscillations initiated by the track do not build up and give rise to high flange forces.

(c) The track offers ample resistance to the highest flange forces likely to be developed.

Assurance will be made doubly sure when it becomes possible to obtain autographic records at any moment of the actual flange forces, and to ascertain the actual measure of track resistance.

207. *Speed of X class Pacifics.*—The general question of speed has been referred to in Chapter IV. As regards this term of reference, we recommend that all existing X class Pacific engines should remain restricted to the maximum speed limit of 45 m. p. h., subject to the conditions already imposed by the Railway Board. With the actual test records before us, showing the flange forces attainable at 60 m. p. h. even with modified engines, we cannot feel justified in recommending the raising of this lower speed limit until the engines have been altered in accordance with our suggestions, and until the apparatus developed by the Railway Board has demonstrated that the present flange forces have been reduced.

We anticipate that when the engines have been modified according to our recommendations, and when measures have been adopted to improve track and engine maintenance on the lines indicated by us, it will be permissible to remove the restriction of speed now in force on X class Pacifics.

We do not, however, consider that it is within our remit to prescribe the maximum appropriate speeds for the various sections of Indian Railways. These are ultimately dependent on the actual condition of track and engines pertaining at any time and place, which can be appropriately judged only by the authorities in charge, to whom, therefore, the decision must be left. We expect that due regard will be paid to seasonal and local restrictions when and where necessary, to the highest practical standards of track and engine maintenance, and to the necessary measures to minimise deterioration of these as the result of the monsoon and other climatic conditions common in India.

XA Engines on G. I. P. R.—Special conditions arise in connection with the 109 XA engines; the Railway Board informed us as follows:—

> "*Except for some derailments on the G. I. P. R. due to a special cause, there have been no cases of track distortion attributed to them (XA engines) over 10 years at speeds up to 60 m. p. h., even in the unmodified condition. A tendency to nosing has been obviated by the fitting of the latest improvements, and the engines so modified on the G. I. P. R. are being allowed to return from 45 m. p. h. to 60 m. p. h. maximum on the S. G. I.'s authority.*"

There appears, however, to be evidence that certain of the derailments (six in number) referred to were accompanied by track distortion; after the fourth accident, the Chief Engineer in January, 1931, stated that:—

> "*Divisional Engineers and Resident Engineers are of opinion that the oscillation of the XA type engine is more detrimental to the track than is the running of other types of engines, and I have received many reports to this effect. In view of the derailments and reports of damage to track by these engines, I have considered it necessary personally to watch their performance at speed, and I have come to the conclusion that at speeds over 50 miles per hour they are liable to violent side to side oscillations, which leaves little or no factor of safety.*"

We understand that the Government Inspector's recent permission to run the engines up to 60 m. p. h., after the modifications referred to, was based on his personal experience of riding on a number picked at random over certain sections. Nevertheless, it has already been pointed out that steady and comfortable riding on the footplate does not preclude the incidence of considerable flange forces; we consider, therefore, that these engines, even as modified, should only be allowed to continue to run at a maximum speed of 60 m. p. h., subject to the following safeguards:—

(1) That steps be taken to ascertain the flange forces exerted on both straight and curved track of different types, using the apparatus developed by the Railway Board. Should excessive flange forces be recorded, the speed of all the engines involved should be reduced again to a maximum of 45 m. p. h.

(2) That early steps be taken to alter the engines in accordance with our recommendations.

It should be understood that the foregoing does not apply to XA engines which have not been fully modified in accordance with the Railway Board's instructions of April 1938. These should continue to be restricted, as under present orders, to 45 m. p. h. until they have been altered in accordance with our recommendations.

208. *Responsibility for Assessment of Maximum Permissible Speeds.*—In the prevailing circumstances, it would appear desirable that regulations governing maximum permissible speeds of X class Pacifics should be issued by the Railway Board, on the recommendations of the respective General Managers, based on the advice of their Engineers and endorsed by the Government Inspector concerned.

We also consider that when the Chief Engineer and Government Inspector jointly inspect sections of the railway, they should give particular consideration to the appropriate relationship between maximum permissible speed and the standard of track construction and maintenance. We understand that this is in effect the general practice today; but we feel that their findings should be definitely recorded, and that it would be desirable to lay this down as a specific duty, having regard to the frequent changes of officers, which is largely unavoidable in India. Such an arrangement would legislate for variations in standards of maintenance, while permitting of review of the margin of safety by mutual agreement between the Administrations and the Government's representatives.

While the Chief Engineer thus lays down the maximum permissible speeds, we recommend that, when drawing up the working timetable, the Operating Department should obtain the concurrence of both the Chief Engineer and the Chief Mechanical Engineer to the maximum booked speeds. We feel that in the past there may have been some lack of co-operation in this respect. A number of trains running day after day at or near the maximum permissible speed will be more detrimental to the track than an occasional train running at high speed; if the Chief Engineer finds that the effect of the number of high speed trains on his track is severe, he has two courses open to him :—

(a) To reduce the maximum permissible speed, or

(b) To retain the maximum permissible speed, but lower the maximum booked speed.

In paragraph 194 we have stressed the importance of the margin of safety, and, to this end, we feel that the Civil Engineer should not hesitate to impose a reduction in the maximum permissible speed wherever, in his opinion, this is necessary to maintain this margin. On the other hand, he may be able to advise that, provided the maximum booked speeds for all trains are reduced, he would have no objection to the retention of the existing maximum permissible speed. The effect of this would be that, for the most part, trains would be running at slower speeds with less adverse effect on the track; if however an occasional train were running late, the Operating Department would still retain the maximum facility for making up time.

209. *Obedience to Speed Restrictions.*—One of a driver's difficulties is to avoid unconscious infringement when, in order to obey a restriction, he is called upon to reduce speed considerably below that at which he has just been running. It is becoming increasingly necessary in railway practice to provide some means of informing the driver of the speed at which he is actually travelling, and many Railways are fitting their engines with some form of speed indicator with or without recorder. We consider that the indicator with recorder has great advantages, but such equipment is expensive in first cost, maintenance, and supervision, and would entail a special allocation of staff to deal effectively with the records. In all the circumstances, therefore, we feel that the most practical way of helping drivers in India would be to instal indicators without recorders, which are comparatively cheap, and we recommend that early steps should be taken to equip all engines operating mail and express passenger trains with such instruments. This should make for greater confidence both of the staff and of the public, and we have already discussed the matter with the Railway Board.

We also discussed the subject of speed with a number of Railway officers and Government Inspectors; it appears that, in the past at any rate, on some sections of line, the authorised maximum speeds have not been strictly obeyed. It is clearly the responsibility of Railway Administrations to ensure that the maximum permissible speed as laid down by the Engineers, whether confirmed by the Government Inspector or not, is rigidly observed. The assessment in this respect should have regard to all the circumstances and should be notified to all concerned.

While we emphasise the importance of appropriate speed restrictions and their strict observance, we would deprecate any tendency on the part of Administrations to adopt a complacent attitude and to consider that they have discharged their duty entirely by the imposition of special speed restrictions on track or engines, or both. The majority of such restrictions should be regarded as cautionary palliatives, only to be resorted to until the standards of construction or maintenance no longer render them necessary. Obviously, the chief aim of the Engineering Departments should be to effect improvements in track and engines, with a view to removing speed restrictions, and to enable the Operating Department to retain efficient services.

210. *Government Inspectors.*—Having regard to the nature of our Inquiry, we deemed it necessary to consider the functions of the Government Inspectors in respect of their Inspection and Accident Inquiry procedure, and we discussed with them questions relating to safety of operation, such as speed, fitness of track, and their responsibilities in connection with their approval and inspection of way, works, engines, etc.

Under Section 4 of the Indian Railways Act of 1890, the duties of an Inspector of Railways are as follows :—

(a) "To inspect railways with a view to determining whether they are fit to be opened for the public carriage of passengers, and to report thereon to the Governor General in Council as required by this Act;

(b) To make such periodical or other inspections of any railway or of any rolling stock used thereon as the Governor General in Council may direct;

(c) To make inquiry under this Act into the cause of any accident on a railway;

(d) To perform such other duties as are imposed on him by this Act, or any other enactment for the time being in force relating to railways."

In 1921, the Acworth Committee observed that they could not believe that the minute engineering inspection of every mile of Railway every year was essential apparently with a view to providing money for increased traffic inspection, they suggested that the eight Government Inspectors' circles should be reduced to three, though they recognised that it might be necessary in one or two of the circles to appoint, in addition, an Assistant Inspector. No action appears to have been taken on these recommendations, but, in October, 1931, the Railway Retrenchment Sub-Committee made the following recommendations with a view to effecting economy :—

(1) "That minute annual inspection of the lines be abandoned, and that inspections once in two years should be prescribed as sufficient; and that the Chief Engineer of each Railway should be held responsible for keeping the line in good condition;

(2) That the number of circles of inspection be reduced from 8 to 5;

(3) That, for purposes of status and emoluments, Government Inspectors be graded with Deputy Chief Engineer (except Burma Railways, where the Inspector should continue to be an Executive Engineer);

(4) That the cost of tours of inspection should be reduced."

We gather that the Railway Board did not accept these recommendations *in toto*, but they issued instructions that subsidiary lines need be inspected only once in two years. The circles were reduced to five, under two Chief Engineers and three Deputy Chief Engineers; all are drawn from the Engineering Cadre of the State Railways, and are directly subordinate to the Railway Board. This may be embarrassing, particularly in the case of

Officers who may find themselves in the position of having to criticise the administration of a Railway to which they may later return.

Before 1925, when the E. I. R. and G. I. P. R. came under State-management, this difficulty may not have been so marked; but now that more than half the total route mileage is so managed, it seems to be a matter for consideration whether the General Managers, who are State Officers, should not be held entirely responsible for the proper upkeep of their systems, rolling stock, etc. The Chief Engineer and the Chief Mechanical Engineer of each Railway are required to render annual certificates in these respects; if such certificates are to be of value, we feel that the duty of inspection should devolve upon these officers, and that the Government Inspector's responsibility with regard to detailed inspection should be confined to new Railways, diversions, important new works and major bridges in connection with running lines, new signalling, etc.

We recognise, however, that, in the case of Company-managed Railways the present arrangements, by which apparently the greater part of the main lines are still inspected annually by the Government Inspector, should be continued, and it may also seem desirable that he should inspect certain sections of State-managed Railways as occasion arises. In any case, some procedure of this kind, by which Government Inspectors are relieved of a measure of responsibility for inspection should result in the heads of Departments making annual detailed inspections of their jurisdictions. To ensure that public requirements are being adequately met, it would be desirable that copies of such Inspection Reports should be sent to the Government Inspector for his information. This should enable him, as custodian of the public interests, to satisfy himself that the Railways are being efficiently maintained and operated.

We understand that, under the Government of India Act, 1935, it is contemplated that the Inspectorate will be separated from the control of the Railway Board. This is very desirable, in so far as it will eradicate the present anomaly of the Board being the Inspecting as well as the Executive Authority. We were informed that the Board fully appreciate the position, and would welcome the change, although it appears that, in practice, Government Inspectors have generally retained their freedom of judgment. We would only add that, for the efficiency and success of the new Inspectorate, the officers selected should have the assurance of permanence and continuity of appointment. It would, therefore, appear necessary to prescribe that persons selected will not normally revert to individual Railway Administrations, or to posts under the Railway Board, except in special circumstances.

With reference to the investigation of accidents, we understand that Government Inspectors are at present required personally to inquire into all accidents to passenger trains which involve loss of life or serious injury to passengers, and when damage to property amounts to Rs. 10,000 and over. In all other cases, it is left to the Government Inspector's discretion either to make formal Inquiry himself or to leave it to the Administration concerned; in the latter event, he receives the report of the Departmental Inquiry.

Up to October 1933, as stated in Chapter II, there were ten derailments (including Ganjkhwaja) of passenger trains which were attributed, or since believed to be due, to hunting of X class Pacifics. In addition, there were two derailments of an M. class Pacific in similar circumstances. In only three of the twelve cases were Inquiries held by Government Inspectors, and no less than seven of these derailments on the G. I. P. R., between April 1930 and August 1931, were dealt with departmentally. We are of opinion that, *prima facie*, every derailment of a passenger train, whatever the incidence of casualty and damage, should be the subject of formal Inquiry by a Government Inspector, unless he is promptly satisfied by the Administration concerned that the cause is clear and is admitted.

We recognise that action on the foregoing lines might involve additional work on the part of the Government Inspectors, but we feel that, as time goes on, it would have a material influence in ensuring higher standards of safety and maintenance; indeed, it may be necessary to supplement the existing staff, although we hope that some relief would be obtained from the suggested reduction in the amount of detailed inspection work. We do not, however, recommend an immediate increase in the personnel of the Inspectorate, as the merits of such increase can only be judged after our suggestions have been fully considered; moreover, the normal incidence of accident to passenger trains in India is fortunately small.

We need hardly emphasise the advantages of co-operation on the part of the Railways in this matter, and between the Government Inspectors themselves by means of the frankest discussions and the early exchange of Accident Reports, each of which should also be promptly and widely circulated among the staff of all Administrations. Further, we draw attention to the necessity for recording as soon as possible after a derailment has occurred, and so far as is practicable, the fullest information regarding track conditions.

CHAPTER X.

TERMS OF REFERENCE 5 AND 6.

5. *Any modifications which would have the effect of increasing their scope without any sacrifice of safety.*

211. The alterations necessary to ensure the safety of X class Pacific, as vehicles on the track, have already been dealt with. The reference to "Increase of Scope" is assumed to mean improvement in Reliability, Economy, Availability and Haulage Power.

It has to be admitted that in these respects, apart from riding, the engines have given a great deal of trouble, and their effectiveness has been considerably less than could reasonably be expected from a modern design. During our investigations we had abundant evidence of this, both from personal observation and from information provided by the Railway Board and the Administrations.

As in the case of hunting, action has been taken by the Board in each case, based on reports submitted by the Administrations. In certain cases, however, a considerable amount of time elapsed before the true significance of the original reports could be assessed. The parts which gave trouble were frames, firebox tubeplates, bogie axleboxes, coupling and connecting rods. In addition, from our observations, we have certain comments and recommendations to make regarding cylinders, valves, valve gear, and regulator.

212. *Frames.*—Fracture and breakage of frames, occurring mainly at the leading coupled horn gap, has been a continual source of trouble with these engines throughout India. As originally designed, the frames were without horizontal transverse stays, but later deliveries were so fitted, and a large number have been dealt with in the Shops in an endeavour to remedy the defect. Only moderate success, however, was attained, and a measure of the extent of this serious trouble is given in the following table :—

Class of Engine.	Railway.	No. owned.	Total No. of original fractures to date.	No. of Repetitions after repair of original fractures.
XA	G. I. P. R.	49	8	..
	N. W. R.	58	47	4
	E. I. R.	2	4	..
	N. S. R.	4	*Nil.*	*Nil.*
XB	E. I. R.	38	75	74
	E. B. R.	18	46	10
	M. & S. M. R.	25	6	2
	S. I. R.	11	32	5
	N. S. R.	7	8	5
XC	N. W. R.	28	46	14
	E. I. R.	30	58	32
	B., B. & C. I. R.	14	17	8

The following modifications have been tried by the Board with a view to eliminating the defect :—

(1) Provision of stretcher plates located above the springs.

(2) Provision of stretcher plates located immediately above horns.

(3) Removal of boiler support brackets.

(4) Fitting of new horn block castings between the frames.

(5) Fitting of patch plates at leading horn gaps.

(6) Provision of new horn clips with tapered faces.

(7) Provision of radius on frame edges in horn gaps.

With regard to the stretcher plates, the original engines had a horizontal plate extending from the back of the saddle casting to the cross stretcher, level with the outside motion plates; beyond this point there were no horizontal stretchers. The plate referred to had a large hole cut out to accommodate the two vacuum cylinders, and, in our opinion, although the provision of a stay from saddle to motion plate is essential, this particular application lacks rigidity. Where stretcher plates have subsequently been fitted from the level of the motion plate back to the firebox throat plate, the weak stay under the vacuum cylinders has been allowed to remain.

We observed, however, that, on two Railways, radically opposite means of dealing with stretcher plates had been adopted. On the B., B. & C. I. R., at the time of our visit, all their XC engines were being fitted with longitudinal stretcher plates, which were stiffened by deep angles riveted along the diagonals; this makes even a stiffer arrangement than the Railway Board's proposal. In addition, this layout, on one engine, has been carried right through to the saddle casting under the vacuum cylinders, thus avoiding any weak section at this point. On the other hand, the B. N. R. on their M class Compound Pacifics, which are very similar to XC's, have no longitudinal frame staying at all, and little or no trouble with frame fracture has been experienced.

From our observations, the following factors appear to have an influence on this defect :—

(*a*) Heavy flange forces.

(*b*) Restriction of side displacement of bogie.

(*c*) Inadequate staying across the bottom of the horn gaps.

(*d*) Sharp edges left on frame plates.

(*e*) Absence of large diameter radii at the top corners of horn gaps.

(*f*) Absence of adequate frame staying between cylinders and leading coupled wheels.

(*g*) Incorrect location of frame staying.

A reduction of flange forces should result from the recommendations already made in this Report. The horn clips at the bottom of the horn gaps are of poor design with small bearing surface; the Board are now trying a new design in which the horn clip is pulled up against a tapered edge of the frame, but it is too early yet to say if this will be more satisfactory. It is obvious that any looseness at this point will allow vertical breathing in the frame, and cracks will soon appear at the top corners of the horn gap. A more robust form of clip is required, which bears on the horn guides as well as on the frame.

It has long been known, and has been abundantly confirmed by recent research, that nothing is more conducive to fatigue flaws than the presence of sharp edges. Nonetheless, we noticed in India a widespread lack of appreciation of this, which, in our opinion, combined with the small radii in the corners of the horn gaps, had to a considerable extent contributed to the fractures sustained. On the M class Pacifics on the B. N. R., which have given little or no trouble in this respect, a $\frac{1}{4}''$ radius is employed round the edge of the plate at the top of the gaps, and the top corners are radiused to 3″ or 4″. The Locomotive Standards Committee have drawn attention to the importance of this matter in their 1937 report; but we are surprised that attention to the point was not specified by the Consulting Engineers.

The frame staying between the cylinders and leading coupled wheels has already been commented on. In the case of the B. N. R. Pacifics, the presence of inside cylinders, in addition to the stiff frame stretcher between the backs of the outside cylinders, has undoubtedly had the effect of stiffening up the frame at the front end, thus avoiding the incidence of fracture. Moreover, the fact that the leading coupled axle is cranked, and is therefore more flexible, may have brought about some reduction in the forces actually transmitted from the flanges to the frames.

213. *Cylinders and Valve Gear.*—From the behaviour of most of the XB and XC engines on which we rode, it was obvious that there was something defective with the steam passages, ports, or steam distribution. Although the valve gear is of modern design with $1\frac{1}{2}''$ steam lap and long travel, the engines were sluggish, and even with cut-offs of 33 per cent. with

full regulator they were in some cases unable to attain 60 m.p.h., with our 353-ton train on the level. While not all the engines were equally bad, we consider that their performance was much inferior to that obtainable in Great Britain with engines of comparable tractive effort; both in haulage capacity and economy, the engines appeared to be doing less than they should. We recommend a searching investigation into the whole steam cycle, so that, when it is necessary to renew cylinders, an improved design can be utilised. We also frequently noticed that reversing shafts were not sufficiently stiff; the arm remote from the reversing lever vibrated, and must have affected the steam distribution while running. On the other hand, XA engines do not exhibit the sluggishness of the XB's and XC's, are free-running, and, in spite of their small wheel diameter, are fast.

214. *Fireboxes.*—Serious trouble has been experienced with firebox tubeplates cracking in the radius of the top flanges. The following table summarises information supplied by the Railway Board :—

Class of Engine.	Railway.	No. owned.	No. of Firebox Tube-plates changed to date.
XA	G. I. P. R.	49	40
	N. W. R.	58	45
	E. I. R.	2	1
XB	E. I. R.	38	1
	E. B. R.	18	6
	M. & S. M. R.	25	22
	S. I. R.	11	9
XC	N. W. R.	28	41
	E. I. R.	30	26
	B. B. & C. I. R.	14	16

The action taken by the Board consisted of :—

(1) Fitting girder roof stays instead of sling stays at the front end of the crown.

(2) Fitting steel tubeplates.

(3) Increasing the radius of the top flange.

We were informed that these measures, especially the last, were having the effect of reducing the number of failures. We examined a tubeplate at Dohad from an XC engine, which had developed a serious crack along the top flange. This had been clearly caused by the top front edge of the firebox being held too rigidly at a point where there is considerable expansion; apart from the increase in radius which has already been adopted, we recommend that the first row of vertical stays be set further back from the edge of the plate, and that the top row of superheater flue tubes be lowered, to provide a certain amount of flexibility in the top flange. In many British designs it is the custom to have a row of small tubes above the top row of flues, in order to meet this point. In this connection, we draw attention to the methods adopted for tube expansion; if this work is not done carefully, the tube plate becomes forced upwards, which aggravates the shortage of radius at the top.

215. *Bogie Axleboxes.*—Heating of bogie axleboxes has been a troublesome feature ever since these engines were put into service, but not perhaps more so than on other classes. The whole question of heated bearings has been the subject of a special investigation by the Railway Board, and, so far, promising results are being obtained. It is no part of our remit to comment in detail on this investigation, except to say that, amongst the measures now being taken, the provision of suitably designed shields, to exclude dirt and grit, is a step in the right direction.

We will confine ourselves to drawing attention to two aspects, which do not appear to have received sufficient attention. The first has already been referred to, and concerns the way in which the weight is transferred from the spring cradle to the axlebox top. The present method allows the weight to come on one edge or other of the box, and we recommend that a ball end be fitted to the cradle bars which will ensure a central loading of the box in all positions. Freedom of the box in the horns is also desirable, so that when one wheel is higher than the other, the boxes will not bind in the horns. We suggest that this can be effected by the horn cheeks of the boxes being tapered top and bottom, leaving a parallel portion of about 3″ at the centre.

The second point concerns the bearing surface of the axlebox face against the wheelboss. It has already been emphasised how important it is from a riding point of view to reduce side wear on bogie boxes to a minimum; an increase in the surface of contact is desirable, as well as adequate means of lubrication at that point. It was noted that the area of bearing surface had been reduced by the application of some design of dust shields, and this is undesirable.

Making every allowance for the difficulties of operation in India, we feel that the hot box problem is capable of solution. Important results have already been obtained both by the Board's special investigation and by the individual initiative of certain Administrations. It is not the case that this problem is equally acute all over India. On the B. N. R., for example, abnormal trouble is almost a thing of the past; this line has no particularly favourable natural features, and if only all Railways could be brought up to this level, material operating and financial benefits would follow.

216. *Coupling and Connecting Rods.*—Breakage of these rods has also been very troublesome on X class Pacifics. At the time of our visit all the XC engines on the B., B. & C. I. R. were out of service on this account, and were awaiting new rods from England. On information supplied by the Railway Board, the general position throughout the country is :—

XA Leading Coupling at Leading Eye	1
Leading Coupling at Fluted Section	Epidemic.
XB Connecting Little End Eye	4
Connecting Big End Strap	5
Leading Coupling Leading Eye	Epidemic.
Leading Coupling Fluted Section	5
Trailing Coupling Trailing Eye	Epidemic.
XC Leading Coupling Leading Eye	Epidemic.
Leading Coupling Main Crank Pin Eye	1
Leading Coupling Fluted Section	Epidemic.

In August 1937, the problem was submitted by the Board to the Consulting Engineers, who made a mathematical analysis of the design of the rods and issued a report dated July 1938, recommending the substitution of a rectangular section, in place of the I section, when renewals are required; the new rods have increased cross sectional area, giving reduced unit stress. In addition, it was recommended that the sideplay of coupled wheels and axles relative to the frame should be limited to a total of $\frac{1}{2}$″, and should be brought back to normal whenever coupling rod bushes were renewed; also that any grinding necessary to recondition the internal diameter of the coupling rod eyes should be limited to a 3 per cent. increase on the original. Certain other recommendations were also made regarding the material, which was to continue to be plain carbon steel. No rods to the new dimensions have yet been delivered in India, although a number are on order.

From our observations we suggest that the problem of broken side rods would also be assisted by closer attention to axlebox wedge adjustment, a matter which is referred to in Chapter VI. Moreover, we gained the impression that, when bushes are renewed at Running Sheds, the pressing-in pressure is often an unknown quantity, and may attain very high values, thus imposing a severe initial stress in the coupling rod eyes. We recommend that a table of maximum pressing-in tonnage be drawn up for the different sizes, and that hydraulic presses in Running Sheds be equipped with calibrated gauges showing the tonnage which is actually being attained. Where lubrication holes are provided in the eyes of the rods, the edges of such holes should be rounded and polished.

217. *Steaming and Boiler Ratios.*—The steaming qualities of X class Pacifics were noticed to be only moderate. Although not really free steamers, the XA and XC engines were at least reasonably satisfactory; but

all XB engines upon which we travelled showed some restraint in this respect, which can best be summed up by saying that 150 lbs. per sq. in. was the pressure usually observed on the gauge rather than the designed working pressure of 180 lbs. per sq. in.

There are two main factors which may be influencing this, namely, leakage at the valves, and boiler tube ratios. While we did not make any special investigation into steam leakage, there was much in the behaviour of different engines to suggest that leakage through the valves was taking place in varying degrees. We recommend the acceleration of certain trials already commenced with multi-narrow ring piston valve heads.

With regard to the boiler tube ratios, an examination revealed some features worthy of comment. Experience in Great Britain has shown that the ratio of free area through the tubes, to grate area, has a considerable influence on boiler performance; so long as each individual tube is of correct proportions, the heat transfer possible down the boiler barrel will be proportional to the free area through the tubes. The values of this ratio in British practice, for superheater boilers, range from 11·5 per cent. to 17 per cent., and, provided all the other requirements of good design have been satisfied, it is found that boilers occupying the range from 14 per cent. to 17 per cent. are free steamers. Allowing for the 20 per cent. increase in grate area, which is necessary to deal with low grade coal, satisfactory ratios should be of the order of 11½ per cent. to 13½ per cent.

The ratio for the XA is 11·6 per cent. and for the XC 11·4 per cent., but for the XB is only 9·5 per cent. This means that on the XB the total quantity of hot gases, which can pass along the tubes, is restricted to less than the firegrate is capable of releasing, and a severe limitation is thereby placed on the maximum output of the boiler. British experience has shown that boilers so restricted are sluggish steamers at moderate output, and become definitely "winded" when called upon to sustain high output. Individual boiler tube proportions are in accordance with the best practice, as is the ratio of superheater to evaporative tube areas. It is only in total free area, therefore, that the XB is defective, and we recommend that, when tubeplates are renewed, the tubes be re-arranged, if possible, to give similar free area ratios to those on the other X class Pacifics, due regard, of course, being paid to the retention of adequate bridges between the tubes.

218. *Regulator.*—The double beat type of regulator valve is in general use, and it was noted that a slotted quadrant and wing nut secured the regulator handle in any required position, owing to the tendency of this type of valve to work shut. When emergency closing of the valve is required, serious delay may be caused by having to unscrew the wind nut first. We recommend that the wing nut arrangement be abandoned, and suggest that a form of notched quadrant with spring catch be fitted. Figure 32 shows an arrangement based on one already in successful use in England, which should be capable of adaptation to existing stuffing boxes on engines in India.

6. *Any modification that should be made in the procedure hitherto followed for the trial and purchase of engines.*

219. Before dealing with the procedure which we recommend should be followed in future for the trial and purchase of engines, it seems well to consider the possible methods which can be employed for this purpose. We refer later in this Chapter to the possibility of India eventually designing and building broad gauge engines. We confine ourselves here to the following methods which can be used on the assumption that for some years to come engines will continue to be built outside India :—

(1) The Railway Board can supply brief particulars of their requirements to a selected firm of Builders, and leave the details of design and construction to them, subject to inspection by suitable Engineers, either from England or India, reporting direct to the Board. In our view, this course would be undesirable, as it would prevent open tenders.

(2) The Board could send similar particulars to Consulting Engineers, who would be responsible for preparing the necessary drawings and specifications for obtaining tenders in the open market. On acceptance of the tenders, and on placing the orders, the Consulting Engineers would be responsible for approving manufacturing drawings and for inspection. We understand that this was the procedure generally followed by the various Administrations prior to the formation of the Locomotive Standards Committee, and it is still followed by Company-managed Railways when they obtain non-standard engines. The procedure has proved generally satisfactory.

(3) The Board could prepare diagrams of the required engine, specifying the leading dimensions. They could also issue directions as to the different components and fittings to be used. These particulars would be sent to the Consulting Engineers who would then prepare the necessary drawings and specifications, subject to the final approval of the Board. This involves a joint responsibility between the Board and the Consulting Engineers, but leaves the detail design to be worked out by the Consulting Engineers and by the Builders. This was the course adopted in the supply of the X class Pacific engines.

(4) There is a fourth course which appears to be more applicable to modern requirements, and has in a measure been adopted in the case of the new W series of engines now under construction. This is a development of (3) above; the Board, having strengthened its organisation for dealing generally with design and specification, should be able to advise Consulting Engineers more fully as to the detailed requirements of the country. The responsibility would still be shared, but a greater proportion would rest with the Board, who would call for the submission of *as made* drawings prior to manufacture.

We are of the opinion that development in future should follow the procedure outlined in (4) above. The Board, on the one hand, being in close touch with the Administrations, have first hand knowledge of conditions in India, and can act as a clearing house for many of the problems put forward by the users. The Consulting Engineers, on the other hand, having wider contacts and experience, should be able to advise in the light of practice and developments in other countries. The combination of the two should ensure that Indian designs reflect both the needs of the country and the best experience in the world at large. From recent experience it appears that the authorities in India must gradually assume a fuller measure of responsibility for design, and in any case we emphasise the necessity for adhering to the policy of trial before bulk orders, since modern research should now enable decisive results to be obtained with a small number of units.

220. *Relationship between the Railway Board and the Consulting Engineers.*—The Government of India have had the advantage of association with one firm of Consulting Engineers since 1872, in connection with large engineering undertakings for Railways and public works; it cannot be said that their assistance has not been mutually valuable in the past. India is a vast country and, in its development, has an increasingly large number of problems peculiar to itself, many of which can only be properly understood and catered for by those within the country. The formation of the Central Standards Office is an instance indicating the desire of the Government of India to grapple with their peculiar problems in a co-ordinated and scientific manner, and it is no disparagement of the skill and experience of the Consulting Engineers when we say that, in the future, more and more work of design will be thrown on India. With this in mind, we have made our recommendations regarding the expansion of the staff and work of the Central Standards Office.

It has been suggested that the Consulting Engineers, to be effective, should be at the centre of business interests, and have numerous contacts, the more international the better. From this angle, no more suitable centre than London could be selected. Even so, we realise the disadvantages of remoteness, accentuating as it does the difficulties of intimate contact between the Consulting Engineers with Headquarters in Great Britain and the responsible Railway Officers in India, with their fuller knowledge of local conditions. We feel that not only should representatives of the Consulting Engineers frequently visit India, but that it would undoubtedly be to the ultimate benefit of the country if suitable officers on the active list were seconded for special duty with the Consulting Engineers. The experience which these officers would be in a position to gain should be invaluable, particularly when construction of locomotives in India becomes possible.

221. *Construction of locomotives in India.*—We have considered the possibility of India eventually designing and building her own engines, in which even the Consulting Engineers in London would be relieved of all responsibility, except for such purpose of consultation that may at the time be required. While we realise that it will be necessary also to collect a staff of designers and engineers in India, we feel, that, in keeping with the general policy of encouraging industrial development, steady progress is likely to be made in undertaking more and more work of this nature. If this policy is brought to fruition, the prudent course would be to build engines of a type which has been well tried out; it would be undesirable to commence with new types, in connection with which the experience and services of the Consulting Engineers would still be required. Even then, for many years, it appears that it will be necessary to import the major portion of the material.

In this connection, moreover, it is well to bear in mind that, for a long time now, the shops at Ajmere on the B., B. & C. I. R. have been building a few metre gauge engines annually. The work consists of a substantial volume of manufacture in the shops, and the assembly of some parts which are purchased from abroad. We can well envisage the extension of this practice to a certain number of broad gauge engines at one of the major works, such as Jamalpur on the E. I. R., which, with the necessary additional equipment, should be able to handle such an undertaking.

222. *Relationships between the Railway Board and the Administrations.*—We have given considerable thought to the impressions which we gained in India from the various Administrations that their officers felt that much of the responsibility for the type of engine, and for the details of design in connection with it, had been taken from their hands, as the result of the Board's Standardisation policy and the method of dealing with that policy. We are satisfied, however, that there must be some final authority for this purpose, and obviously it must be the Board.

Design and development is dealt with by the Locomotive Standards Committee, which is now on a wider basis than it was when originally formed, and consists of five or six Chief Mechanical Engineers. While this Committee remains so comprised, there is less likelihood of the views and requirements of Administrations being overlooked, and we recommend that there should be no reduction in numbers. We do not know how far the experiments connected with development are dealt with by this Committee, but we consider that there must be some responsible technical authority to decide the type and extent of engine trials to be made. At the present time, however, there appears, on the part of Administrations, to be a lack of interest in the scope of the work undertaken by the Central Standards Office. This is no doubt largely psychological, as the officers of the Administrations take only a small part in this technical development.

We feel that this lack of interest would be overcome by delegating some work to the Administrations themselves; investigations and experiments in connection with locomotive boilers and carriage underframes could be delegated to the Chief Mechanical Engineer of one Railway. Similarly Dynamometer Car tests could be assigned to another Chief Mechanical

Engineer who could also appropriately undertake the work in connection with carriage body design. Electric rolling stock and Metre Gauge locomotives might be dealt with by a third. These are merely suggestions, and it should be possible to allocate other investigations in a similar manner.

The individual Chief Mechanical Engineer who carries out such work would have to institute any trials and experiments connected therewith, and would have to co-ordinate the results of all Administrations undertaking any sections of the work, for which he was being held responsible. It would then be his duty to make interim (if necessary) and comprehensive final reports on the investigation to the Railway Board. On the introduction of any new types of engine, an officer from the Research and Standards Section should be seconded for the special purpose of arranging and supervising the trials. As already suggested in Chapter VII, this officer should work in close association with the Chief Mechanical Engineer concerned, and should jointly report upon the results of the trials to the Board.

223. *The effect of the foregoing Recommendations.*—Action on these lines should relieve the existing Central Standards Office organisation of some work, and would also have the following advantages :—

(1) It should promote the interests of the Railways concerned, and ensure an equitable distribution of work.

(2) Nearly every important scheme would become a direct responsibility of the Director of Research and Standards, and of the Chief Mechanical Engineer concerned; the Chief Mechanical Engineer, would also have a personal and individual responsibility *vis-à-vis* his colleagues on the Locomotive Standards Committee for his share of the work.

(3) A flexible system of distribution would ensure that, within practicable limits, such work was assigned to those Chief Mechanical Engineers, and their Staff, who are best equipped to deal with it.

224. *Functions of the Research and Standards Office.*—Having regard to the value of the work done in the past by the Central Standards Office, it would be unwise to handicap in any way the range of its future activities. The work has been of great benefit to Railway Administrations, and has also contributed to the development of industry in India. We have already referred to this in connection with the standardisation of vaccum brake equipment and components, the results of which have provided a real incentive to manufacture in India. We understand that it is now possible to purchase in the country nearly all the component parts of this equipment, of a standard of workmanship which compares favourably with that obtaining elsewhere. The manufacture of wagons, permanent way materials, signalling, interlocking equipment, and bridgework, has also benefited.

This organisation also co-ordinates the activities of seven Standardisation Committees, and deals with the decisions to be made in connection with work done by the Consulting Engineers, by the Metallurgical Inspector, by Research Officers, and in the manufacturing shops at Tatanagar for carriage underframes. In our opinion, in the interests of efficiency, and for the purpose of training designers the organisation should be considerably strengthened.

We have already referred in Chapter VII to the desirability of continuity of employment for work of this kind. Our views on the Research and Development Section have been stated there, and we feel that it is just as important that similar arrangements should be made in connection with work of Standardisation. One of the outstanding problems which the enlarged Research and Standards Office should keep before it at the present time is the reduction in the tare weight of passenger rolling stock; the introduction of increased amenities for the public generally means additional weight, which reacts on the power of the engine required, and ultimately increases engine axle load, and therefore increases the cost of track construction and maintenance.

225. *Functions of the Mechanical Section of the Indian Railway Conference Association.*—We understand that this section of the Association consists of all the Chief Mechanical Engineers, and meets once a year; it has remitted to it matters relating to the operation and use of material connected with locomotives. It is difficult in such a large country to arrange for more frequent meetings, and, as a consequence, considerable delay occurs in advising Administrations of defects which have been experienced, and which have probably been dealt with independently before the matter has been considered by all concerned.

We suggest that the arrangements pertaining to the Civil Engineering section of the Association should, so far as possible, be applied to the Mechanical Section. These arrangements provide that sections of the work are dealt with by Assistants and Deputy Chief Engineers selected from the Administrations and appointed by the Main Committee, who now meet with the Deputy Chief Controller of Standardisation and make recommendations. This encourages the interests of Assistants in the detail work of the Standards Office, and enables solutions to be found more rapidly than if the matter were considered less frequently at main Committee meetings.

226. *Detailed procedure for the Design and Supply of new Engines.*—After obtaining from the Railways concerned the particulars of their power requirements, and having ascertained that there is no appropriate available standard, or, alternatively, having regard to the information acquired from Consulting Engineers or from Technical Reports which have come to notice, the Railway Board decide that a new type of locomotive is required, the necessary specifications and diagrams should be prepared giving the following information:—

(1) Load gauge.
(2) Wheel arrangements and wheelbase.
(3) Diameter of driving wheels.
(4) Maximum weight on axles.
(5) Approximate weight.
(6) Boiler pressure.
(7) Tractive effort.
(8) Standard parts to be utilised.

The decision regarding the necessity for the new type, and as to the general dimensions and specification, should be taken by the Railway Board. The Research and Standards Office, in turn, should embody in the diagrams and specifications the views of the Locomotive Standards Committee, composed, as already stated, of five or six Chief Mechanical Engineers. We recommend, however, that on completion of this stage, and before any further action is taken, full particulars of what is proposed should be circulated to all Administrations likely to use the new design, so that any views they may have can be given full consideration. In this way, each Administration should feel that it has had some share in the new design, and the criticism that standardised designs are imposed from above should be largely met.

The information should then be sent to the Consulting Engineers to develop the necessary specifications and drawings for tender purposes; the tenders should be submitted to the Board with any recommendations which the Consulting Engineers desire to make. After examination of the tenders, the Board should issue their instructions for the placing of the order; thereafter the Builders should submit to the Consulting Engineers such drawings as are specified, with any suggestions and comments on the design. The Consulting Engineers should forward these drawings, with their own and the Builders' comments, to the Board for approval before work is put in hand.

We are of the opinion that responsibility for all design should jointly rest with the Board and the Consulting Engineers, and the latter should, as usual, inspect the work in progress. Indeed, this joint responsibility must persist, so long as Consulting Engineers are employed, irrespective of the fact that construction drawings may, or may not, be submitted to the Board for approval. In the event, of course, of the Board insisting on any particular feature of design being incorporated contrary to the advice of the Consulting Engineers, the responsibility for that would naturally have to be assumed by the Board.

We recommend that not more than two engines of any new type should be built until a thorough trial has been made under service conditions. After delivery, the responsibility for the organisation of all tests should rest with the Board. An officer from the Directorate of Research and Standards should be placed in charge and he should work with the officers of the Administration concerned. He would record any defects or modifications required, as also the results of all tests made. In this way, the Board would satisfy themselves that all new types of engines are satisfactorily meeting the requirements for which they were designed.

During the tests, advantage should be taken of carrying out any modifications that may be found necessary, so that further trials can be made and the engines altered until the Administration concerned and the Board are satisfied. Until this is done, no more engines of the particular type should in any circumstances be ordered. The Consulting Engineers cannot be held responsible for the trials, but we suggest that they should be kept generally informed of the results, and, if necessary, there should be no hesitation in seeking their advice, so that the fullest advantage may be taken in future design, not only of the experiences in India, but of the information available through the Consulting Engineers.

227. *Summary.*—Our recommendations under this Term of Reference are made with the following objects in view :—

(1) To provide facilities for training designers by strengthening the existing Central Standards organisation, and, therefore, to assist India in the direction of ultimate self-sufficiency. In this way, the proportion of responsibility carried in the preparation of new designs will be gradually increased.

(2) To outline future procedure for the design of engines obtained outside India.

(3) To ensure that there shall be the fullest co-operation, and prompt interchange of information, as between the Administrations, the Railway Board, and the Consulting Engineers with regard to all new designs.

(4) To broaden the base on which Research, Standardisation, and Development are carried out in India.

CHAPTER XI.

Concluding Remarks.

228. We have completed our task in the anticipation that discussion of the subjects under our Terms of Reference will help towards a better understanding of past difficulties in India, and will give a clearer lead for the future. We are aware that our explanation of the complicated phenomenon of hunting has certain limitations, but our recommendations, which are based on practical considerations and experiments, should result in suppressing abnormal oscillation. Arising from our assumptions and deductions, we hope that further investigations will be made, which should increase knowledge of the relationship between track and locomotive, and, consequently, improve operation and enhance safety. For convenience, we have made a summary of our principal recommendations, which will be found, duly referenced, as Appendix I.

229. We are not called upon to consider the justification for the policy of expansion which was being pursued during the years following the Acworth Inquiry; but it is clear that optimistic views were held as to the trend of trade and traffic. Further, the necessity for generously and quickly replacing old locomotives, while curtailing the fuel bill and pursuing Standardisation as another avenue for economy, were matters which were looked upon as of paramount importance, little progress having been possible during, and immediately after the Great War.

Accordingly, 218 X class Pacific engines out of 284 were authorised in less than three years between 1925 and 1928; we are satisfied that such large and repeated orders would not have been placed had not all concerned been confident as to design, which followed established practice and available experience in Great Britain at the time. Nevertheless, in view of the warnings received, the wiser course for the Board to have taken, as indeed they admit today, would have been to continue the purchase of further well tried B. E. S. A. engines (suitably modernised), pending the pursuance of the policy of thorough trial of the new Pacific types, a policy which the Board had previously laid down and are resuming in the case of the new WL class Pacifics.

In view, however, of the state of knowledge, and method of testing adopted at the time, it seems unlikely that, except for reducing the number of Pacific engines now in service, adherence to this policy would have assured immunity from subsequent troubles, or altered the conditions of operation which have led to this Inquiry. Indeed, one main defect in design, namely, the weakness of the bogie control springs, though recognised as early as January 1929, was not effectively pursued. In fact, its correction, with the other basic defects which render these engines so sensitive to condition of the track, has unfortunately been unduly delayed, on account of uncertainty and lack of decision with regard to fundamental requirements.

230. One test of Railway efficiency is the rapidity with which preventive measures are adopted when a reasonable factor of safety has been shown to be lacking. It is desirable that formal Inquiry by Government Inspectors should, *prima facie*, be undertaken in every case of passenger train derailment, and their Reports should be circulated without delay. We feel that, in the past, a too rigid departmental outlook was prone to exist, and may have reacted detrimentally; but if confidence has been shaken, this has resulted as much from the time taken to make effective alterations as from lack of knowledge of what has already been done to improve both engines and track.

The action taken since 1929 has been described, and we have had regard to the apparent delay in realising the underlying causes of the trouble experienced, namely, the punishing effect of imperfectly controlled engines on indifferent portions of track. Although it may appear today that the circumstances leading up to the earlier derailments were not fully recognised and taken advantage of at the time, we are generally satisfied that the major defects, which have affected the engines as vehicles, have been under constant consideration by the Railway Board.

Developments, however, took place slowly because of the complexity of the problem of hunting, the lack of quantitative data, and particularly because of the conflicting nature of the reports received. It was not until research was commenced by the Board that it became possible, for the first time in India, to bring the relationship between engine and track under scientific examination. The Board are now in possession of autographic records and quantitative results, which were placed at our disposal and which have been of great assistance to us in arriving at our conclusions.

231. We consider that the introduction of Pacific engines into India was justified, and that they have a definite field of use for efficiently meeting certain traffic and technical requirements; a good big engine is always better than a good little one from the operating point of view. At the same time, we were informed that a large amount of business could be more economically undertaken with improved and modernised B. E. S. A. type engines. We draw attention, on financial and traffic grounds, to the desirability of reducing the weight of trains and of individual rolling stock; we feel that serious consideration should be given to this subject, and to the development of additional standard designs of engines.

232. Our investigations have proved beyond doubt that X class Pacific engines are particularly sensitive to defective portions of track, and to poor conditions of engine maintenance; either or both induce oscillations which may readily build up to serious hunting at certain speeds. Further, owing to the side controls of the bogie and hind truck being inadequate, this phenomenon sets up heavy flange forces at the coupled wheels, which may result in track distortion or gauge spreading, where conditions of formation, construction or maintenance are unfavourable.

With regard to the suitability of the track for these engines, there is little doubt that when they were introduced they immediately reacted to weak spots; but we are satisfied that, generally, suitable action by speed restriction and strengthening was taken to meet the situation which arose from introducing machines, the capacity of which may be said to have been materially ahead of the characteristics of the track. This was a case of history repeating itself; it has happened in other countries, and we make this comment with no intention to criticise, having regard to the results of recent research and experience which were not available in the past.

233. In our opinion, the main avenues by which difficulties can be surmounted in future concern the design and maintenance of the locomotive, the construction and maintenace of the permanent way, and the speed of operation. We desire to emphasise that design must have regard to the inescapable features of the country, and to the financial limitations which control the conditions of both track and engine. From what we saw of track, shops, sheds and engines, we were, on the whole, favourably impressed by the standards of maintenance; but the fall in expenditure is significant of the efforts being made towards retrenchment.

It is no part of our remit to consider the details of the Government's financial policy, and we do not suggest that, up to the present, this policy has impaired the efficiency of the Railways. But we feel that steps should be taken to guard against the conceivable development of a position whereby the allocation of adequate moneys to the Railways may be jeopardised. Indeed, it seems that already there may be some tendency towards too easily carrying economy beyond the limit, as based perhaps on theoretical, rather than on practical, considerations. While there appears to have been lack of appreciation regarding the design, as a vehicle, of the X class Pacific, adequate maintenance of both engine and track is of great importance in considering the problem of the reactions of one on the other.

We feel, therefore, that it is our duty to draw the attention of the Government of India to the comparative ease with which false economy can be effected, with perhaps misleadingly creditable results, and to the serious economic and psychological consequences of persistent financial pressure in this respect. High speed operation of heavy modern engines, even of perfect design and upkeep, will cause inestimable damage to unsuitable track within a very short period. Deterioration can only be made good over an extended period, and at considerable expense, far in excess of that incurred by appropriate systematic maintenance. Before the advent of Pacific engines, heavy train services were worked by comparatively small engines, and maximum speed was limited by boiler capacity. The larger Pacifics, with their greater boiler horse-power, are able to sustain higher average speeds, thus maintaining maximum speeds for longer distances, and therefore increasing the stress on the track, showing up weaknesses more easily and more frequently.

234. At any given speed, the flange forces acting through an engine depend on the measure of track irregularity which is encountered under load. The value of these forces depends on the extent to which oscillation of the engine develops, and the principal means of control in this respect is the sufficiency of the reactions afforded by the guiding wheels, in relief of the coupled wheels. The extent of the lateral forces brought to bear on the track has only recently been appreciated in India; the necessity, therefore, for the continuance of the research, which has already been initiated, is fundamental. In addition to the extended use of the Hallade track recorder, consideration should be given to the introduction of special test cars for the co-ordinated and direct measurement of track irregularities and flange forces.

We recommend an enlarged organisation for Research and Standards, so that technical development can be progressively dealt with, and the necessary training and experience gained, to enable India, as time goes on, to cope with her own problems, including the building of Broad Gauge locomotives. We also refer to the necessity for improving the means of collaboration between the Administrations, the Railway Board, and the Consulting Engineers.

We draw particular attention to the present speed of operation, and the necessity for strictly complying with permissible maxima as laid down by the Chief Engineers; such maxima should have regard to all the circumstances, and in addition to the working speed, should be notified to all concerned. Although it is common knowledge, confirmed by our observations in India, that experienced drivers can gauge their speed within narrow limits, they are prone to under-estimate it when decelerating to observe speed restrictions; we recommend that all engines operating mail and express passenger trains be fitted with speed indicators. We have already referred to the importance of maintaining the unfettered discretion of the responsible Civil and Mechanical Engineers in respect of safety.

235. The record of safety in operation of Indian Railways is an enviable one; the 284 engines, to which our Terms of Reference apply, have run no less than 90 million miles, and the incidence of derailment has been mainly confined to the first five years of service. The well-merited confidence, however, which was placed in the Railways by both the public and the staff, appears to have been shaken, following the accident at Bihta, the unfortunate results of which were quite exceptional.

We hope that our recommendations, and the action which should follow them, will re-establish confidence, and that this Report will focus attention on the inter-dependence of the standards of construction and maintenance in relation to speed and load, as affecting both track and locomotive. There appears to be no reason why X class Pacifics should not have many years of useful and reliable work ahead of them, provided that they are modified as recommended, that attention is paid to particular aspects of track and locomotive maintenance, and that speed of operation is adjusted to prevailing conditions in both respects.

We have the honour to be,

SIR,

Your Lordship's most obedient Servants,

A. H. L. MOUNT,
Lt.-Colonel,
Chairman.

R. CARPMAEL,
P. L. DHAWAN,
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} *Members.*

E. S. COX, *Technical Assistant.*

K. C. BAKHLE,
Secretary.

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APPENDIX I.

(Reference Paragraph 228.)

SUMMARY OF PRINCIPAL RECOMMENDATIONS AFFECTING THE RIDING OF X CLASS PACIFIC ENGINES

(Numbers in italics refer to relevant paragraphs and figures.)

Bogie :—

1. Spring control to be increased and alterations to be made. *(76, 77 ; 79-81 ; 109 ; 111 ; 112 ; 151 ; 163 ; 167 ; 199 and Figs. 30 and 31.)*

2. The surface of the bogie slides to have as low and constant a coefficient of friction as possible. *(167 ; 199.)*

3. The slides to be reduced in area and ground to a smooth finish. *(167 ; 199 and Figs. 30 and 31.)*

4. The circular pivot plate of the bogie to be faced with friction material. *(199 and Figs. 30 and 31.)*

5. The flanges of the wheels to be increased in thickness on each side. *(77 ; 199.)*

6. Limits of wear and sideplay to be prescribed and rigidly enforced. *(77 ; 111 ; 199.)*

7. A ball and socket arrangement to be provided between the ends of the spring cradle bars and the axleboxes. *(199 ; 215 and Fig. 30.)*

8. Axlebox flanges to be tapered outwards or the horncheeks barrelled; adequate dust shields to be provided. *(199 and Fig. 30.)*

Coupled Wheels :—

9. Limits of wear of the hub face of axleboxes to be prescribed and rigidly enforced. *(111.)*

10. Recommendation 8 to apply. *(77 ; 199.)*

Hind Truck :—

11. The Cartazzi slides to be removed and replaced by flat slides with unlubricated friction material. *(79-81 ; 109 ; 151 ; 164 ; 200.)*

12. The lip type bearing to be standardised. *(200.)*

13. The guiding surfaces of the radial axleboxes to be increased and fitted with renewable sections; axlebox flanges to be tapered outwards or the horncheeks barrelled. *(200.)*

14. Recommendations 5 and 6 to apply. *(77 ; 111 ; 200.)*

Main Frames :—

15. Adequate stiffening to be provided between the bogie pin and the leading coupled wheels. *(77 ; 109 ; 111 ; 202 ; 212.)*

16. Attention to be paid to weight distribution. *(206.)*

Connection between Engine and Tender :—

17. The Goodall drawgear to be replaced by a plain bar type, and independent side buffers to be fitted in conjunction with flat rubbing blocks. *(82 ; 109 ; 165 ; 201 and Fig. 22.)*

18. Where German buffing gear has been fitted this may be retained with certain modifications. *(82 ; 201.)*

Tender :—

19. Discs of friction material to be fitted to the centre plate of each bogie. *(203.)*

20. Brasses of the lip type to be fitted to all journals of bogie and six-wheeled tenders. *(203.)*

Engine Trials :—

21. Two engines of each of the three classes to be altered in accordance with our recommendations, and a full series of trials on straight and curved track, to be carried out with each using apparatus for recording flange forces. *(155 ; 204 ; 206.)*

22. During the life of engines, spot checks to be made under different conditions of track, weather, and maintenance. *(155 ; 206.)*

Engine Maintenance :—

23. Mechanical Inspectors, divorced from routine office work to be appointed for the specific purpose of visiting motive power depots. These Officers also to make periodical visits to the main workshops. *(120.)*

Speed :—

24. The present limit of 45 m.p.h., conditionally imposed by the Railway Board, should not be raised, until test records prove that the flange forces of engines modified to our recommendations have been reduced to suitable values. *(191-193 ; 207.)*

25. Regulations governing maximum permissible speeds of X class Pacifics, should be issued by the Railway Board on recommendations of General Managers, based on the advice of their Engineers, and endorsed by Government Inspectors. *(208.)*

26. Whilst the Chief Engineer lays down the maximum permissible speeds, the Operating Department, when drawing up the working time-table, should obtain the concurrence of both the Chief Engineer and the Chief Mechanical Engineer to the maximum booked speeds. (*100 ; 208.*)

27. Early steps to be taken to fit speed indicators on engines operating mail and express passenger trains. (*209.*)

Track :—

28. On black cotton and other weak soils, rigid sleepers, preferably timber, should be used. (*92.*)

29. Systematic research into the problem of the best method of blanketing and ballasting on various soils to be undertaken. (*94.*)

30. Research should be undertaken also to determine the lateral stability of tracks, with different kinds of sleepers, commencing with the D. and O. plate sleeper. (*74 ; 88 ; 134 ; 154 ; 155.*)

31. The number of sleepers to be raised to a minimum standard of N +3 for all main lines, increased where necessary on weak formation and on curves. (*93 ; 195.*)

32. Where the heavier X class Pacifics run on tracks weaker than the standard 90 lbs. F. F., renewal with the standard permanent way should be carried out within an economically practicable period. (*86 ; 194 ; 196.*)

33. Extended use to be made by Civil and Mechanical Engineers of the information afforded by the Hallade track recorder or similar apparatus. Special testing cars should be introduced. (*97 ; 101 ; 138 ; 139 ; 142 ; 155.*)

34. Manning standards of main line permanent way gangs should be reviewed. (*98 ; 99.*)

35. The system of training of permanent way staff should be encouraged and extended. The recruitment of literate gangers is worthy of consideration. (*96.*)

Notes :—

(i) Other recommendations with regard to X class Pacifics are contained in paragraphs 113 ; 211 to 218.

(ii) Recommendations affecting new Pacific engines are contained in paragraph 205.

(iii) Recommendations for the organisation of Research and Development are contained in paragraph 156 ; 157 ; 222 to 226.

APPENDIX II.

(Reference paragraph 23.)

Railway Board's Memorandum of 1923 on Standardisation of locomotives circulated to Agents of Class I Railways.

In 1903 the Locomotive Committee of the British Engineering Standards Association at the request of the Secretary of State for India, with the assistance of the Consulting Engineers and Locomotive Manufacturers of the country, considered the question of the most suitable design of locomotives for use on the railways in India and of the Standardisation of their component parts. The Committee prepared designs of certain types which it was thought would prove universally useful on the majority of Indian railways. Designs for additional types were subsequently evolved and from time to time modifications and improvements have been incorporated in the original designs.

2. The B. E. S. A. standard types were adopted for all railways worked by the State, but State railways worked by companies although ordering similar types of locomotives designed them to their own standards. In many cases it has been found that the differences in detail vary very little from the B. E. S. A. standards but differ sufficiently to preclude interchangeability. In recent years some of the State Railways worked by companies have adopted B. E. S. A. standard types but the full advantage of doing so has been somewhat vitiated by the departure from standard in certain details. Locomotive Superintendents of the State Railways have also specified this or that gadget which has involved departures from standards.

3. It is fully admitted that mistakes were made in the original designs of the B. E. S. A. standard types, mistakes which were principally due to the fact that the designs were prepared on inadequate data supplied from India and further aggravated by large numbers of locomotives being built and sent out to India without any attempt being first made to try out one or two of each type in order to discover and eradicate errors which must inevitably arise however carefully designs are prepared. Most of the errors have been corrected and do not appear in modified designs.

4. There is no reasonable doubt that all railways are now faced with the problem of getting out designs for more powerful locomotives to meet altered conditions owing to increases in the loads of passenger and goods trains and the urgent necessity of increasing grate areas suitable for the quality of coal they now have to burn.

5. In this connection, it is desirable to refer to the very great importance of adopting universal standards for all types of locomotives both on the 5′ 6″ and metre gauge railways, in order to meet demands for concentration and ordinary rushes of traffic which at times cannot be dealt with by the total locomotive stock on the parent line. It is unnecessary to dilate on the advantages of meeting such contingencies by being able to transfer types of locomotives, which are in all details interchangeable with those already existent on the system to which they are transferred.

6. The possible grouping of certain Administrations is also an incontrovertible reason why locomotive stock should be standardised, as it is obvious that no economy in working costs of the locomotive department can be anticipated if workshops have to maintain duplicates, patterns, dies, etc., for a multiplicity of different classes of types of locomotives.

7. A Committee appointed by the Indian Railway Conference Association to consider Resolution No. 31 of the 1922 proceedings has recently recommended that the Standardisation of locomotives, coupled with periodical revision of standards, is essential in the interest of economy and efficiency and recommend that additional types be introduced suitable for burning low grades of coal.

8. The Railway Board are in entire agreement with the Committee's recommendation and trust it will be adopted by all Administrations.

9. The Railway Board desire to bring the following points to notice and particularly wish to emphasise that they realise a certain amount of latitude must be allowed in the interchangeable details of standard types of locomotives. For instance, on some systems water may be unsuitable for steel tubes and steel fireboxes ; in such cases there would be no objection to brass tubes and copper fireboxes being specified ; others may not require a bogie tender, in which case they are at liberty to specify a six-wheeled tender ; in some cases when two classes of a type are standardised, an Administration would be permitted to adopt the one most suited to local conditions of traffic.

10. The Board are of opinion that in dealing with the question of Standardisation it is important that a general specification and diagram for each type and classes of a type should be prepared in India and submitted to the Railway Board for approval. These will be sent to the Secretary of State, who will be asked to arrange with the B. E. S. A. to prepare working drawings in consultation with the Consulting Engineers to the Government of India, and manufacturers of locomotives. The drawings when completed will be submitted to India to the Railway Board, who will forward them to the Locomotive Standards Committee for scrutiny. After approval by the Committee the drawings with modifications, if any, will be returned to the Railway Board for final approval and will then be submitted to the B. E. S. A. through the Consulting Engineers to the Government of India.

11. As soon as the designs of types or classes of a type have been finally accepted by all concerned, each Administration requiring engines should be permitted to indent for not more than two or three of a type or class of a type. These engines should be thoroughly tried out

for at least two years. During that period records should be maintained of running and maintenance costs and any defects carefully noted. All the information obtained by each Administration should be communicated from time to time to the Locomotive Standards Committee and at the end of the trial period the pooled experience of all Administrations should be carefully analysed by the Committee and any modifications, which must be unanimously agreed to, must be incorporated in the standard designs and submitted to the Railway Board for approval before any bulk orders are placed.

12. Once the design has been finally approved, no deviation should be permitted in any Indent without the previous approval of the Locomotive Standards Committee and the Railway Board.

13. Improvements on original design should be encouraged and Locomotive Superintendents should be given a free hand to try them out, but the trials should be confined to as few engines as possible and preferably on more than one system, so that pooled experience will be available for the consideration of the Locomotive Standards Committee and the Railway Board before a modification in design is recommended.

14. It is further desirable in order to ensure efficiency and progress and to prevent stagnation that standard designs should be reviewed periodically and added to as required.

15. The Railway Board do not propose to specify types or classes of types which should be adopted, but consider the following points which require special consideration :—

(*a*) Number of types and classes of a type to be kept down to a minimum.

(*b*) Axle loads to conform to the standards of loading recommended.

(*c*) Balancing in co-operation with engineering requirements.

(*d*) Lighting of reciprocating parts.

(*e*) Accessibility and economical cost of working.

(*f*) Adequate boiler power.

(*g*) Largely increased grate areas to permit of the more extended use of inferior coals. Up to date practice in other countries should also be kept in view. The possible benefits to be derived from using 3 and 4 cylinder locomotives, boosters, mechanical stokers, combustion chambers, the necessity for interchangeability of boilers and the interlocking of details such as cylinders, axleboxes, wheels and axles, mounting, are all points which should be carefully considered.

16. Although it is realised that on some Administrations an articulated type of locomotive may be required, it is essential that an additional class of a new standard type should not be introduced for a particular Administration because the present weight of rail or strength of bridges is not up to the proposed new standard of locomotive. In such cases the Administrations should either bring its rails and bridges up to suit the new type or class of a type, or if the traffic offering does not warrant such measures existing standard B. E. S. A. types should be specified.

17. It is recognised the Standardisation of locomotives to meet present and future requirements is a work of some magnitude and cannot be efficiently or expeditously carried out, unless a whole time committee is employed on the necessary investigations. The Railway Board, subject to the concurrence of the Indian Railway Conference Association, propose to nominate two locomotive Officers and a Secretary, to deal with the recommendations made by the locomotive committee of the Indian Railway Conference Association and formulate proposals for consideration by the Locomotive Carriage and Wagon Superintendents' Committee at their meeting in February next. The Board also propose that this Committee should subsequently become a permanent standing committee to be known as the Locomotive Standards Committee, which will refer all questions of locomotive Standardisation direct to the Railway Board.

18. It is recognised that some time must elapse before the new standard types of locomotives will be available for use, but it is felt that a very careful preliminary investigation is of paramount importance and new types should be thoroughly tried out before standards are finally accepted.

19. The Railway Board attach considerable importance to the introduction of the existing B. E. S. A. standard types of locomotives on all 5′ 6″ and metre gauge systems, particularly as new standard types will, it is believed, embody many of the details which have proved satisfactory in existing B. E. S. A. standards. The Board, therefore, hope that all Administrations will assist them to attain the desired Standardisation of locomotives and component parts by retraining from ordering other than B. E. S. A. standard types of locomotives in all future indents. Apart from the reasons already adduced in favour of Standardisation, it would seem that manufacturers would be able to build at a lower cost and in a shorter time if they knew there was a reasonable prospect of getting repeated orders to standard types ; also it may safely be anticipated that stocks of spares would be held in India by the agents of manufacturing firms, and the necessity for Administrations to hold large balance of duplicates by indenting on England would, to a very great extent, be obviated.

APPENDIX III.

(Reference paragraph 25.)

ENCLOSURE TO RAILWAY BOARD LETTER NO. 204-S., DATED 14TH FEBRUARY 1924.

Memorandum for the Committee appointed to standardise the several modifications introduced into British Engineering Standards Association types of locomotives and to prepare diagrams and general specifications for new types required on broad and metre gauge systems.

The Committee will be a permanent one consisting of two members and a secretary nominated by the Railway Board dealing with all questions affecting locomotive design and all matters in connection therewith should be addressed to the Secretary.

2. In order to carry out its initial investigations it will be a whole time committee for approximately three months submitting its report to the Railway Board. The Committee should arrange to visit the headquarters of the different administrations and obtain from the technical officers all necessary information regarding practical difficulties which have been experienced and steps taken to surmount them.

3. The existing B. E. S. A. types of locomotives have been in existence for several years but due to modifications introduced by individual administrations it is generally admitted it is now almost impossible to ensure complete uniformity in the designs of any one type or interchangeability as between types.

4. An organised effort is now required to bring existing B. E. S. A. types up to date incorporating such modifications as practical experience has shown to be necessary with a rigid adherence in future to accepted standards. Once amended or new designs are accepted, no modifications are to be introduced by users, Consulting Engineers or Manufacturers, without the previous approval of the Railway Board. In order to ensure progress and prevent stagnation standard designs should be periodically reviewed.

5. When a modification of an approved design is desired the locomotive superintendent or chief mechanical engineer should, after consultation with the transportation department where the operating of and running repairs to locomotives are not under his jurisdiction, prepare drawings and state reasons for the modification. The proposal should then be submitted to the Committee through the Secretary for examination, and, if approved, arrangements will be made for a trial to be carried out not only by the administration advocating it but by all systems using the type of locomotive on which the alteration is suggested. The trials and their duration should be restricted to the number of locomotives and the time considered essential by the Committee to obtain satisfactory results. On completion each system should report results to the Secretary and the Committee will then forward its recommendations to the Railway Board, who will decide whether the modifications proposed should or should not be incorporated in standard designs.

6. As regards designs of new types of locomotives the Committee's special attention is drawn to the Railway Board's letter No. 900-W.-23, dated the 15th November 1923 on the coordination of requirements in respect to axle loads, weight of rails and strength of girders ; and should also bear in mind the schedules of dimensions recommended for 5 ft. 6 in. and metre gauge standard dimensions.

7. The new types to be evolved will depend on the actual requirements of all administrations, but the chief points, among others, requiring special attention are :—

(*a*) Number of types and classes of a type to be kept down to a minimum.

(*b*) Axle loads to conform to the standards of loading existing and recommended.

(*c*) Balancing in co-operation with the Engineering department.

(*d*) Lightening of reciprocating parts.

(*e*) Weight in relation to tractive effort.

(*f*) Accessibility and economical cost of working and maintenance.

(*g*) Adequate boiler power.

(*h*) Largely increased grate areas to permit of the more extended use of inferior coals.

The possible benefits to be derived from using more than two cylinders, boosters, mechanical stocking, combustion chambers, the avoidance of tortuous exhaust passages, the necessity for interchangeability of boilers and the interlocking of details such as cylinders, boxes, wheels and axles, mountings, the possible advantages of steel fireboxes, etc., etc., are all points requiring careful investigation.

8. When dealing with new types or classes of a type the Committee should prepare diagrams and general specifications bringing to notice and special points they desire should be incorporated in the design. These diagrams and general specifications will then be forwarded to the Consulting Engineers to the India Office who will be asked to prepare working drawings in consultation with the British Engineering Standard Association and manufacturers of locomotives. The drawings when completed will be submitted to India to the Railway Board and forwarded to the Committee for scrutiny. When finally approved by the Committee and the Railway Board, arrangements will then be made for two engines of each type or classes of a type to be built for

each administration requiring them and these engines should be thoroughly tried out for at least two years. During that period careful records should be maintained of running and maintenance costs and submitted to the Committee embodying also any alterations required. The pooled experience of the administrations should be considered by the Committee and any modifications proposed must be incorporated in the original designs and approved of by the Railway Board before any large orders for new types are placed.

9. As far as possible the Committee should in preparing diagrams and general specifications for new types reproduce existing standards where such have proved to be satisfactory, but there should be no hesitation in departing from existing standard practice where practical experience has shown that an improvement is absolutely necessary.

10. The Railway Board wishes to emphasise the vital importance of a strict adherence to accepted standards and desires the Committee to particularly impress on the locomotive officers of the different administrations the very considerable advantages to be gained by specifying B. E. S. A. designs as now to be revised by the Committee when replacing or adding to locomotive stock.

APPENDIX IV.

(Reference paragraph 28.)

No. of Engines built.		Trailing Coupled Wheel to Hind Truck.	Actual Coupled Axleload.	Maximum Virtual Axleload at 5 r. p. s.	Engine Weight in working Order.	Tractive effort at 85 per cent. boiler pressure.	Total Engine Wheel-base.	Weight per foot run of Wheel-base.
			Tons.	Tons.	Tons.	lbs.		Tons.
	4-6-0 type.							
	B. E. S. A. . .	..	17·5	21·64	73·1	22,600	27′ 3″	2·68
2	B. N. R. 1938 .	..	17·0	21·69	74·9	27,797	26′ 7″	2·81
	Pacifics 1924.							
2	B. B. & C. I. R. .	9′ 8″	19·75	24·57	94·2	27,200	34′ 8″	2·72
2	E. I. R. . .	7′ 6″	16·6	19·87	82·45	23,100	33′ 2″	2·48
2	M. & S. M. R. .	9′ 0″	17·0	21·44	82·4	28,021	33′ 9″	2·44
	Pacifics 1928-32.							
113	XA . . .	7′ 0″	13·0	15·94	66·6	20,960	29′ 7″	2·25
	XA . . .	8′ 0″	13·0	15·94	67·15		30′ 7″	2·20
	XB . . .	8′ 0″	17·0	21·23	90·25		33′ 7″	2·69
99	XB . . .	9′ 6″	17·0	21·23	89·36	26,760	35′ 1″	2·55
	XB 1935 . .	10′ 6″	17·0	19·16	89·36		36′ 1″	2·48
72	XC . . .	9′ 6″	19·7	24·56	97·1	30,625	35′ 1″	2·77
18	B. N. R. M Class Pacifics, 4 cylinder, 1929.	9′ 6″	21·45	22·88	105	40,653	36′ 1″	2·91
4	XS 4 cyl. 1930 N. W. R. . . .	9′ 6″	21·5	23·63	108	34,400	35′ 5″	3·05
2	XP 1937 G. I. P. R.	10′ 6″	18·66	21·40	99	31,220	36′ 10″	2·69

APPENDIX V.

(Reference paragraph 30.)

NOTE DATED 12TH JANUARY 1925, BY A PARTNER OF THE CONSULTING ENGINEERS ON STANDARDISATION OF LOCOMOTIVES FOR INDIA AND THE WORK OF THE BRITISH ENGINEERING STANDARDS ASSOCIATION (B. E. S. A.).

Having now visited a number of Railways, both Board and Metre Gauge, and seen nearly all classes of Standard Locomotives at work, I take the opportunity of making a few remarks concerning the British Engineering Standards Committee in London, whose splendid work in connection with Indian Railways, continued over many years, it seems to me there is in some quarters a tendency to ignore.

2. Short as my time in India has been, I have been able to see specimens of practically all of the *latest* types of B. E. S. A. locomotives. They are well reported on by their Drivers, are economical as regards coal consumption, and will bear favourable comparison with similar engines on the leading Railways of Great Britain and the Continent. Where trouble has been experienced, it was found that it has been in many cases confined to the older patterns and these have been rightly dealt with by the Standards Committee in India in their Report.

3. It may be of interest to recall briefly the composition of Committee of the B. E. S. A. on standard locomotives and the function of the Association. It seems to be assumed in some quarters that the Association is a body of designers who produce types of locomotives which *they* consider suitable for India, and who have no knowledge of the conditions obtaining there, and that they have failed to produce types suitable for the country or to keep pace with the growth of traffic and modern design.

These ideas require correction. The B. E. S. A. consists of the Consulting Engineers to the Government of India, and also those of other Indian Railways, together with certain of the Locomotive Builders who have wide experience of design all over the world and who are strongly represented on the Committee, as also are the British Railways whose experience of certain details in actual service is most valuable.

4. A considerable percentage of these Members are either *ex*-Indian Railway Officers both on the Consultant and the Manufacturing side, so that there is not the ignorance of Indian conditions which is sometimes assumed.

5. The functions of the B. E. S. A. have been, not to *propose* new types, but to produce designs of the types recommended by India from time to time to meet traffic conditions there.

The Committee meet annually to revise the Standards in the light of reports received during the preceding year and to bring the details up to the latest approved practice. It is a legitimate criticism that the B. E. S. A. have not produced a recent publication of the Standards. This is partly due to the War and change by death and resignation of the personnel, but it is in a way a tribute to the fact that improvements in design have followed so quickly that it has been very difficult to produce a publication which is quite up to date when printed, and it will be understood that the B. E. S. A. are reluctant to put forth to the world a revised publication which is not in accordance with the latest practice approved by them.

All the B. E. S. A. types have been re-designed as Superheaters when so required, with new cylinders, all have been or are being rebalanced and generally brought up to date, and I understand that the revised report and diagrams are in draft and are shortly to be published.

6. A word about " Wide firebox " design :—Wide firebox designs were not included in the B. E. S. A. series because, until quite recently they had not been asked for, and the B. E. S. A. had received no request to design them. The recent demand for them was brought about by the demand for types which would burn the inferior fuel which has now to be used, and which the existing types of B. E. S. A. engines were not designed to burn. That a wide firebox is necessary for this class of coal is readily admitted, even if it does necessitate designs of engines which carry with them the disadvantages of greater first cost, a troublesome trailing wheel, and firebox plates which are difficult to flange and which it is feared may prove somewhat costly in maintenance.

It has been stated that the American Locomotive Builders alone have any experience of these wide-firebox engines, and I have seen some fine specimens of the 4-6-2 and 2-8-2 types recently delivered to the M. & S. M. Railway for trial. It is true that this type is largely used in America, but is also well known in England. Experimental broad-gauge engines of this type have been built by British Builders and are at work on the B. B. & C. I. Railway and the E. I. Railway on the footplate of which I have ridden when doing their regular traffic work. So far they are well reported on, and designs for both Broad and Metre Gauge of this type are now before the Loco Standards Committee for discussion.

Many of the details of these new types the Loco. Standards Committee recommend should be incorporated in the existing B. E. S. A. standards and the B. E. S. A. will, I feel sure, be prepared to deal with them and with the new standards as recommended in para. 8 Appendix I of the Loco. Standards Committee's Report ; in fact the B. E. S. A. are generally in agreement with the recommendations at the Loco. Standards Committee of India, and have informally discussed its recommendations and also the outline designs which I have been able to put before the Loco. Standards Committee for discussion.

APPENDIX VI.

(Reference paragraph 31.)

MEMORANDUM BY CHIEF MECHANICAL ENGINEER, B. B. & C. I. RAILWAY, DATED 7TH AUGUST 1924 ON STANDARDISATION.

The Railway Board, in letter No. 2640-S., dated 23rd July 1924, asks for a record of opinion by the Indian Railway Conference Association on the proposals contained in Railway Board's letter No. 588-F.—16, dated 15th September 1923 and amplified by the Chief Commissioner in his address to the Agents of Class I Railways assembled at Calcutta on 16th October.

The problem naturally resolves itself into two divisions :—

(1) What degree of standardisation is desirable ?

(2) What is the best organisation to secure and maintain that degree of standardisation ?

The degree of standardisation attainable.—

2. On the principle that it is always best to know what work needs performing before deciding on measures to be adopted for performing it, a decision on first question is desirable.

This has often been discussed and a good deal of difference of opinion exists as to what is and what ought to be the ultimate aim. No guiding principle has been laid down and it is admitted that it would be difficult to formulate one that would be comprehensive and at the same time definite.

Standardisation is only desirable in so far as it —

(1) reduces cost of construction,

(2) reduces cost of maintenance, and

(3) facilitates operation by making possible a reduction in the time a machine is under repairs.

Of these three objects the last two offer by far the greatest possible opportunities for securing savings and it will invariably be found that standardisation which reduces cost of construction at the expense of maintenance is undesirable.

3. On page 2, the Chief Commissioner states that (1) " progressive standardisation " is desired, (2) this Committee should " be moving towards improvement ", (3) " we do not want hard and fast standards ", (4) " we do not want to rule out modifications which are found necessary for local purposes ".

It is difficult to believe after perusing item 6 of the Agenda that the two latter objects would be realised under the proposed organisation if attached to the Railway Board.

Considerations affecting degree of standardisation obtainable.

4. Standardisation is a vague term. It has of recent years acquired popularity as a slogan on public platform and in the popular press. It has been hailed as the remedy for so many evils which it is powerless to cure.

We are in this case dealing with an engineering problem and it is necessary to consider what we really want and how we are going to get it.

In any problem of this nature nothing can be lost by studying past history as we are not likely in India to succeed where others have failed under more favourable conditions.

The outstanding examples of successful standardisation will be found almost exclusively in the category of small units from which more complicated machines are constructed. Take for instance screws and screw threads, structural shapes, motor car wheel rims. Nobody questions these. They have come to stay. It would be almost impossible to get on without them. At the other extreme there have been standard ships and standard locomotives in America and India. These are examples of attempted standardisation of highly intricate machines ; of standard ships and the standard locomotives produced during the War in America nothing is heard now-a-days. There were hardly any constructed after the War period.

From item 6 it would appear that the Railway Board does not even consider the standard locomotives in India as a success. The reasons given in Agenda for lack of success of these Indian locomotives will be considered later.

5. Between the two extremes above enumerated standardisation has been tried in various degrees in many fields. The motor car is probably the one which offers the biggest field and is most often quoted. The problem is simplified here as due to many causes the size and power of the motor car is not likely to increase. The motor car needs only to be considered by itself and is not as in case of railway rolling stock constantly subject to increased train loads and altered operating conditions.

It may be taken as an axiom that the more complicated the machine the more changing the conditions and the longer the life of the machine the smaller is the advantage in standardising complete machines and the greater the cost of maintaining such standardisation.

Standardisation in motor car work is usually concerned with the products of one firm and the problem has very little in common with that which presents itself in standardisation of railway rolling stock.

Standardisation on Indian Railways involves standardising the production of many manufacturing firms often 7,000 miles away and of a large number of separate railway administrations whose needs are often diverse.

Difficulties of standardising complete locomotives.

6. It is obvious from attached papers that the aim of the Railway Board is to standardise the complete locomotive or unit of rolling stock and the following is an attempt to indicate some of the difficulties that such a policy must encounter. As the standardisation of the locomotive is the biggest problem it will be well to commence with it.

7. Referring to No. C. 82/24, page 3 under heading 6 (1) locomotives, it is pointed out that in 1903 designs for standard locomotives for Indian Railways were prepared. On page 4, paragraph 2 it is stated " but the full advantage of doing so has been somewhat vitiated by the departure from standard in certain details. Locomotive Superintendents of the State Railways have also specified this or that gadget which has involved departures from standards ". It would have been instructive if the writer of the note had indicated to what extent the " departure from standard in certain details " referred to had been either unnecessary or undesirable. When one considers these designs have been in existence 21 years, that during that time the substitution of Walschaert valve gear for Stephenson and the introduction of superheaters has made necessary very considerable alteration to the structure, I think any unbaised engineer would agree that considering the alterations necessary to incorporate the above features there has been a surprisingly small change in the general design over such a long period as 21 years.

When it is considered that no hard and fast rules existed against railways obtaining what they desired in the way of locomotives and yet an increasing number of railways were all the time obtaining locomotives to general standard design it shows that very little, if any, machinery is needed to keep locomotives to a general design when once a satisfactory design has been introduced.

8. With regard to details, it is admitted that some variations exist between locomotives of same type supplied to same railway by different makers or by the same maker at differeng times. Many of these variations are undesirable and have arisen because the Consulting Engineers were not supplied with any statement from India of those parts or dimensions which it was most desirable to fix from the point of view of easy maintenance here. While some parts of a locomotive are renewed from 10 to 40 times in the life of a locomotive others may only require renewal once or twice and others again will last the whole life. From the point of view of maintenance it is desirable to standardise the part that requires frequent renewal. This point is not always considered by makers who, if some alteration is required, may find it more economical to alter the design of a part requiring frequent renewal than that of a part which generally lasts the life of a locomotive. The following illustration will probably make this clear :—

The reversing screw is a fitting which is renewed four to five times in the life of a locomotive and consequently these are manufactured for stock on most Indian railways. On the standard locomotives supplied to this railway since 1907 *seven* different types of reversing screws have been supplied.

It would have been quite possible to have made *two* standards suit all the engines, but this would have involved the modification of some other parts. As, however, the other parts that would have required modification would rarely, if ever, have required replacing, it would have been better to alter them instead of the reversing screw even though it involved some additional expense.

9. The desirability of fixing standards for brass nuts, pipe couplings, taper pins, cotters, collars and pins does not seem to have been sufficiently emphasised. These items if once fixed as standards need never be altered though the list might have to be added to from time to time.

It must be remembered that new locomotives do not form a very large proportion of the total stock of a railway. It is probable that additions and renewals together do not exceed 4 to 5 per cent. per annum of the existing stock. In introducing standardisation a railway administration has to consider its existing as well as its new stock and it is often found desirable and economical to order new locomotives with fittings which work in with the existing stock where this can be done without appreciable expense.

It is obvious, however, that limits must be set to this practice or undesirable departures from accepted standards may result. One large railway in Western India has recently gone to considerable expense in producing standard fittings which will work in for a large proportion of its locomotive stock. It is certainly undesirable that the economies effected by this procedure should be lessened by forcing it to accept additional standards without good reason.

10. It may be objected that to permit minor departures would be objectionable for the following reasons :—

(1) It would involve difficulty when calling for combined tenders.

(2) It would not be possible to deal with these locomotives if sent to other railways.

With regard to (1), the Consulting Engineers in England have for years been ordering locomotives and rolling stock to general standard designs with minor differences to suit individual railways and no serious difficulties have been met with. It is not possible to say what increase in price such modifications have resulted in, but whatever the sum it will be very small and certainly not commensurate with the advantages obtained in securing the fuller use of maintenance standards in India.

As regards (2), it was at one time urged that one of the advantages of complete standardisation would be that in case of need locomotives could be passed from one line to another without trouble. This was, I think, first put forward by Mr. Hitchcock in a paper read about 1910 before the Institute of Mechanical Engineers. It was then pointed out there was very little advantage to be gained by this as where locomotives are running, working spares have to be provided. If locomotives are passed to another line it is as easy to send the spares with them as keep them idle in the shed from which the locomotives are despatched. Since that time we have had a "little war" and I believe two concentrations on the frontier, but very few locomotives have been loaned. The B. B. and C. I. Railway has had 10 or 15 standard locomotives on loan from the N. W. Railway at one time and although these differed in a few details from our own and we received no spares the additional cost or delay involved was so small as to be indeterminable.

Experience has shown that the same class of engine differing in age five years can rarely have all the renewable parts alike because of the alterations which have been necessary to accommodate the type to improvements that have been made in design. This is quite apart from alterations made to suit the needs of any special administration.

To sum up No. (2) even if the object aimed at was attainable it would hardly justify the expenditure of any appreciable sum of money.

How to secure progressive standardisation.

11. In the Railway Board's note great stress is laid on the necessity for keeping standards up to date. How it is proposed to secure progressive standardisation without alteration of standards is not stated and this is most important.

When once a standard has been generally accepted, it should not be cancelled without the unanimous or practically unanimous concurrence of the railways concerned and it should be permissible for any railway to order any such approved standard as it requires. Constant revision will be necessary if it is decided to standardise the complete units. This will be specially necessary in the case of Locomotives for naturally the more complicated the machine the greater the number of items subject to standardisation and the more frequent must be the revision.

But many of the alterations will not be found necessary on all railways and the question arises, will any railway have to accept all the alterations decided on ? If they do not, engines on order will not all be to same standard ; if they do, the individual railway will necessarily increase its standards. To give an instance, a complaint was received that the G. I. P. and N. W. Railways had been having trouble on some of their heavy sections with cylinders working slack and it was proposed to modify the design of cylinder. On the B. B. and C. I. Railway, with its light road the same trouble was not experienced and no case of loose cylinders occurred though many of the engines had been running 16 years. Has the B.. B. and C. I. Railway which has had no trouble to go to the expense of ordering its new engines with new type cylinders which will necessitate the manufacture of new cylinder patterns and the stocking of two more types of cylinders.

12. In the Railway Board's note it is stated that all alterations to existing designs must be approved by the Standard Committee before being put into operation. It is submitted that this will often be found impossible to carry out in the case of locomotives being manufactured abroad.

For instance, it is decided to adopt some fitting, which promises an increased economy. The detail modifications necessary for applying this fitting must be left for the Consulting Engineers at Home to approve proposals submitted for the minor alterations, which may be found necessary in the structure of the machine to enable the fitting to be applied in the way that will give the greatest satisfaction. There is no disadvantage, but every reason in favour of giving the Consulting Engineers at Home a free hand in such matters provided that as already proposed they are in possession of a statement laying down those dimensions or complete fittings which it is undesirable from a maintenance standpoint to alter. While locomotives and rolling stock are manufactured abroad it would be most undesirable to tie the hands of the Consulting Engineers. Their efforts in the past have been largely responsible for the extensive standardisation which now obtains. While they have always welcomed any suggestion to adopt a modification that appeared to offer prospect of more economical construction, working or maintenance they have striven most successfully to incorporate such standards as had been approved.

13. One of the serious objections to the attempt at standardisation of complete units over all India is that it must lead to increasing the number of standards it is necessary to maintain on each individual administration and thus reduce economy in maintenance. This is not only the case to begin with but will increasingly be felt as time passes. The problem is accentuated on account of the life of the locomotive which may be taken as 30 to 35 years.

Wagon Standardisation.

14. In the case of wagons the necessity for maintaining such fittings as are renewed when on foreign railways is urgent and fortunately the number of these is not very considerable.

Up till about 1916 Railways discouraged the use of interchangeable parts by insisting on free supply of material for repairing wagons damaged on foreign railways. Since railways had to pay for material required for repairs a great inducement was provided to obtain standard fittings. In fact, most railways were obtaining wagons with I. R. C. A. standard fittings before the new designs were prepared by the Special Standard Wagon Committee.

Since then most railways have obtained wagons to the new designs, which when certain weaknesses in design have been remedied will form an excellent basis to work on for the next few years.

Revision of standards—

15. The appointment of successive committees to revise these designs would seem quite unnecessary and is probably the most expensive and unsatisfactory way of remedying any defects which still exist. These do not affect any part that is likely to require renewal while on a foreign railway and in many cases railways have already made such small modifications as have been found necessary and it will be well to give time to ascertain which of the methods adopted gives the best service before revising any designs.

It has already been noted that the Railway Board's note lays great stress on what is termed "progressive standardisation". How is this to be obtained in wagon stock? It is quite certain that to try and obtain it by periodically revising the existing wagon desings is about the worst possible way. The life of a steel wagon is from 30 to 40 years and one hardly dare contemplete the position of Indian Railways if each railway is forced to order the latest revision of A class wagons every time it is in the market for them.

Proposal regarding scope of Standardisation—

16. It is strongly urged that the policy which will result in the largest measure of standardisation not only on railways as a whole but on each railway as well will be as follows :—

(1) The general design of locomotives, wagons and carriage underframes should be decided on.

This has already been done and any minor modifications, which do not involve radical departure from the adopted design should be supplied on reasons being given as has been done in the past. Past experience of 21 years with the standard locomotives is sufficient proof that this will not lead to undesirable departure from the standard design.

(2) The dimensions of material obtained in a finished or partly finished state from abroad in any considerable quantities for maintenance and certain complete fittings in case of rolling stock should be standardised and no departure should be allowed from these standards without strong reasons.

(3) A standard once adopted should not be cancelled without concurrence of at least 75 per cent. of interested railways but additional standards may be added if accepted by a bare majority.

The above proposals will not only result in the maintenance of a more real standardisation than that envisaged in the note but will do so at a tithe of the cost, An attempt rigidly to standardise complete units will either kill the standards or kill progress.

The proposed organisation—

17. The organisation it is proposed to introduce is outlined in the Railway Board's note of October 1923 above referred to. It would appear from paragraph 6 (1) 17, page 6, that in the case of locomotives after the first proposals of the Standard Committee have been referred to the Locomotive and Carriage Superintendents' Committee (which incidentally has not yet been done) all further references will be directly between that Committee and the Railway. From paragraphs 6 (2) and 6 (3) it is gathered that in the case of coaching and wagon stock it is proposed that the Locomotive and Carriage Superintendents' Committee or a sub-committee of it shall deal with the question arising. In the statement of the Chief Commissioner made at the meeting of Agents in September 1923 the following passage occurs referring to the Standards Committee :—

> "My own feeling is that if they are under the Railway Board we may be able to keep the thing going steadily all the year round and avoid any frequent changes in personnel and so on, and also it will enable the technical committees to keep in touch with the latest ideas and improvements at home through the Consulting Engineers. I need not say anything more, but ask you to give your opinion."

That the Committee or Committees dealing with standards should hold their meetings at the Railway Board office is no doubt very desirable as much more information would be available there than could be obtained at any other centre at which the officers of the larger railways could most conveniently meet, but that the Committee should be attached to the Railway Board would seem most undesirable for many reasons.

18. Standards that are forced upon the railways from above will be found to be short-lived and will certainly lead to many evasions and just those practices which it is the object of the Railway Board and the desire of railways to avoid. The only advantage which it would be possible to claim for the proposal is that being free from the necessity to consider any criticisms levelled against its proposals this committee would be able to decide standards in less time than it would take if it were necessary to carry with it the approval of a majority of the interested railways.

Composition of proposed Committee and Status.

19. It would appear hardly possible that the full implication of the proposal has been sufficiently considered. It is proposed to take the Chief Mechanical Engineers of two Railway Administrations and associate with them another Chief Mechanical Engineer, whose knowledge of locomotive details will be something in the way of a reminiscence as he has been unconnected with the actual executive work on railways for a few years. These three men are to constitut

a committee and it is proposed that it shall be in their power to veto or ratify the considered proposals of the Chief Mechanical Engineers of all the railways in India after they have been duly approved by the Agents of those railways at the I. R. C. A. It is feared that the pshychology of the men who would be likely to hold the position of Chief Mechanical Engineer on railways and of whom the Locomotive and Carriage Superintendents' Committee consists was left out of account when these proposals were made and I think it would be found in practice unlikely that the proposed committee would receive any suggestions on these terms.

20. It is also open to question whether a committee composed of Chief Mechanical Engineers would in any case be the best committee available. The Chief Mechanical Engineers' duties are mainly administrative whereas the preparation of standard designs is the work of a specialist. It is therefore desirable that the best men for work in hand should be chosen irrespective of the appointments they hold.

It is probable that if the appointment of this committee is in the hands of the railways a more suitable personnel will be likely than if the committee is appointed by the Railway Board. Again it is questionable whether a committee of three is sufficiently large to cover the requirements of locomotive, carriage and wagon designs for both Broad and Metre Gauge as it will rarely be found that the most suitable officer for the carriage or wagon committee will also be the most suitable for locomotive designs. This also holds good as between Broad and Metre Gauge standards. It is admitted that for any one purpose it is undesirable to have a large committee and most satisfactory designs have been prepared by one man.

If the Committee's decisions are subject to the approval of the Locomotive and Carriage Superintendents' Committee no objection exists to small committees on account of the tendency of small committees to put through freak designs strongly urged by one of its members as these would be effectually countered when the proposals came before the full committee for consideration.

21. The most serious objection, however, to the proposed procedure is the delays that would occur in getting any standard required by railways adopted at all.

Before a Chief Mechanical Engineer suggests a new standard at present he has usually tried the thing out on his own railway and then arranges for it to be incorporated in engines or rolling stock which are not subject to interchange. It is then put up before the Standards Committee and may or may not be adopted. Under the new proposal it would appear probable that another three years at least would elapse before such a standard could be ordered on regular indents. This is assuming that the Standards Committee attached to the Railway Board remains sympathetic to the requirements of railways and adaptable to changes as they become desirable. It is suggested that any unbiased person with experience of departments attached to Government offices would hardly expect to find these qualities evident in any appreciable degree. As a matter of fact there are reasons why the technical branch of the Railway Board office would be interested in blocking proposals put up for additions to existing standards. Each fresh alteration involves difficulty and extra work when orders are being placed for rolling stock. The department is however free from all those worries and operating troubles which are felt by the executive officials of railways due to the use of material which is failing more frequently than is necessary or is not the most suitable for its purpose.

22. The Railway Board should be in a position to take a large view of things and while it does so is able to exercise a guiding or restraining action on railways as a whole. To maintain this attitude it must keep clear of the petty details which are likely to detract from its ability to do so impartially. Except on the rare occasions on which complete new designs are needed standardisation is mostly concerned with consideration of details which needs a very close and constant contact with actual working if the best proposals are to be made for meeting conditions arising.

Again if a standard is suggested by what is practically the Railway Board any criticism of it will be tantamount to a criticism of the Railway Board. It would not be humanly possible for the Chief Mechanical Engineer of the Railway Board to treat criticisms of such proposals made by him or by a committee of which he is chairman in the same dispassionate manner as he would if he was reporting on the recommendations of another committee.

It would also seem a very bad precedent to take design out of the hands of the men held responsible for maintenance and safe running of the locomotive and rolling stock. It is most desirable in the interests of railway progress that nothing shall be done which will tend to the responsible mechanical officers taking less keen interest in progress of design. This will most certainly to be the case if the duty of fixing standards is removed from their jurisdiction as in the proposals made.

Proposal re. *organisation of Standards Committee.*

23. For the above reasons I would strongly urge that the committee on standards should as in the past be sub-committees of the Locomotive and Carriage Superintendents' Committee and their recommendations subject to confirmation by the I. R. C. A.

For the reasons given they should work in Railway Board office and I would suggest the Chief Mechanical Engineer, Railway Board depute some officer to be *ex-officio* member of these committees and that the Secretary of Committee be attached to the Chief Mechanical Engineer's Office.

If for any reason it is considered undesirable to attach the Secretary of committee to the Chief Mechanical Engineer, Railway Board office, he might be attached to the I. R. C. A. office.

APPENDIX VII.

(Reference Paragraph 83.)

The following are the principal types of track over which the Committee travelled :-

Types of Permanent Way.

Railway.	Rails.	Sleepers.	General Soil.
G. I. P. R.	82 lbs. B. H.	C. I. Pots	About 70 per cent. black cotton soil. Remainder moorum and sandy soil.
	85 lbs. B. H.	C. I. Pots and Timber	
	90 lbs. F. F.	Steel Troughs and C. I. Plates.	
	100 lbs. B. H.	C. I. Pots	
M. & S. M. R.	75 lbs. D. H.	C. I. Pots	Sandy. 20 per cent. black cotton soil. Remainder moorum and deltaic silt.
	76 lbs. B. H.	C. I. Pots	
	80 lbs. B. H.	C. I. Pots and Timber	
	90 lbs. B. H.	C. I. Pots and Timber	
	90 lbs. F. F.	Timber and Steel Troughs.	
S. I. R.	80 lbs. B. H.	C. I. Pots	Good and firm soil.
	90 lbs. B. H.	C. I. Pots	
	90 lbs. F. F.	Steel Trough	
N. S. R.	85 lbs. F. F.	Steel Trough	40 per cent. black cotton soil. Remainder moorum.
E. I. R.	75 lbs. F. F.	Timber and C. I. Plates	15 per cent. black cotton soil. Remainder clay sand and moorum. About 5 per cent. Usar (Soil containing Potassium Nitrate).
	85 lbs. B. H.	C. I. Plates (D. & O.)	
	87 lbs. F. F.	Timber	
	88½ lbs. B. H.	C. I. Plates (D. & O.)	
	90 lbs. F. F.	C. I. Plates and Timber	
	100 lbs. D. H.	C. I. Plates (D. & O.)	
	100 lbs. F. F.	Timber	
	115 lbs. F. F.	Timber and C. I. Plates	
E. B. R.	90 lbs. F. F.	Timber and C. I. Plates	Loam. Water standing on both sides of line over long stretches.
	115 lbs. F. F.	Timber	
B. N. R.	85 lbs. F. F.	C. I. Pots and Timber	Sandy but generally firm. 20 per cent. black cotton soil.
	90 lbs. F. F.	Steel Troughs	
B., B. & C. I. R.	75 lbs. F. F.	Steel Troughs and Timber.	20 per cent. black cotton soil. Remainder moorum, sandy clay and rock.
	87 lbs. F. F.	Steel Troughs and C. I. Pots.	
	90 lbs. F. F.	Steel Troughs, C. I. Pots and Timber.	
N. W. R.	87 lbs. F. F.	Steel Trough and Timber.	Sandy clay. Very little Usar (Soil containing Potassium Nitrate).
	88½ lbs. B. H.	C. I. Plates (D. & O.)	
	90 lbs. F. F.	Steel Troughs, C. I. Plates and Timber.	

APPENDIX VIII.

(Reference Paragraph 84.)

Rainfall Statistics.

Section and Railway.	Station.	Rainfall in Inches. Average for 1936 and 1937.	Rainfall in Inches. Up to end of August, 1938.	
Sholapur—Raichur G. I. P. R.	Sholapur	17·62	30·27	
	Dudhni	18·51	18·98	
	Shahabad	17·56	19·42	
Raichur—Madras M. & S. M. R.	Raichur	22·60	20·27	
	Guntakal	17·65	17·04	
	Gooty	16·87	16·52	
	Nandalur	28·53	14·65	(a)
	Renigunta	30·51	7·23	(a)
	Arkonam	28·81	8·21	(a)
	Trivellore	47·16	10·77	(a)
Arkonam—Jalarpet M. & S. M. R.	Katpadi	37·16	13·43	(a)
	Jalarpet	26·40	15·56	(a)
Jalarpet—Shoranur S. I. R.	Erode	33·30	22·16	(a)
Madras—Gudur M. & S. M. R.	Tiruvottiyur	60·97	6·04	(a)
	Sullurupetta	51·86	9·36	(a)
	Nellore	39·46	8·62	(a)
Kazipet—Secunderabad N. S. R.	Kazipet	24·14	15·23	(a)
	Alir	27·94	15·40	(a)
	Bhongir	23·58	11·20	(a)
	Secunderabad	30·95	18·42	(a)
Secunderabad—Wadi N. S. R.	Shankarpalli	19·81	21·87	(a)
	Vikarabad	28·65	17·33	(a)
Akola—Bhusawal G. I. P. R.	Akola	46·75	36·34	
	Shegaon	29·51	21·36	
	Bodwad	22·34	36·79	
	Bhusawal	24·74	30·80	
Bhusawal—Itarsi G. I. P. R.	Burhanpur	32·90	31·55	
	Khandwa	32·24	33·48	
	Bir	32·44	38·00	
	Harda	46·10	42·4	
	Itarsi	52·77	52·49	
Moghalsarai—Bihta E. I. R.	Arrah	52·80	39·17	
	Buxar	53·34	38 29	
Calcutta—Ranaghat E. B. R.	Calcutta	64·00	50·44	(b)
	Barrackpore	45·47	50·77	(b)
	Ranaghat	28·56	32·09	(b)
Khargpur—Dantan B. N. R.	Dantan	51·10	40·40	(b)
Asansol—Lucknow E. I. R.	Asansol	50·49	34·20	
	Dhanbad	47·59	31·92	
	Gaya	42·92	31·02	
	Rafiganj	43·54	29·82	
	Benares	43·85	10·14	(c)
	Partabgarh	40·44	8·51	(c)
	Rae Bareili	45·62	10·15	(c)
	Lucknow	45·07	13·43	(c)
Agra—Delhi G. I. P. R	Agra	21·90	16·80	
	Mutrra	16·36	15·49	
	Delhi	31·61	12·00	

Section and Railway.	Station.	Rainfall in Inches. Average for 1936 and 1937.	Rainfall in Inches. Up to end of August, 1938	
Delhi—				
Lahore	Ghaziabad . . .	24·29	14·17	
N. W. R.	Meerut	31·01	21·80	
	Muzaffarnagar . .	34·41	17·13	
	Saharanpur . . .	41·67	25·25	
	Ambala	32·72	19·79	
	Ludhiana . . .	25·90	13·21	
	Phillaur	25·52	18·96	
	Jullundur . . .	22·04	22·39	
	Amritsar . . .	24·45	21·76	
	Lahore	18·36	10·95	
Kotah—				
Baroda	Kotah	26·69	27·70	
B. B. & C. I. R.	Shamgarh . . .	33·36	36·61	
	Nagda	29·76	27·85	
	Rutlam	32·93	29·71	(b)
	Dohad	23·92	19·43	
	Godhra	38·24	30·65	
	Baroda	35·02	32·1*	

NOTES.

(*a*) The North-east monsoon in this area is heavier than the South-west monsoon, and occurs between September and November. The rainfall up to end of August 1938 was, however, proportionately higher than in the previous years.

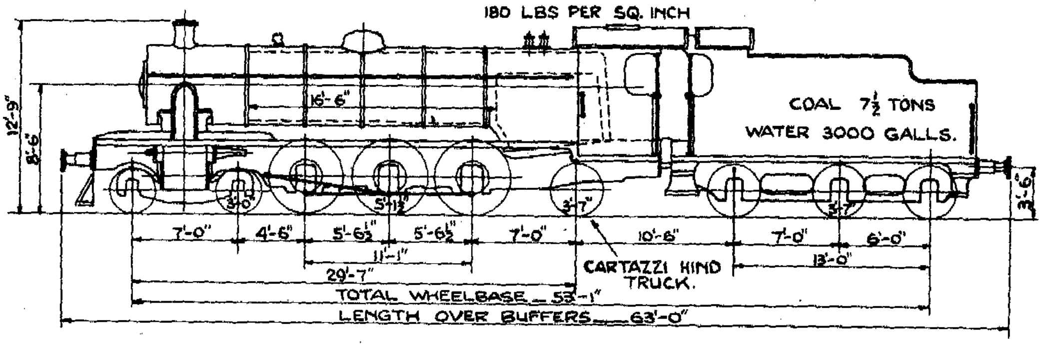
(*b*) Figures are for rainfall up to end of September, 1938.

(*c*) Figures are for rainfall up to end of June, 1938.

GIPD—20RB—14-6-39—650.

P.L.C.

X CLASS PACIFIC ENGINES AS ORIGINALLY BUILT.



WEIGHTS-TONS 15·6 — 13 — 13 — 13 — 12 — 14·1 — 14·05 — 14·1

CYLINDERS — 2 — 18" x 26"

LENGTH BETWEEN TUBEPLATES — 16'-6"

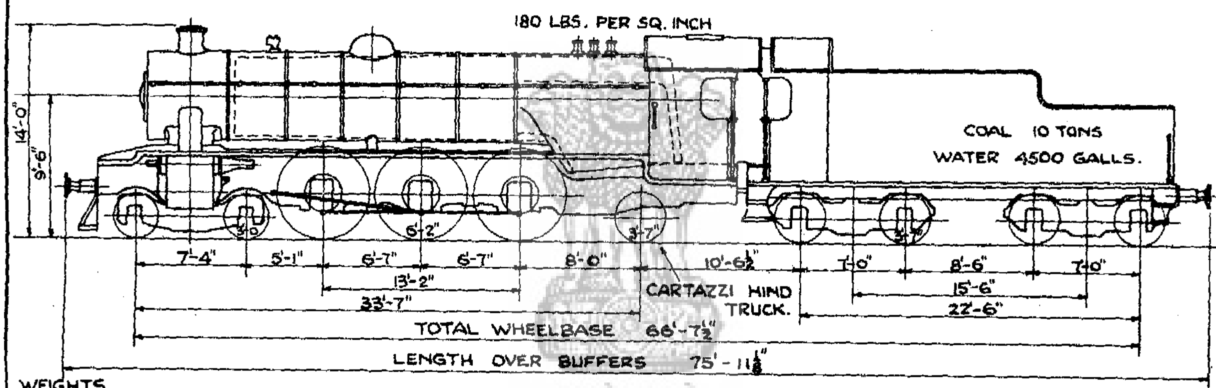
GRATE AREA — 32 SQ. FT.

TRACTIVE EFFORT AT 85% B.P. — 20960 LBS.

WEIGHTS - TONS

	ENGINE	TENDER	TOTAL
LIGHT	61·35	21·42	82·77
LOADED	66·6	42·25	108·85

XA CLASS.



WEIGHTS TONS — 22·6 — 17 — 17 — 17 — 16·65 — 32·82 — 32

CYLINDERS — 2 — 21½" x 28"

LENGTH BETWEEN TUBEPLATES — 18'-6"

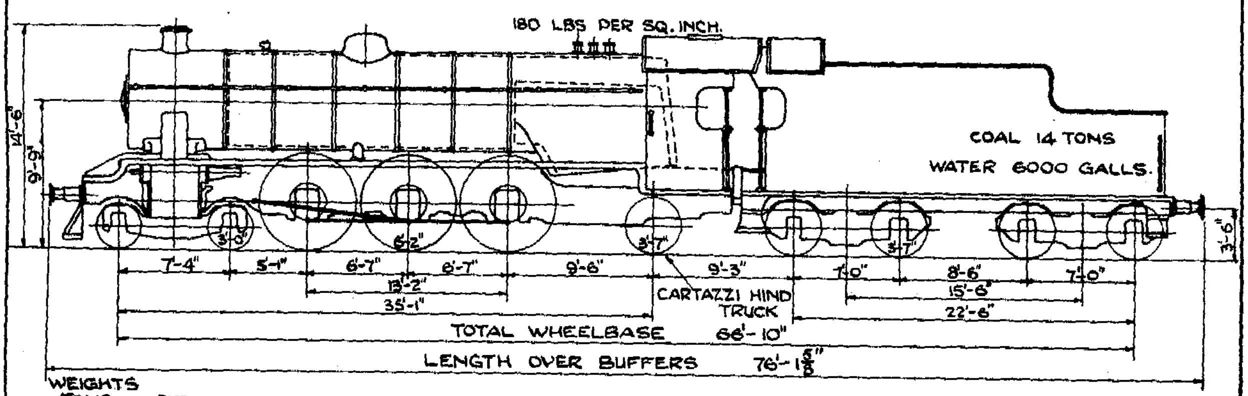
GRATE AREA — 45 SQ. FT.

TRACTIVE EFFORT AT 85% B.P. — 26,760 LBS.

WEIGHTS - TONS

	ENGINE	TENDER	TOTAL
LIGHT	81·65	34·64	116·29
LOADED	90·25	64·82	155·07

XB CLASS.



WEIGHTS TONS — 21·71 — 19·68 — 19·75 — 19·8 — 17·22 — 39·19 — 38·85

CYLINDERS - 2 — 23" x 28"

LENGTH BETWEEN TUBEPLATES — 18'-6"

GRATE AREA — 51 SQ. FT.

TRACTIVE EFFORT AT 85% B.P. — 30,625 LBS.

WEIGHTS - TONS

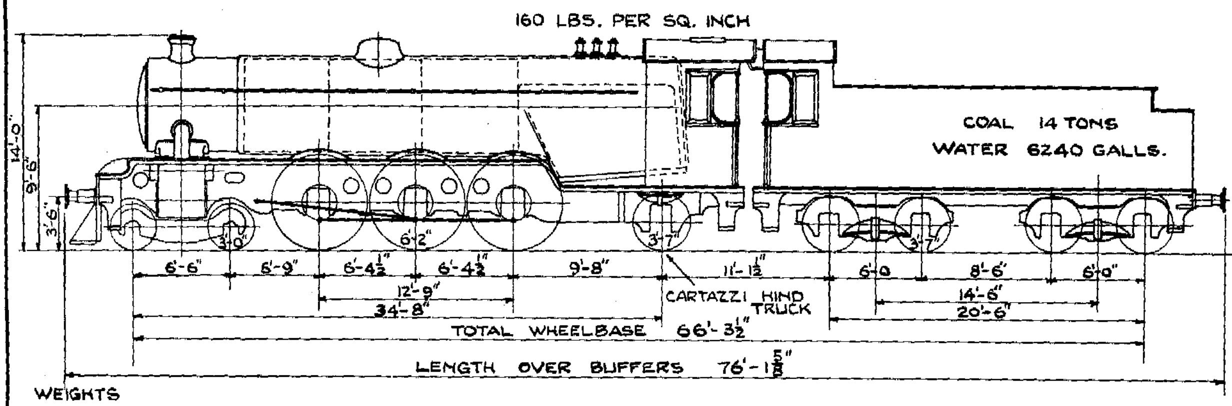
	ENGINE	TENDER	TOTAL
LIGHT	87·04	37·45	124·49
LOADED	98·16	78·04	176·2

XC CLASS.

FIG I

P.L.C.

PRE-STANDARD EXPERIMENTAL PACIFIC ENGINES.



WEIGHTS TONS 18·05 19·75 19·75 19·75 16·9 36·7 36·85

CYLINDERS 2 23" × 28"

LENGTH BETWEEN TUBEPLATES 18'-0"

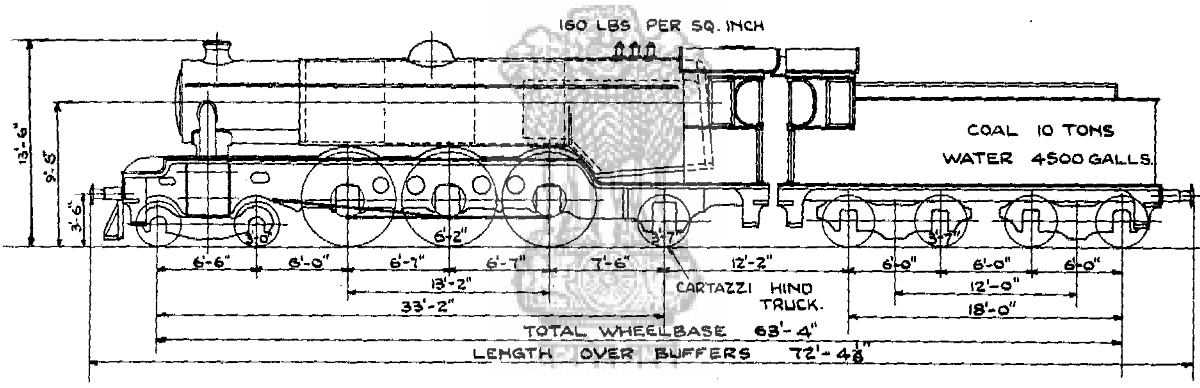
GRATE AREA 48 SQ. FT.

TRACTIVE EFFORT AT 85% B.P. 27222 LBS.

WEIGHTS – TONS

	ENGINE	TENDER	TOTAL
LIGHT	82·75	31·8	114·55
LOADED	94·2	73·55	167·75

P CLASS – B.B. & C.I.R.



WEIGHTS TONS 16·05 16·6 16·6 16·6 16·6 30·4 30·85

CYLINDERS 2 22" × 26"

LENGTH BETWEEN TUBEPLATES 14'-0"

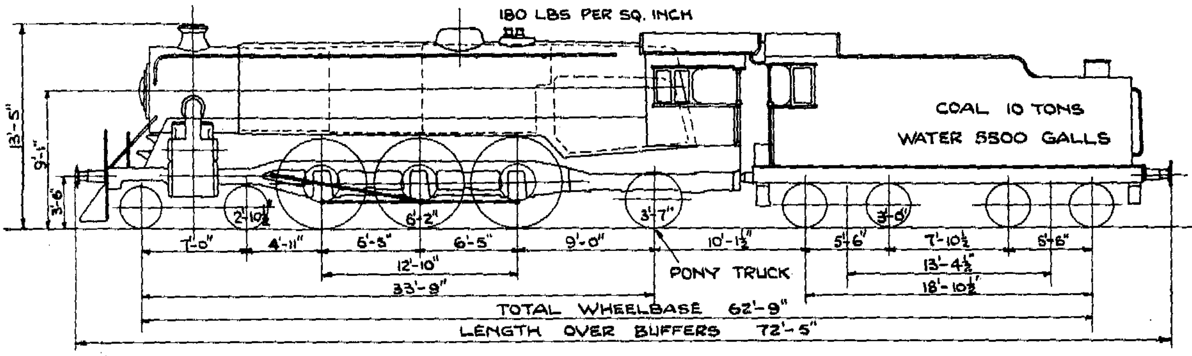
GRATE AREA 44 SQ. FT.

TRACTIVE EFFORT AT 85% B.P. 23127 LBS.

WEIGHTS – TONS

	ENGINE	TENDER	TOTAL
LIGHT	74·4	31·45	105·85
LOADED	82·45	61·25	143·7

PS CLASS – E.I.R.



WEIGHT TONS 16·49 17 17·05 17 14·86 31·9 31·9

CYLINDERS 2 22" × 28"

LENGTH BETWEEN TUBEPLATES 20'-6"

GRATE AREA 48 SQ. FT.

TRACTIVE EFFORT AT 85% B.P. 28021 LBS.

WEIGHTS – TONS

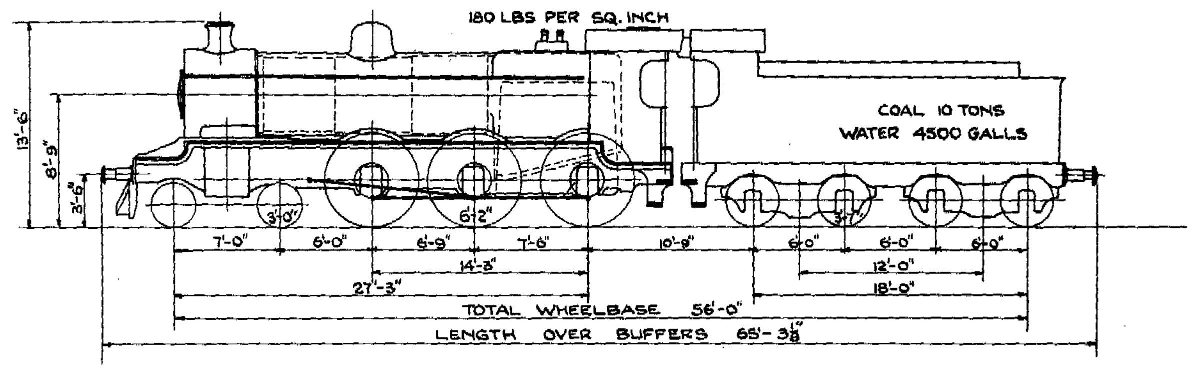
	ENGINE	TENDER	TOTAL
LIGHT	72·71	29·95	102·66
LOADED	82·4	63·8	146·2

BALDWIN CLASS – M. & S.M.R.

FIG 2

P.L.C.

OTHER ENGINES REFERRED TO IN REPORT.



WEIGHTS_TONS____20.85________17.475____17.475_____17.3______________30.8__________30.75

CYLINDERS__2___20$\frac{1}{2}$" × 26"

LENGTH BETWEEN TUBEPLATES __15'-10$\frac{1}{2}$"

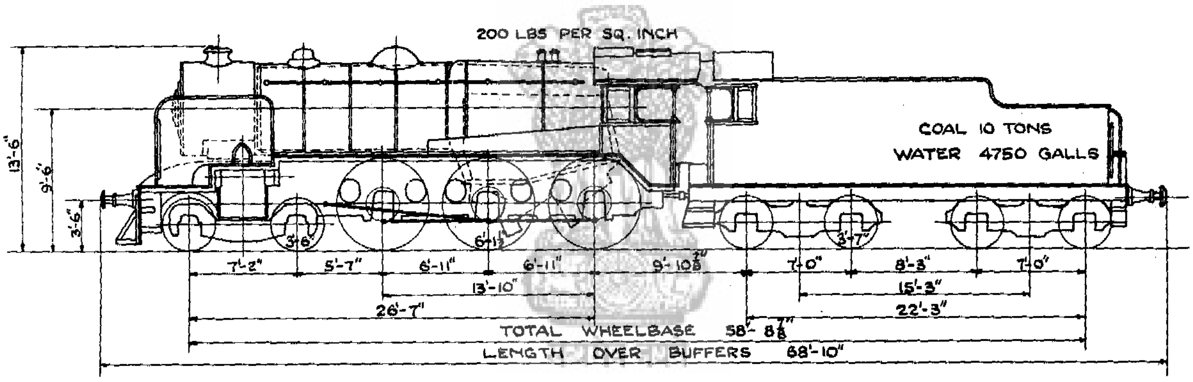
GRATE AREA ____32 SQ. FT.

TRACTIVE EFFORT AT 85% B.P.___22,597 LBS.

WEIGHTS - TONS

	ENGINE	TENDER	TOTAL
LIGHT___	66.95	31.1	98.05
LOADED___	73.1	61.55	134.65

STANDARD B.E.S.A. 4-6-0 CLASS.



WEIGHTS___TONS__24.1__________16.9________17.0_______16.9______________33.6_______________32.05

CYLINDERS___2___21$\frac{1}{2}$" × 26"

LENGTH BETWEEN TUBEPLATES____13'-6"

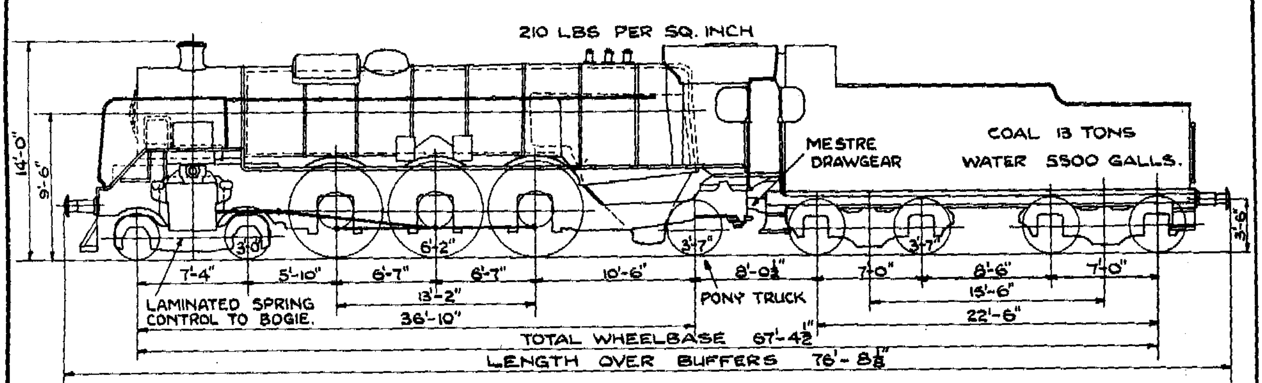
GRATE AREA____38 SQ. FT.

TRACTIVE EFFORT AT 85% B.P.____27 787 LBS.

WEIGHTS - TONS

	ENGINE	TENDER	TOTAL
LIGHT______	67.3	34.5	101.8
LOADED___	74.9	65.65	140.55

G.S.M. CLASS 4-6-0 B.N.R.



WEIGHTS __TONS__25.96__________18.58________18.55______18.66__________17.25______________36.83______________37.3

CYLINDERS___2___21$\frac{1}{2}$" × 28"

LENGTH BETWEEN TUBEPLATES____18'-6$\frac{3}{8}$"

GRATE AREA___45 SQ. FT.

TRACTIVE EFFORT AT 85% B.P.___31 220 LBS.

WEIGHTS-TONS

	ENGINE	TENDER	TOTAL
LIGHT_____	90.49	36.91	127.4
LOADED___	99.0	74.13	173.13.

EXPERIMENTAL PACIFIC XP CLASS G.I.P.R.

FIG. 3

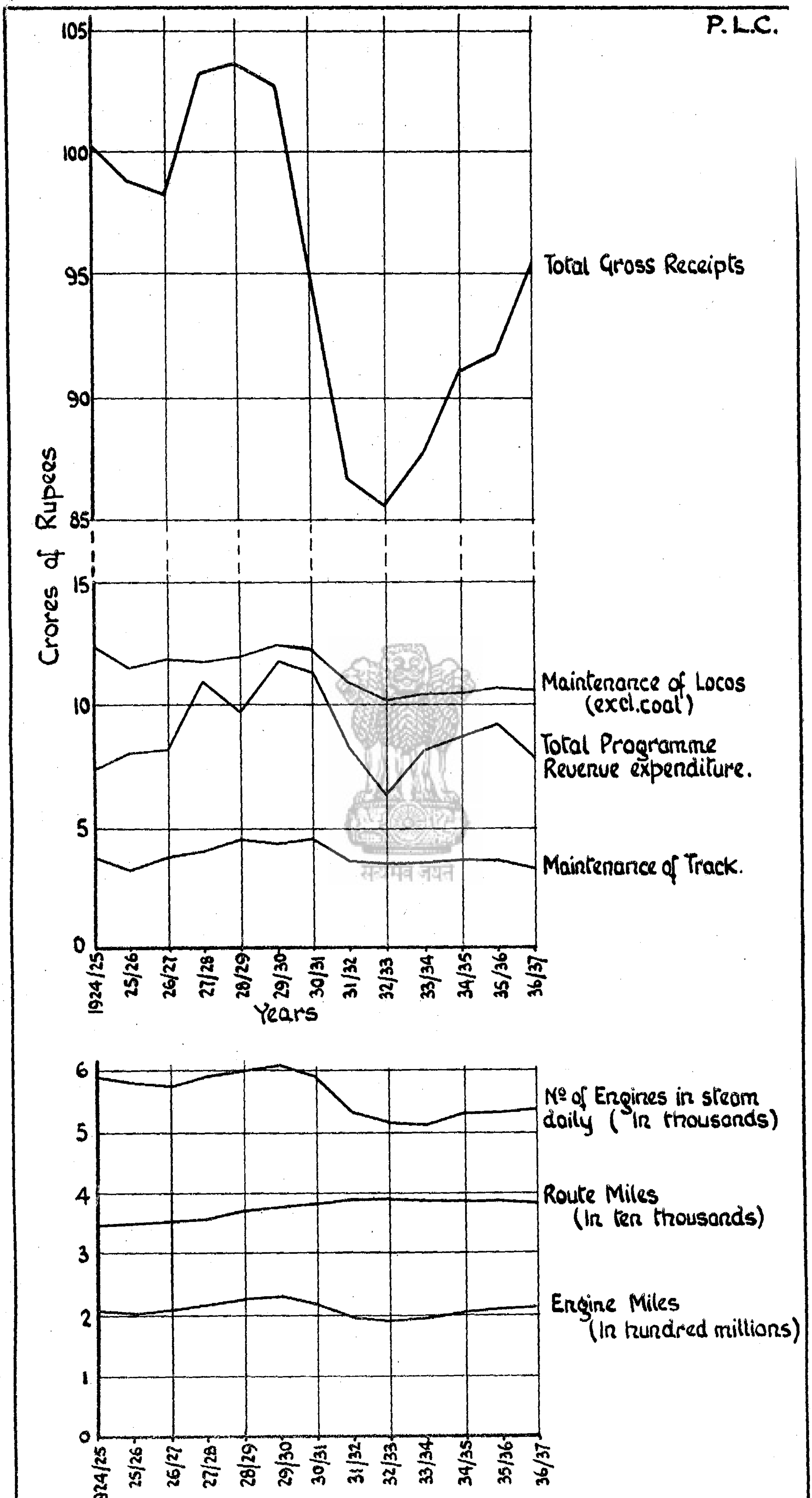
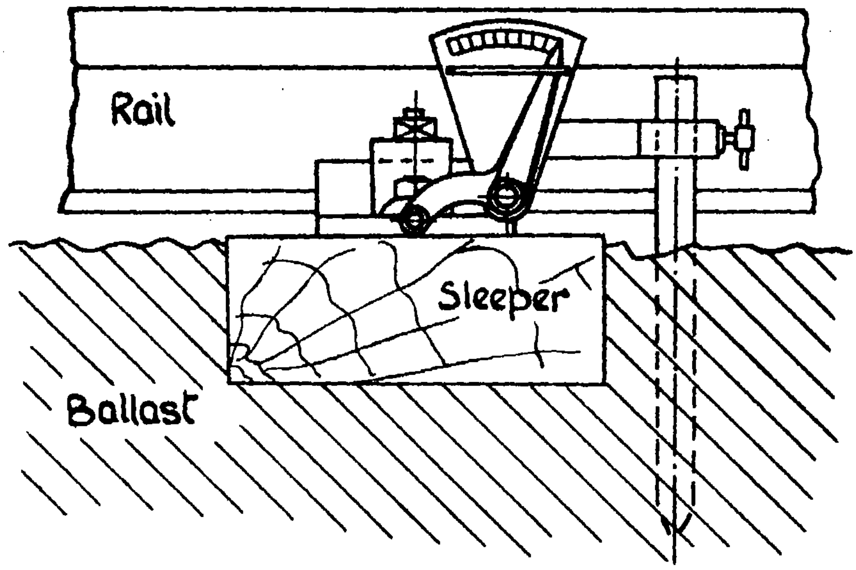
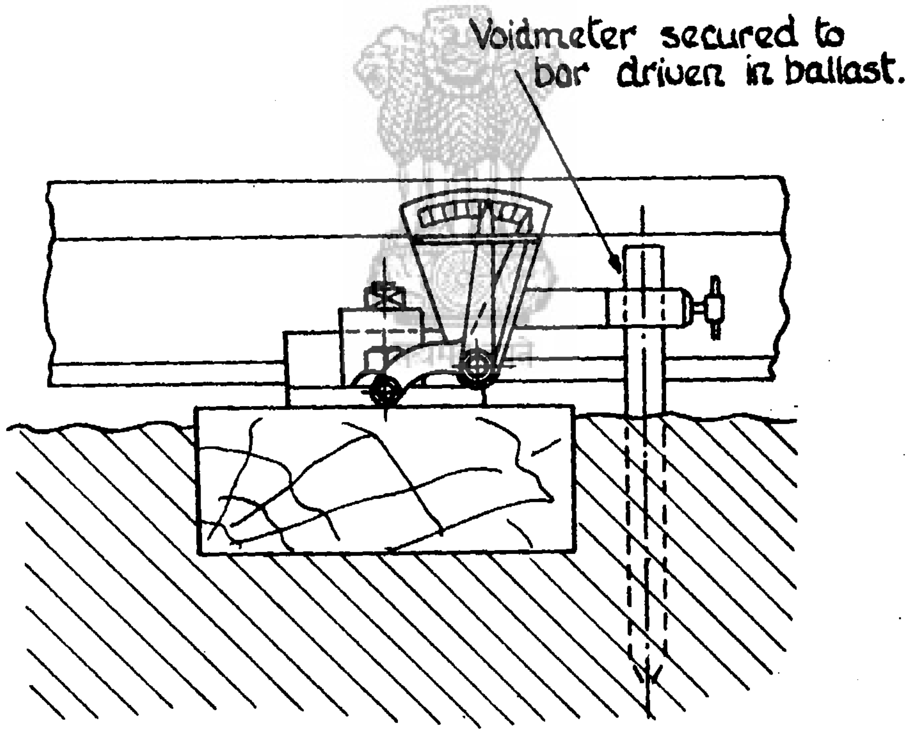

P.L.C.
Crores of Rupees
105
100
95
90
85
15
10
5
0
Total Gross Receipts
Maintenance of Locos (excl.coal)
Total Programme Revenue expenditure.
Maintenance of Track.
1924/25
25/26
26/27
27/28
28/29
29/30
30/31
31/32
32/33
33/34
34/35
35/36
36/37
Years
6
5
4
3
2
1
0
Nº of Engines in steam daily (In thousands)
Route Miles (In ten thousands)
Engine Miles (In hundred millions)
Years

FIG. 4



Position of pointers before passage of train.

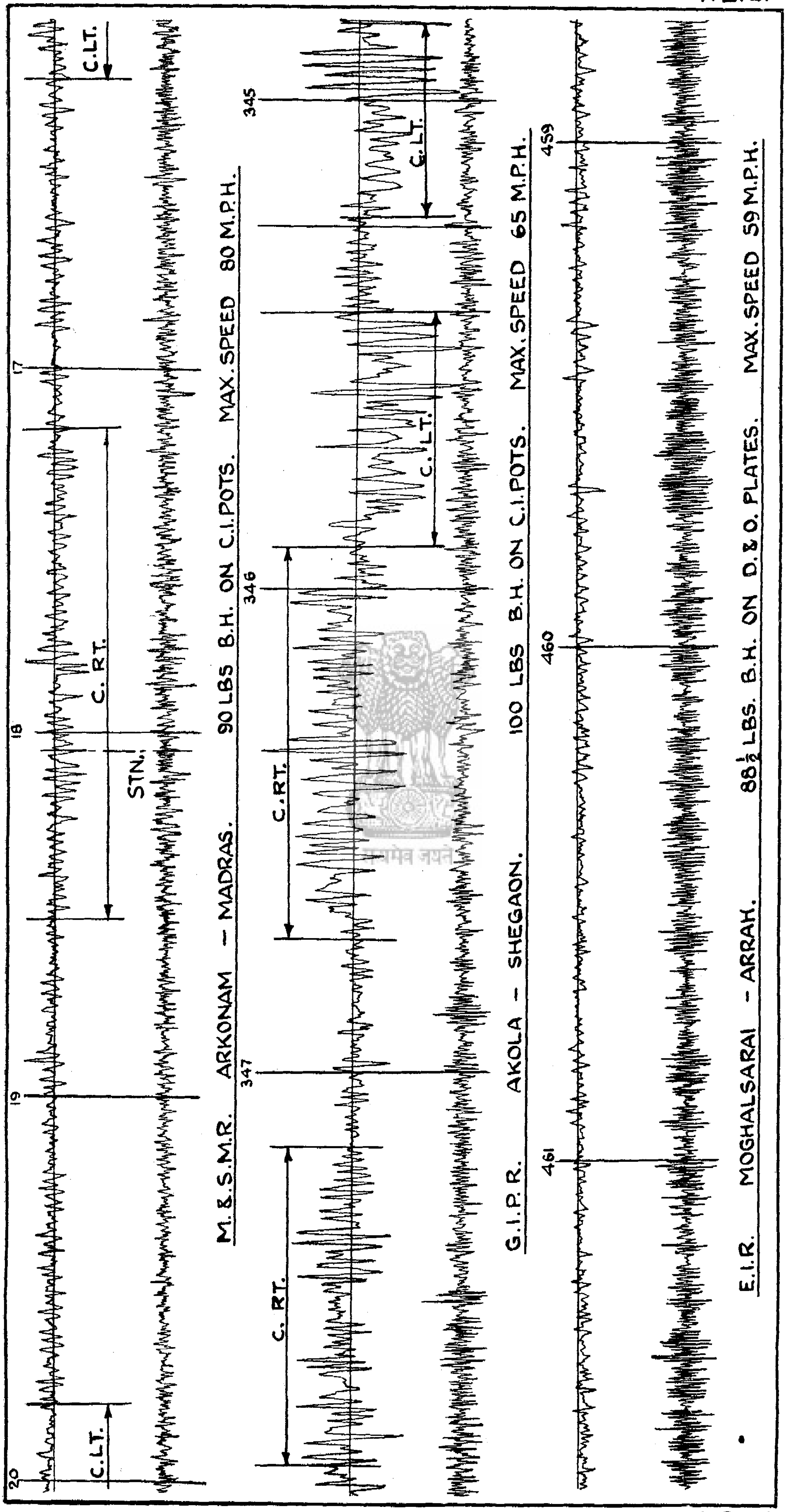


Position of pointers after passage of train.

DIAGRAM OF VOIDMETER IN POSITION ON TRACK.

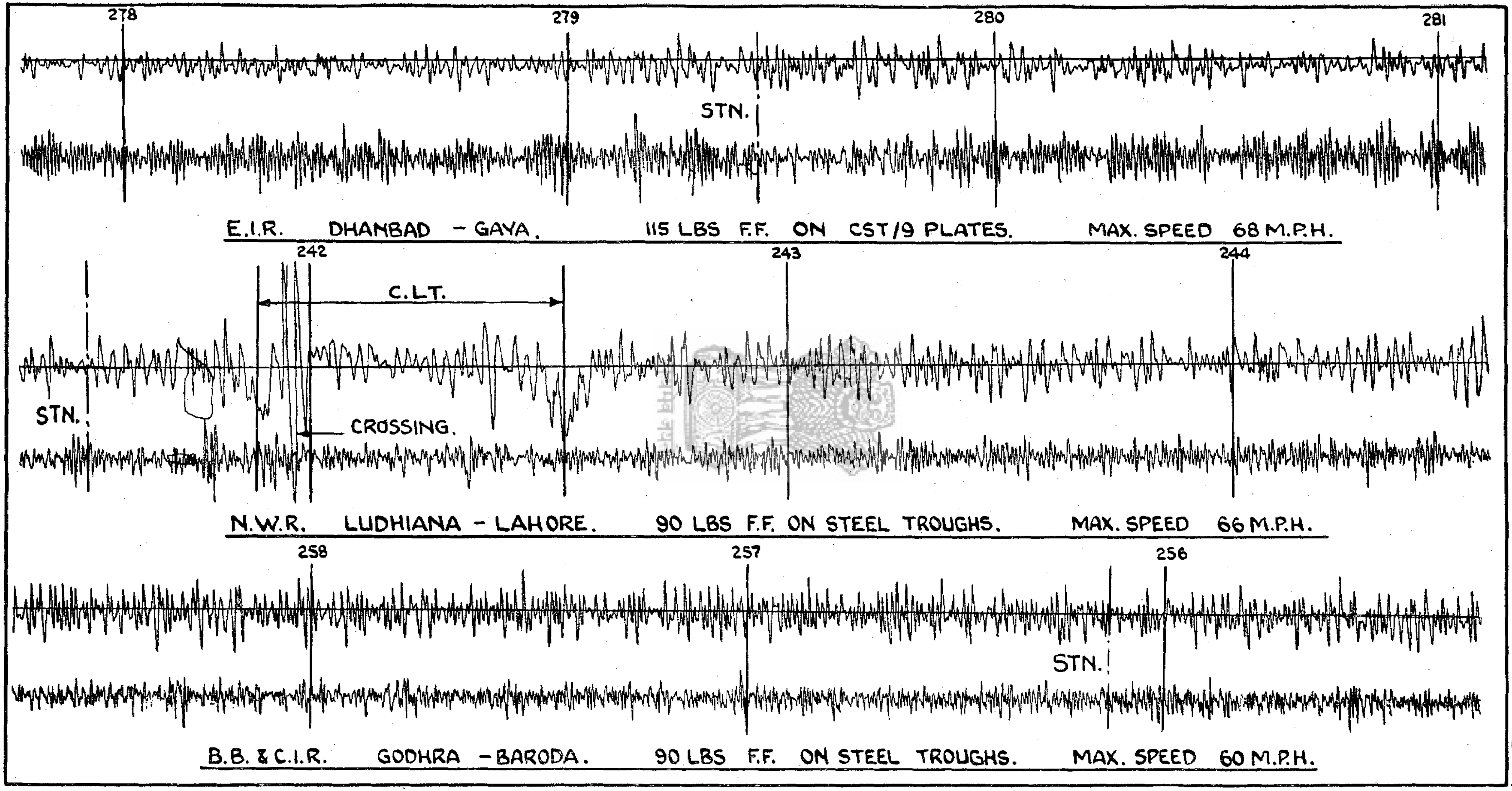
FIG. 5.

P.L.C.



M. & S.M.R. ARKONAM – MADRAS. 90 LBS B.H. ON C.I. POTS. MAX. SPEED 80 M.P.H.
G.I.P.R. AKOLA – SHEGAON. 100 LBS B.H. ON C.I. POTS. MAX. SPEED 65 M.P.H.
E.I.R. MOGHALSARAI – ARRAH. 88½ LBS. B.H. ON D. & O. PLATES. MAX. SPEED 59 M.P.H.
C.LT.
C.RT.
STN.
17
18
19
20
345
346
347
459
460
461

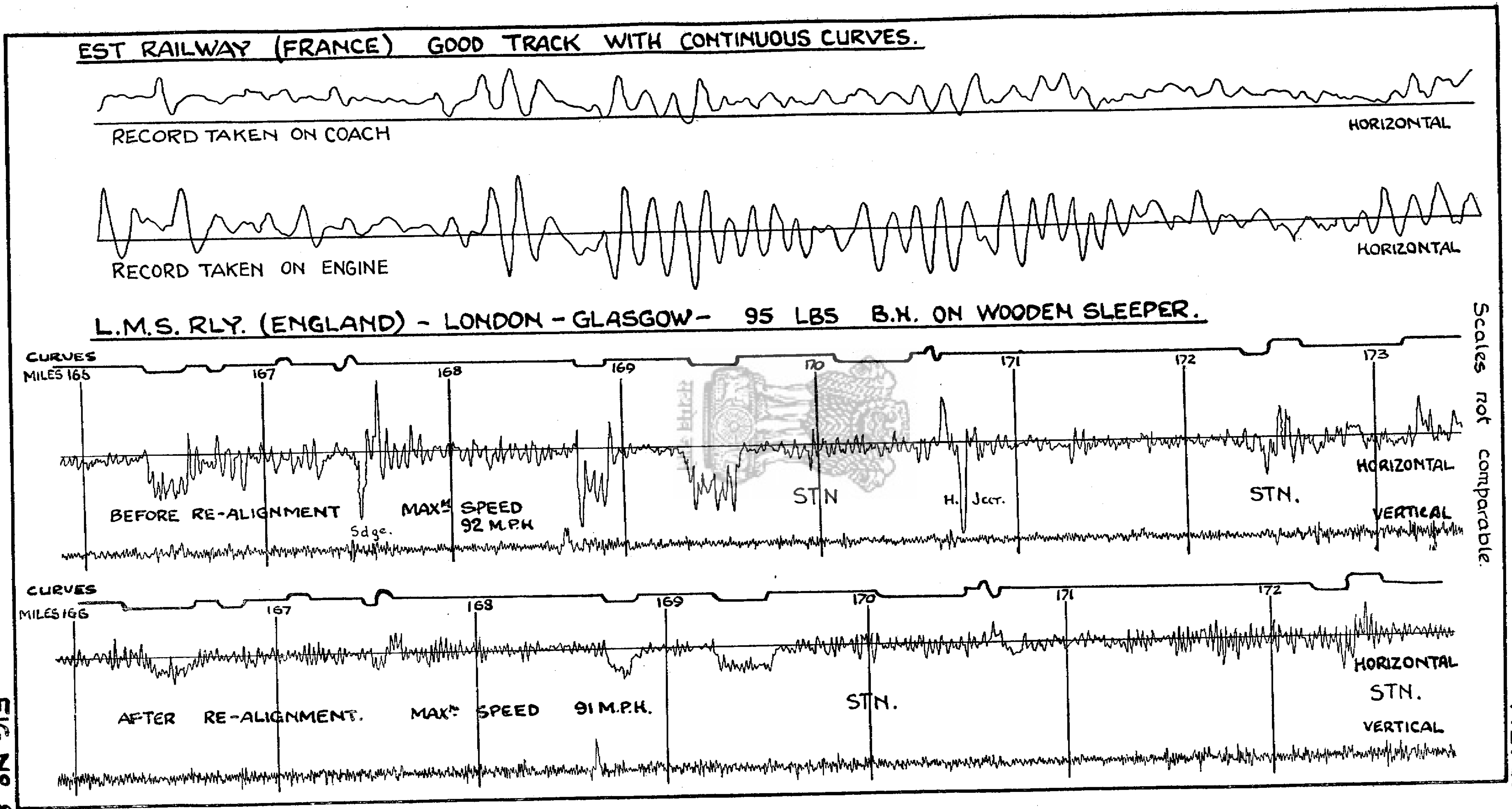
FIG. 6.


278
279
280
281
STN.
E.I.R. DHANBAD - GAYA. 115 LBS F.F. ON CST/9 PLATES. MAX. SPEED 68 M.P.H.
242
243
244
C.L.T.
STN.
CROSSING.
N.W.R. LUDHIANA - LAHORE. 90 LBS F.F. ON STEEL TROUGHS. MAX. SPEED 66 M.P.H.
258
257
256
STN.
B.B. & C.I.R. GODHRA - BARODA. 90 LBS F.F. ON STEEL TROUGHS. MAX. SPEED 60 M.P.H.

P.L.C.

FIG. 7.

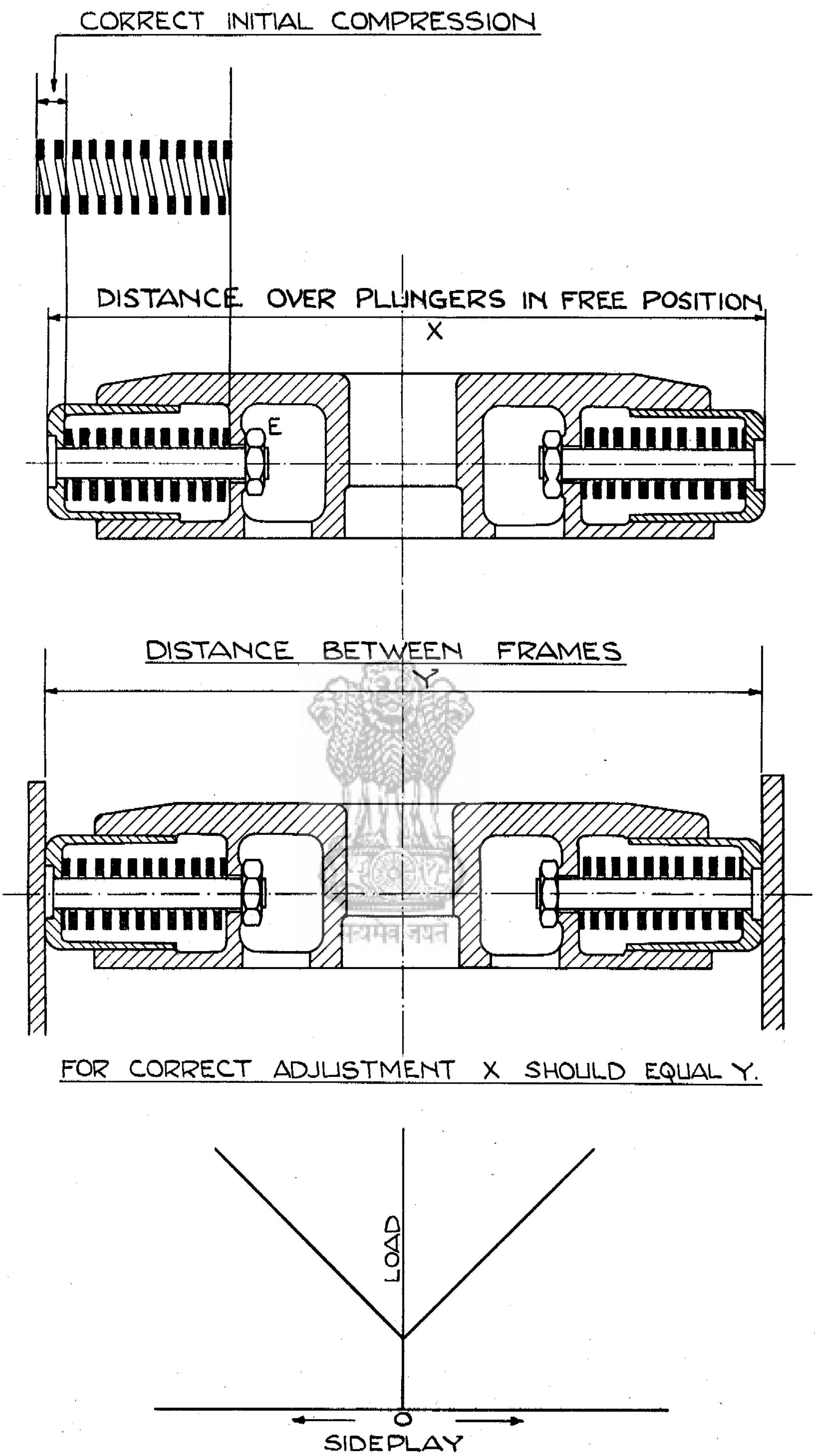
P.L.C.



EST RAILWAY (FRANCE) GOOD TRACK WITH CONTINUOUS CURVES.
RECORD TAKEN ON COACH
HORIZONTAL
RECORD TAKEN ON ENGINE
HORIZONTAL
L.M.S. RLY. (ENGLAND) - LONDON - GLASGOW - 95 LBS B.H. ON WOODEN SLEEPER.
Scales not comparable.
CURVES
MILES 165
167
168
169
170
171
172
173
HORIZONTAL
BEFORE RE-ALIGNMENT
Sdge.
MAXM SPEED 92 M.P.H
STN
H. Jcct.
STN.
VERTICAL
CURVES
MILES 166
167
168
169
170
171
172
HORIZONTAL
STN.
AFTER RE-ALIGNMENT.
MAXM SPEED 91 M.P.H.
STN.
VERTICAL

FIG No 8

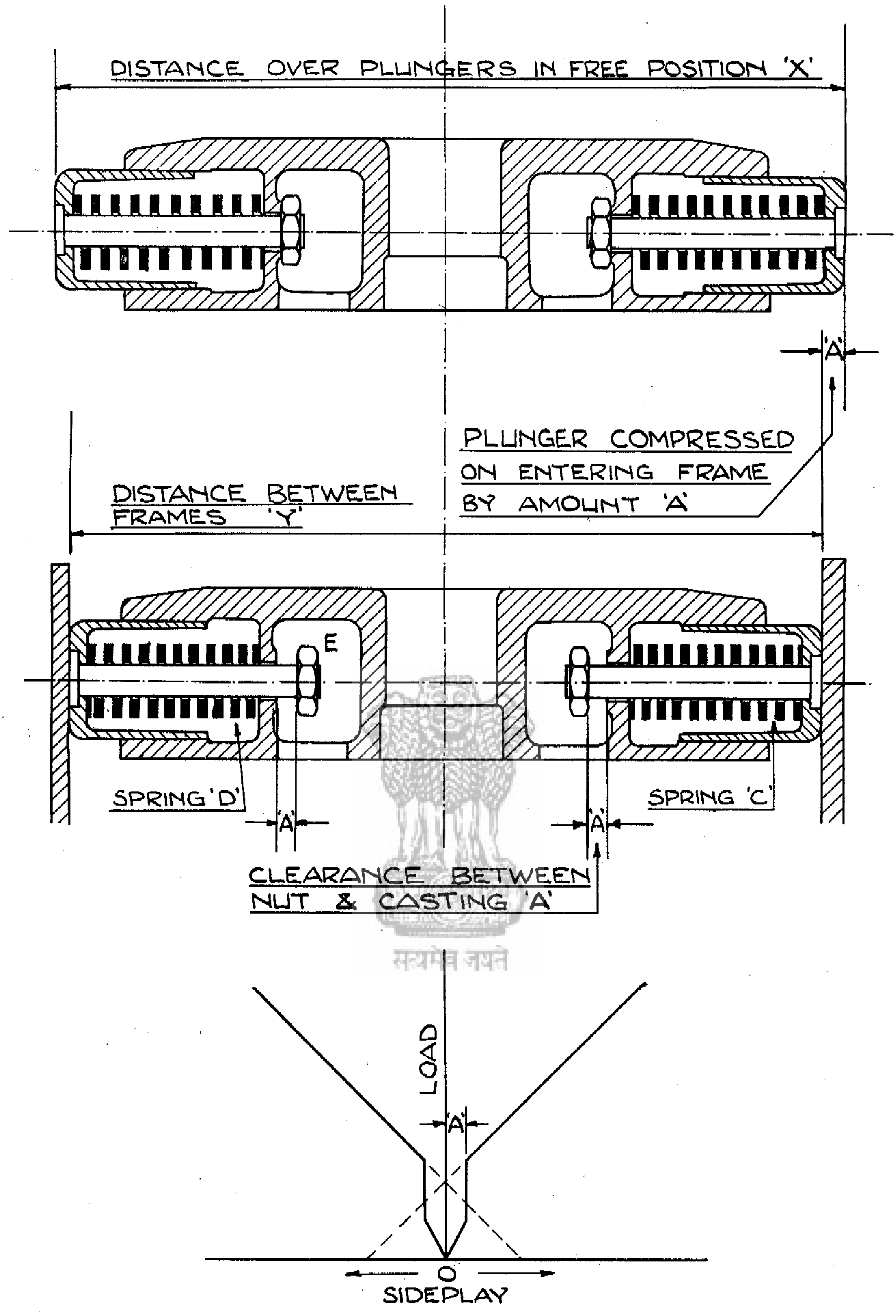
P.L.C.



SIDEPLAY & CENTRING FORCE DIAGRAM FOR SPRING CONTROL SHOWN ABOVE.

DIAGRAM OF CONTROL SPRINGS ~ BOGIE OF X CLASS PACIFICS.
CORRECT ADJUSTMENT.

FIG. 9.

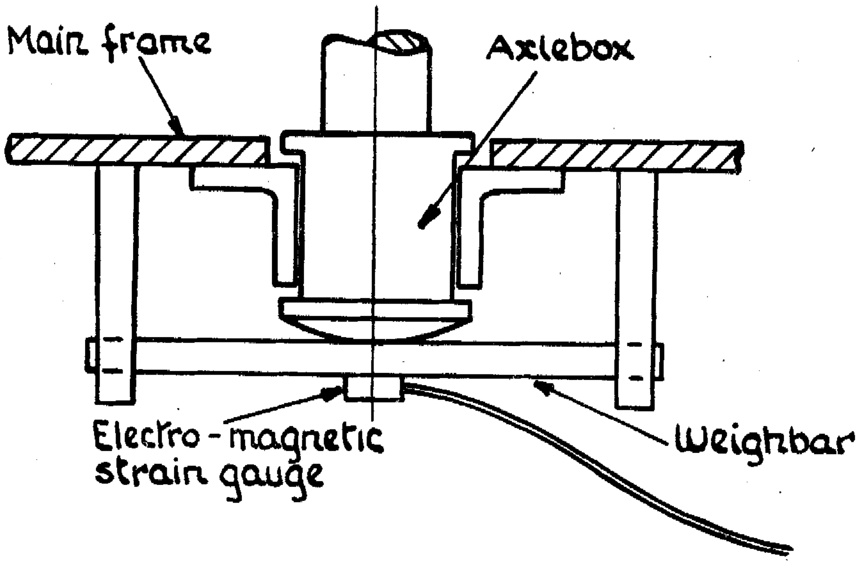


ASSUMING A MOVEMENT TO THE RIGHT SPRING 'C' IS BEING COMPRESSED & IS THUS OFFERING INITIAL RESISTANCE WHILE SPRING 'D' IS BEING RELEASED UNTIL DISTANCE 'A' IS TAKEN UP. SPRING 'D' IS THEREFORE ACTING AGAINST SPRING 'C' AND ACTUAL CONTROL OBTAINED IS AS SHOWN IN SIDEPLAY & CENTRING FORCE DIAGRAM GIVEN ABOVE.

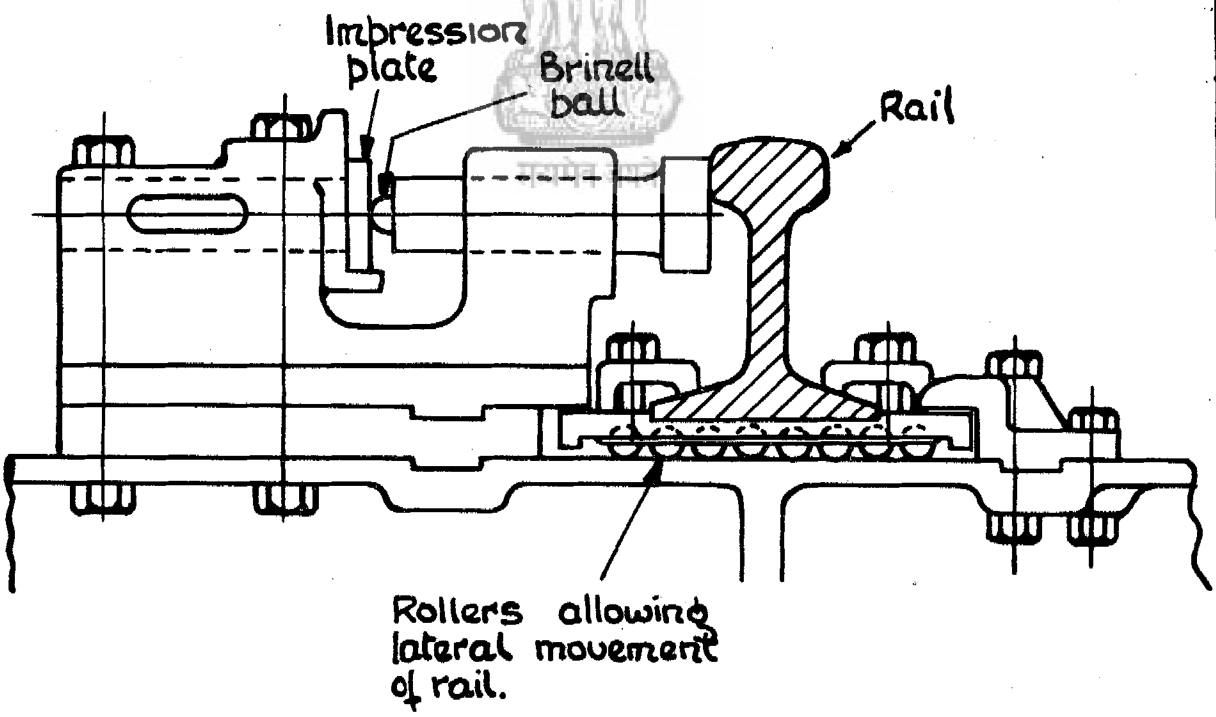
DIAGRAM OF CONTROL SPRINGS - BOGIE OF X CLASS PACIFICS.
INCORRECT ADJUSTMENT.

FIG. 10.

P.L.C.



ARRANGEMENT OF WEIGHBAR & ELECTRO-MAGNETIC STRAIN GAUGE FOR MEASURING FLANGE FORCES. (Shewn applied to locomotive with outside frames and axleboxes)

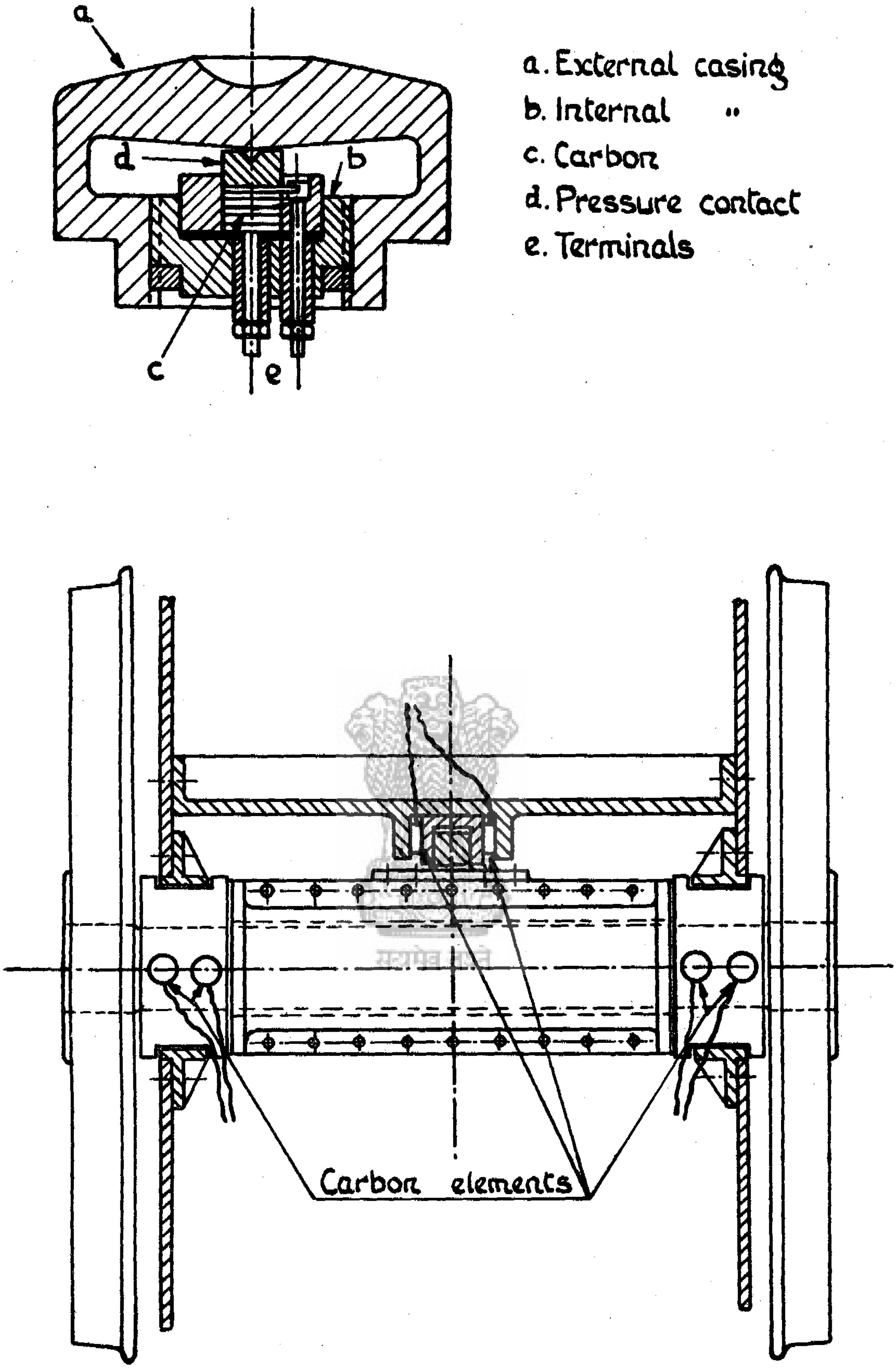


METHOD OF RECORDING FLANGE PRESSURES BY MEANS OF SPECIAL RAIL FASTENING.

AMERICAN EXPERIMENTS.

FIG. 11.

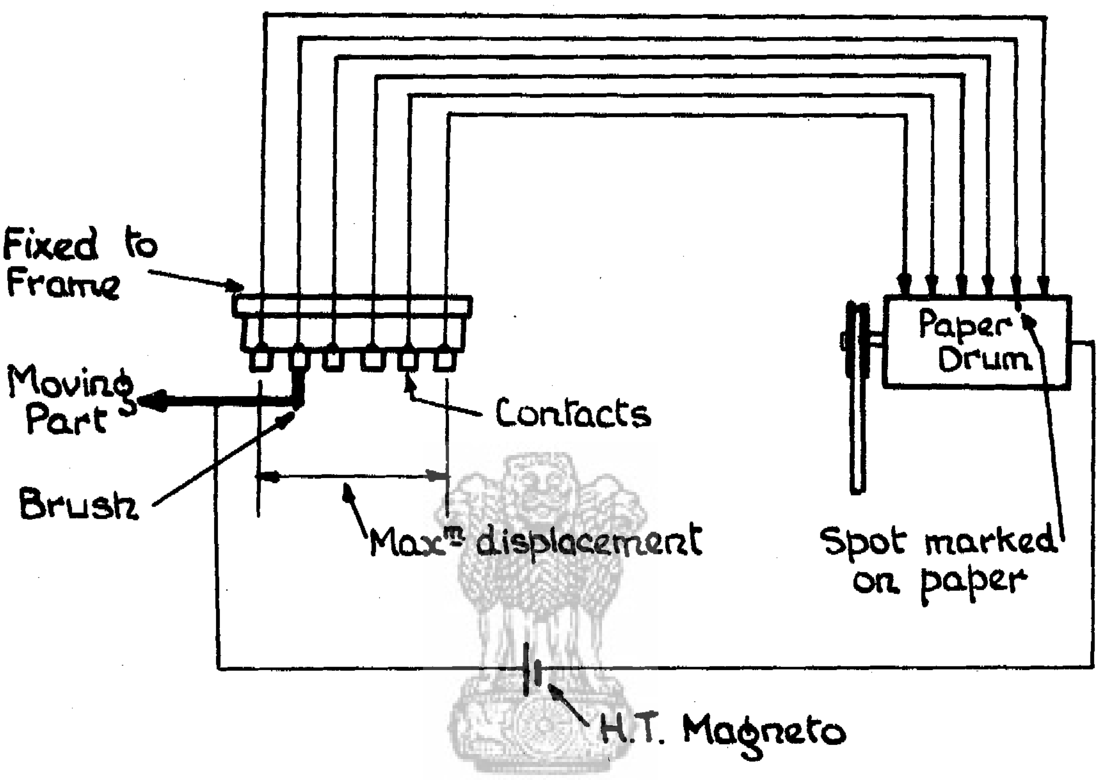
P.L.C.



Plan view of pair of coupled wheels.

CARBON ELEMENT & ITS APPLICATION.
GERMAN EXPERIMENTS.

FIG. 12.



EARLY ELECTRICAL APPARATUS FOR RECORDING DISPLACEMENT.

FRENCH EXPERIMENTS.

FIG. 13.

P.L.C.

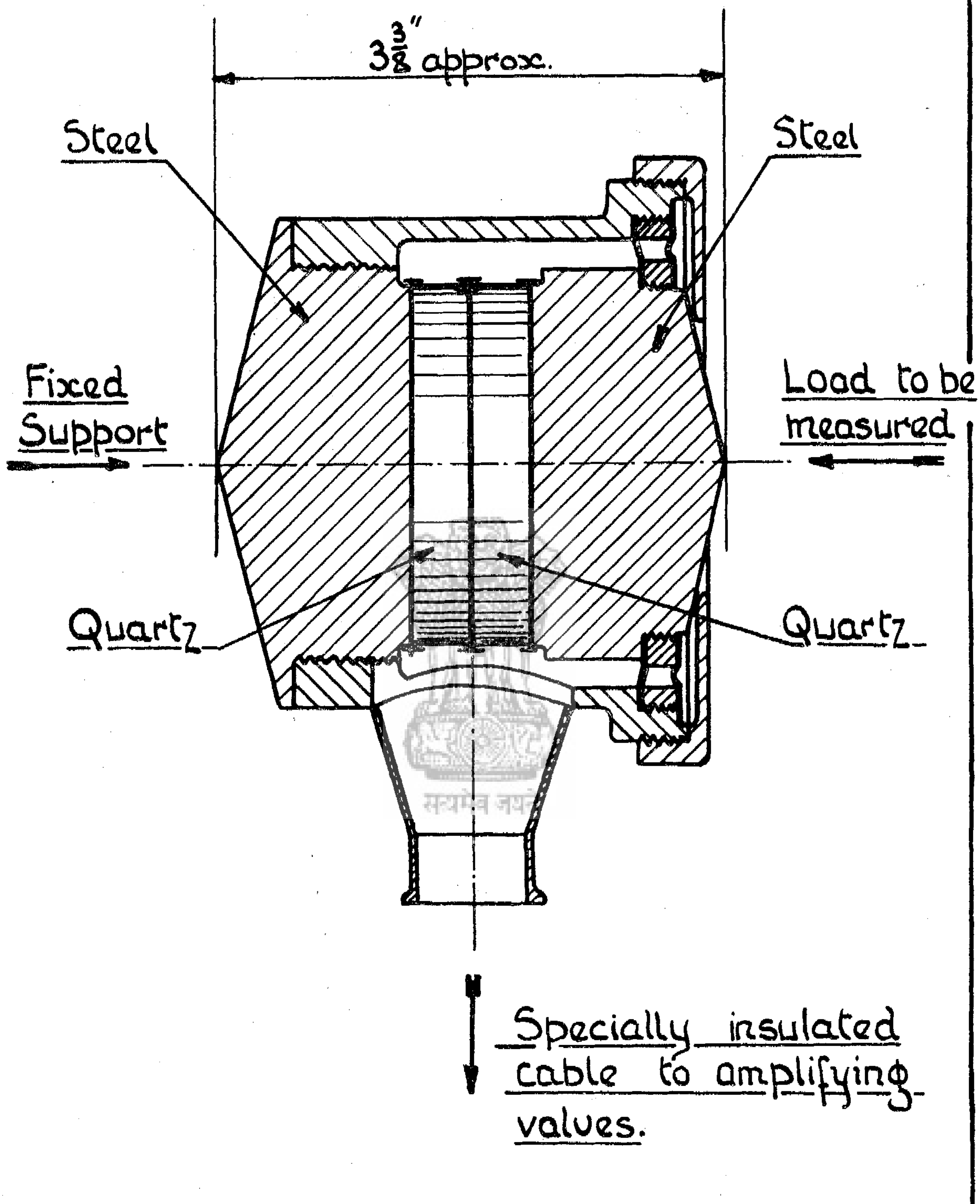


DIAGRAM OF QUARTZ UNIT AS APPLIED TO AXLEBOXES. FRENCH EXPERIMENTS.

FIG. 14.

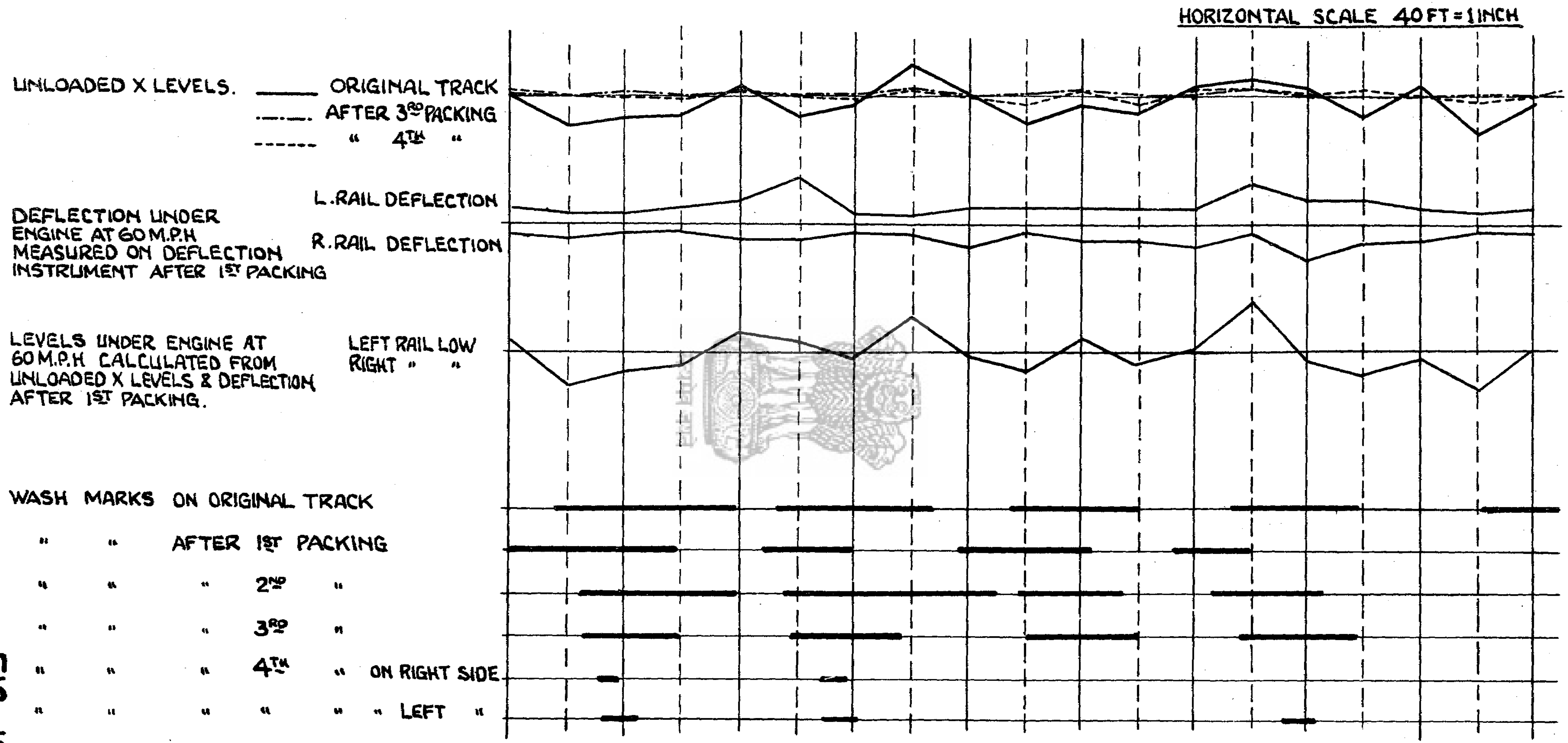
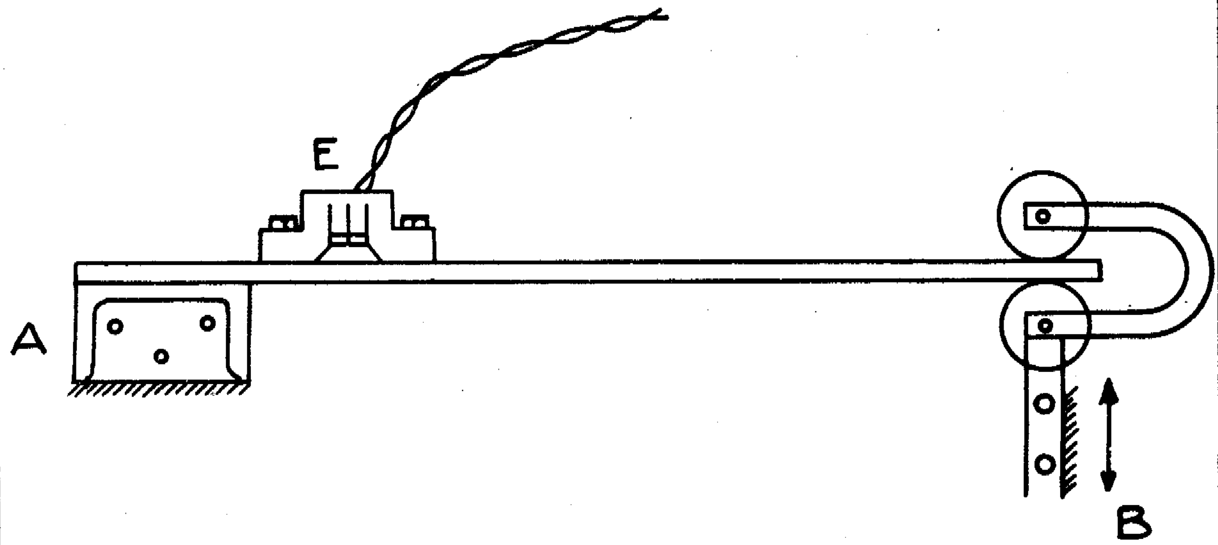


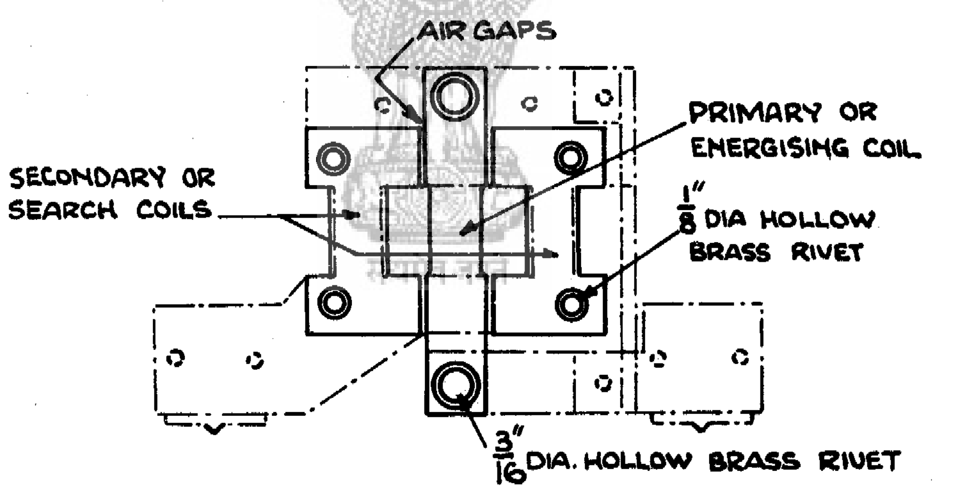
FIG. 15.

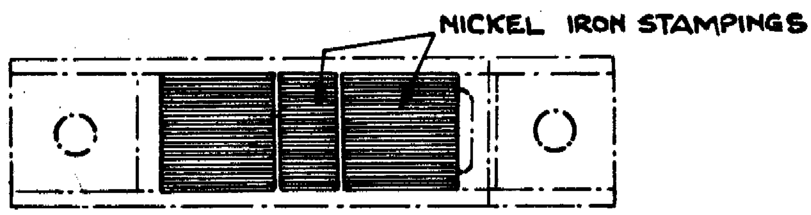
TESTS ON B. B. & C. I. RLY. TO SHOW EFFECT OF REPEATED PACKING OF SLEEPERS ON ENGINE HUNTING.

P.L.C.



ELECTROMAGNETIC STRAIN DETECTOR ASSEMBLY



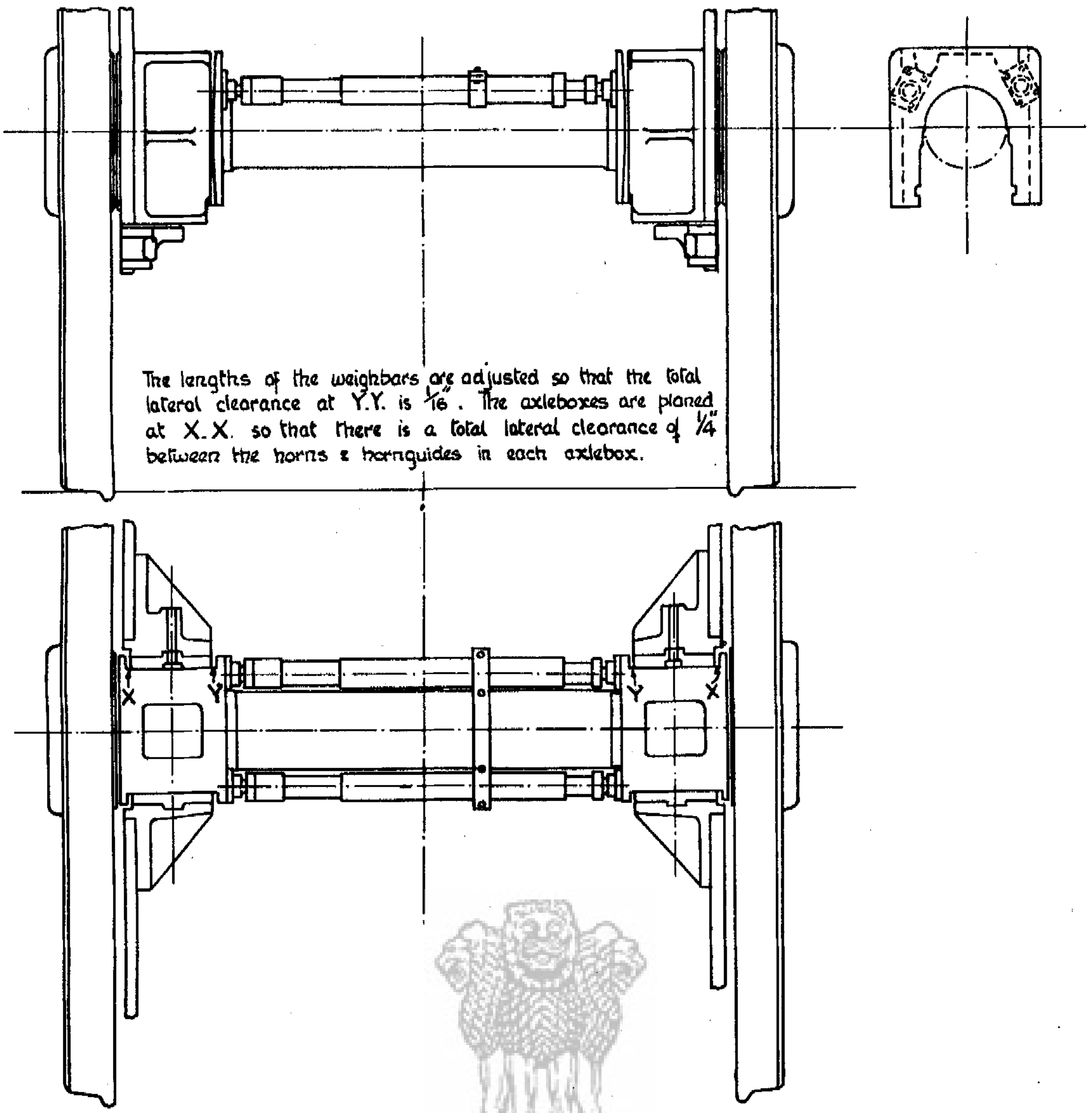


APPARATUS FOR MEASURING DISPLACEMENT.

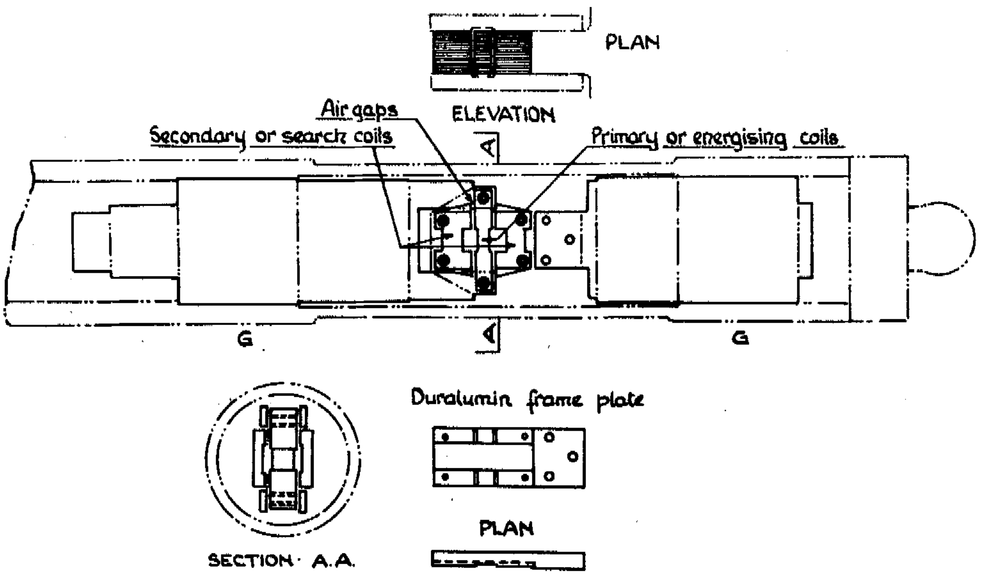
RAILWAY BOARD'S RESEARCH.

FIG. 16.

P. L. C.



ASSEMBLY OF WEIGHBARS BETWEEN AXLEBOXES.



ELECTROMAGNETIC DETECTOR FOR WEIGHBARS.

APPARATUS FOR MEASURING FLANGE FORCES.
RAILWAY BOARD'S RESEARCH.

FIG. 17.

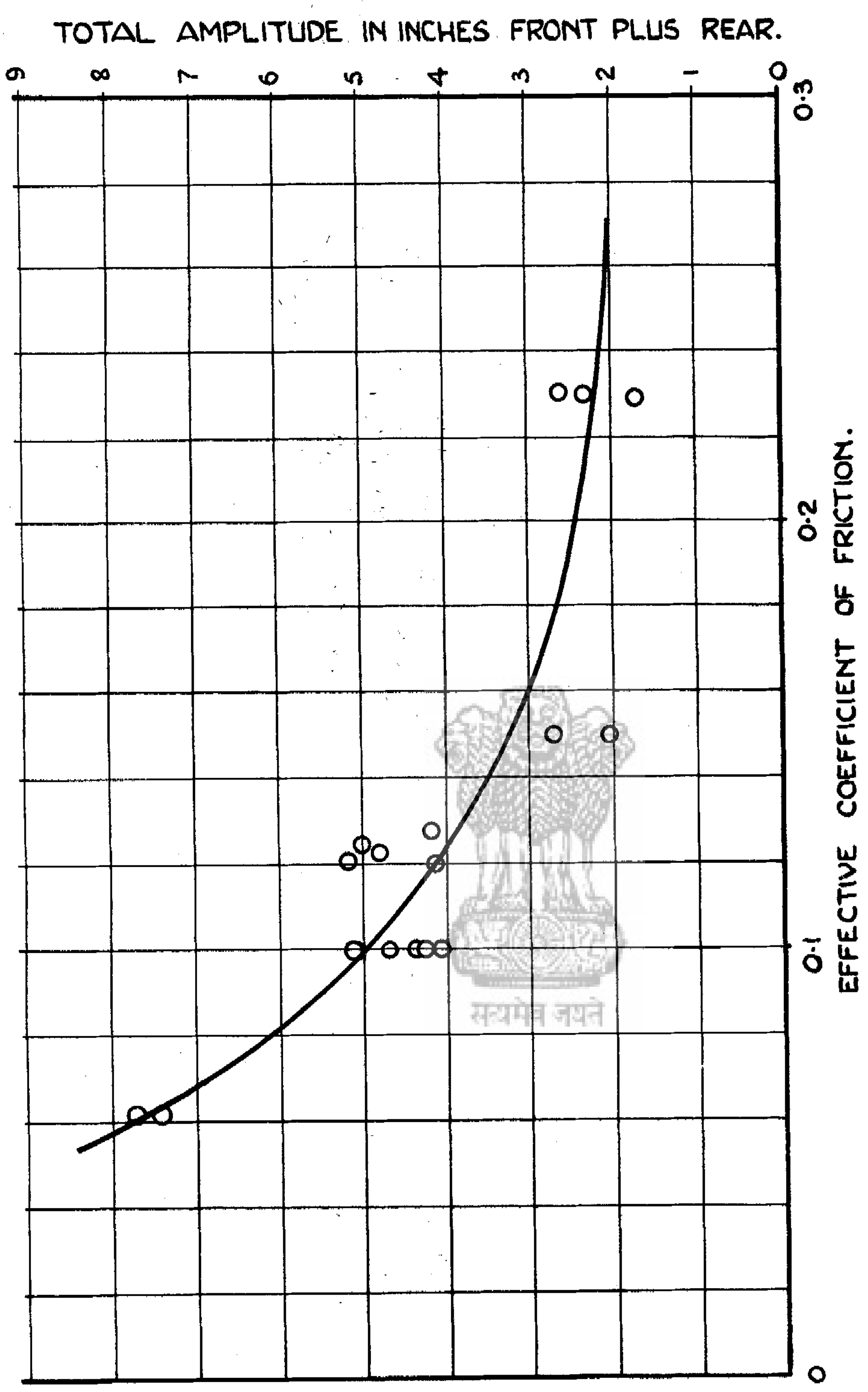


DIAGRAM A.

FIG. 18.

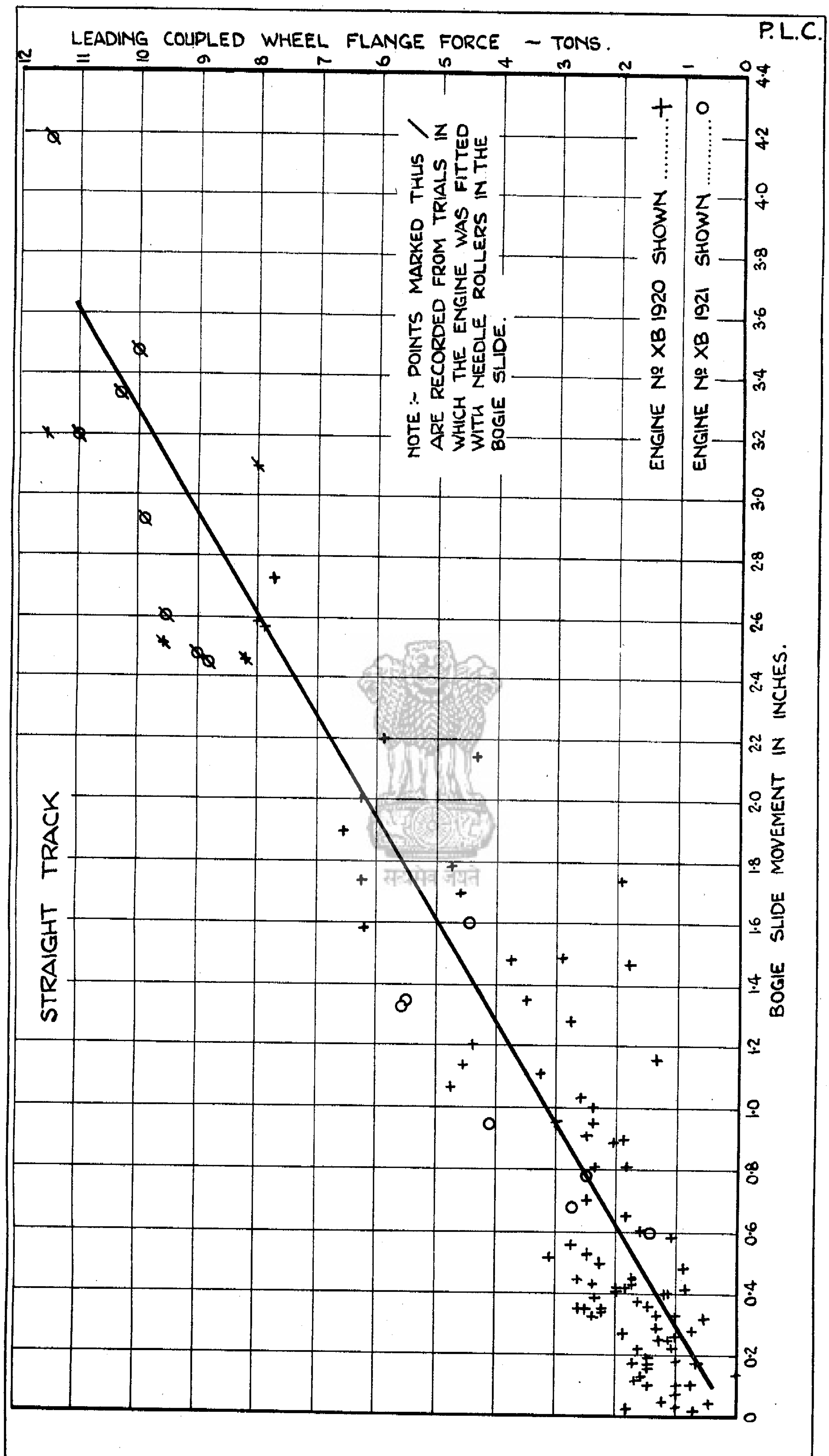
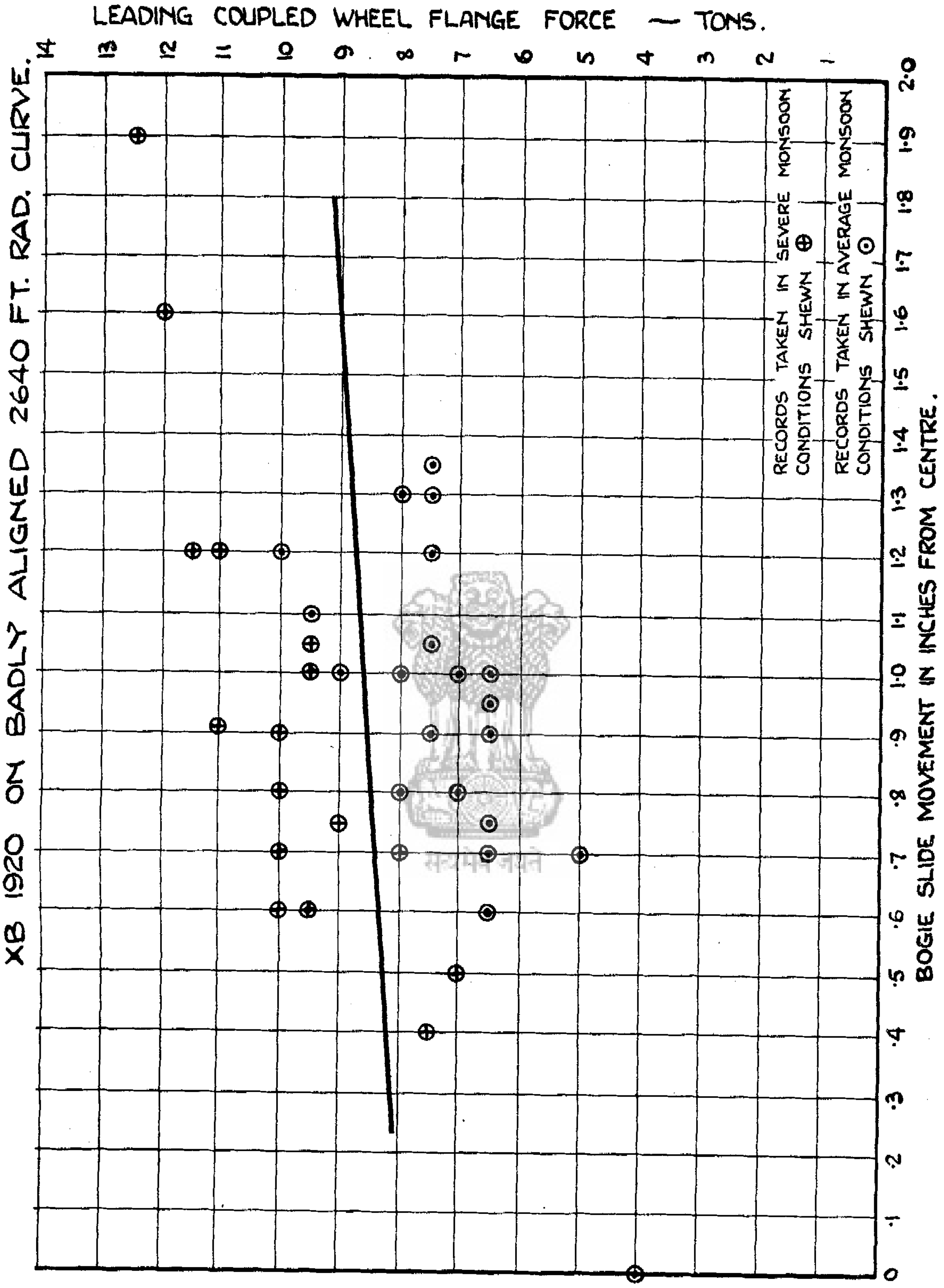


DIAGRAM B

FIG. 19.

P.L.C.



RELATION BETWEEN FLANGE FORCE & BOGIE DISPLACEMENT ON CURVES.

FIG. 20.

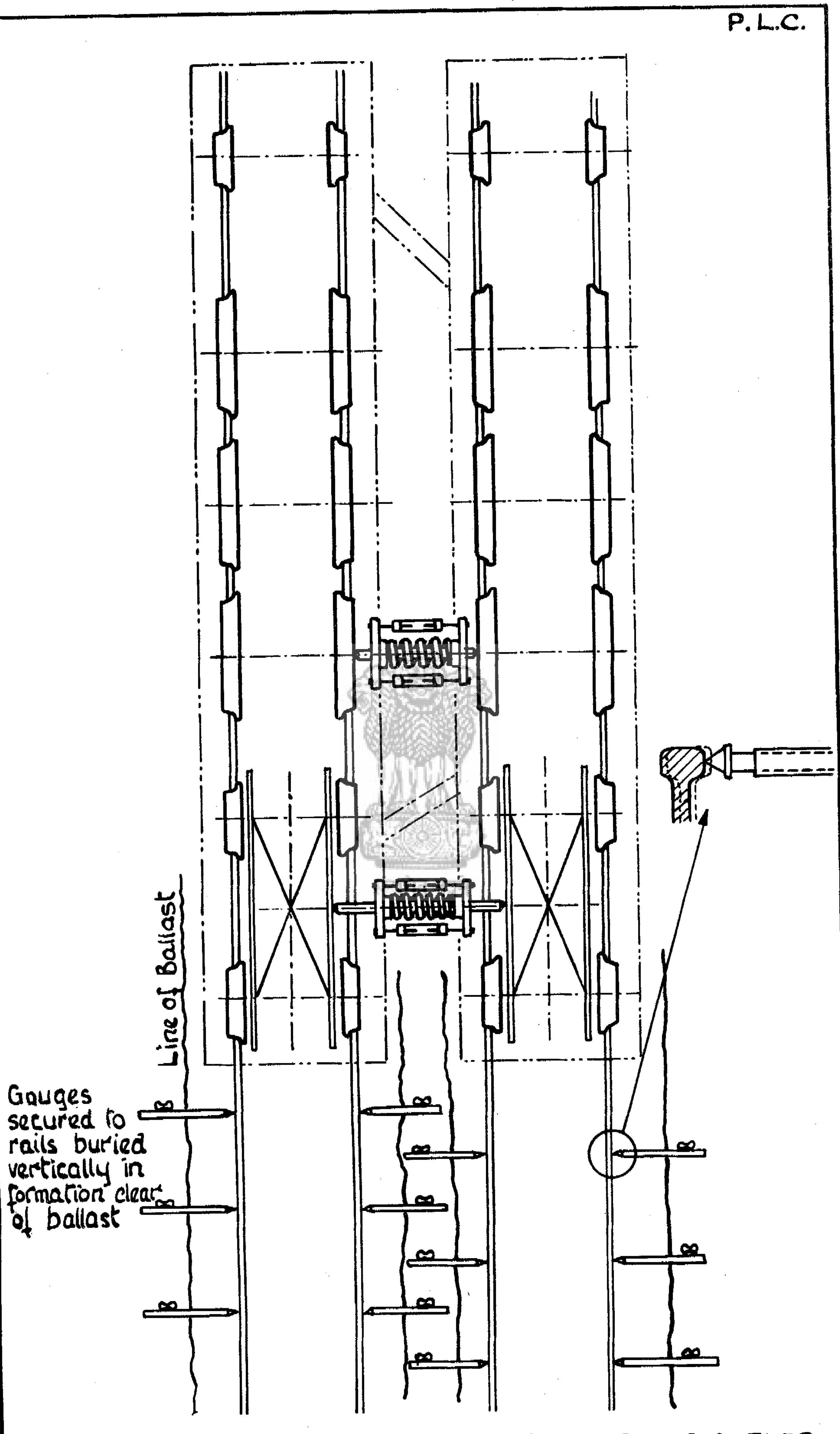
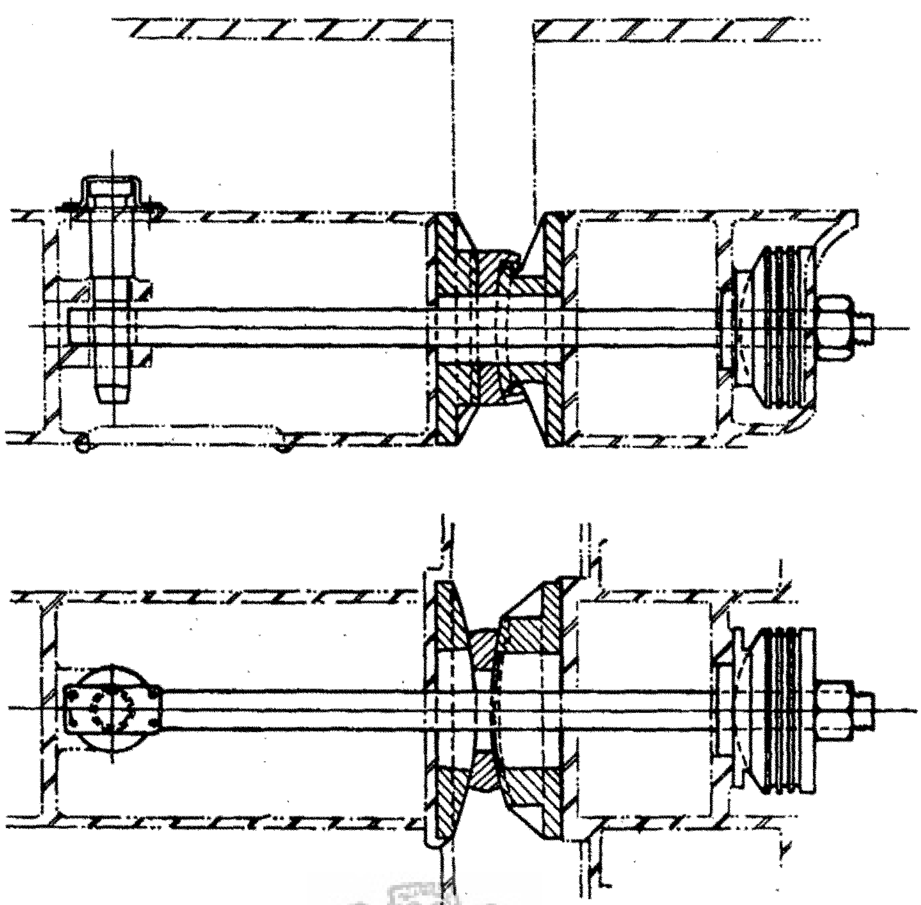


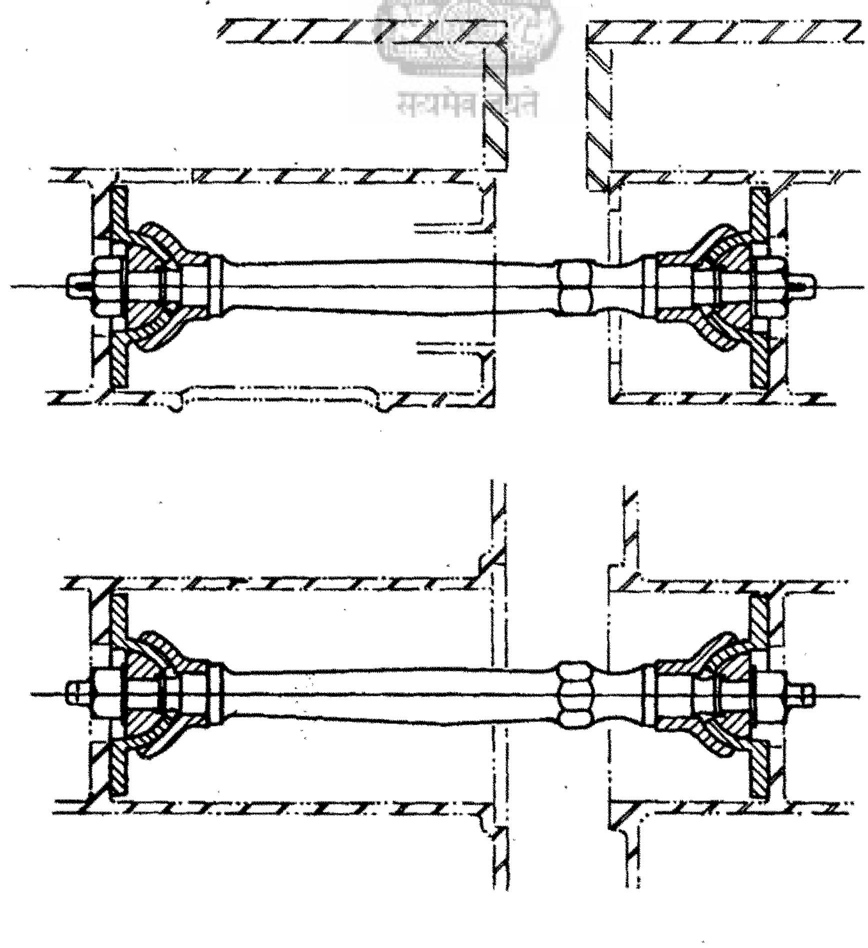
DIAGRAM SHEWING ENGINES COUPLED TOGETHER FOR TRACK TESTS

FIG. 21.

P.L.C.



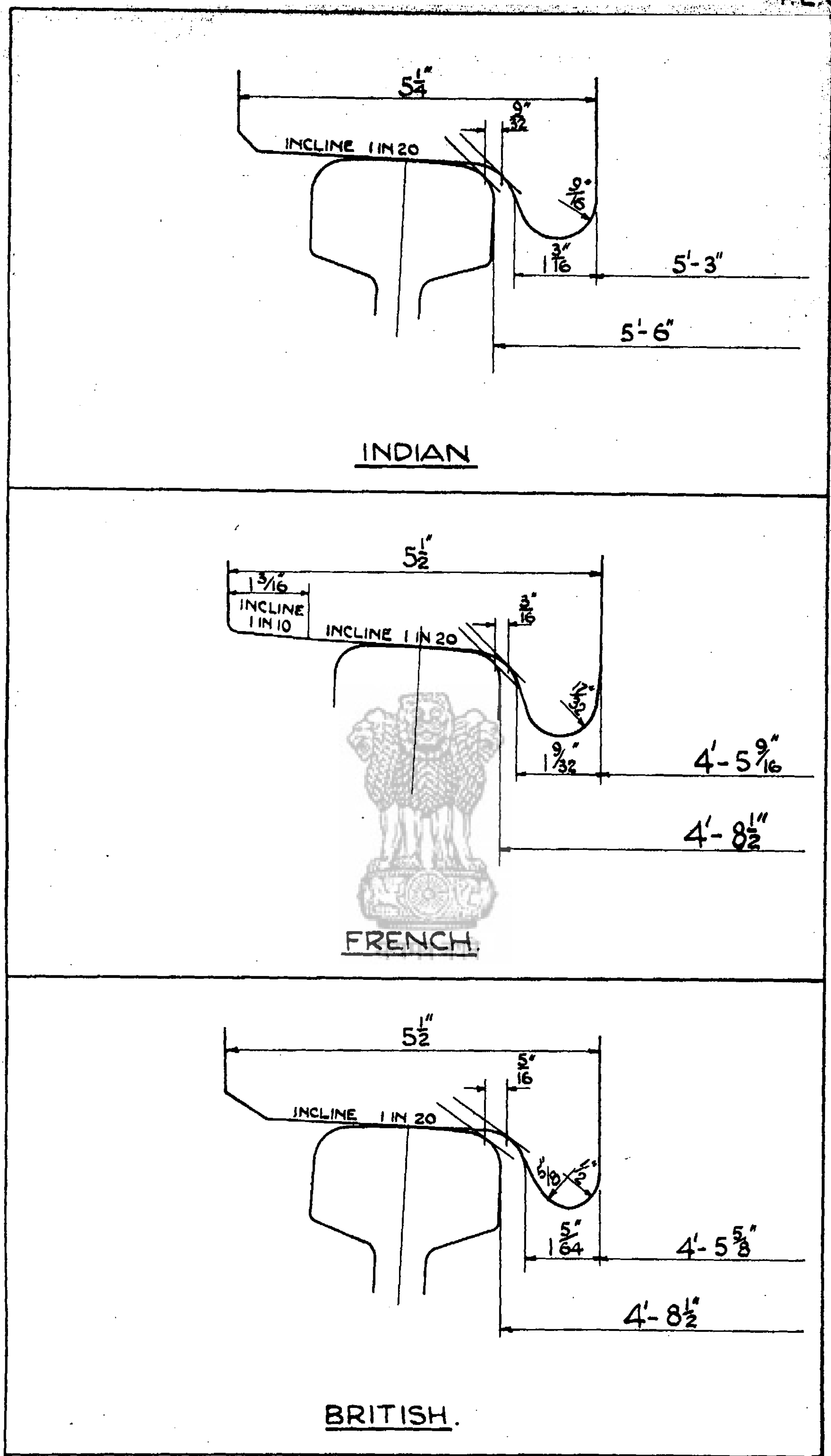
AMERICAN TYPE DRAWGEAR.



GOODALL TYPE DRAWGEAR.

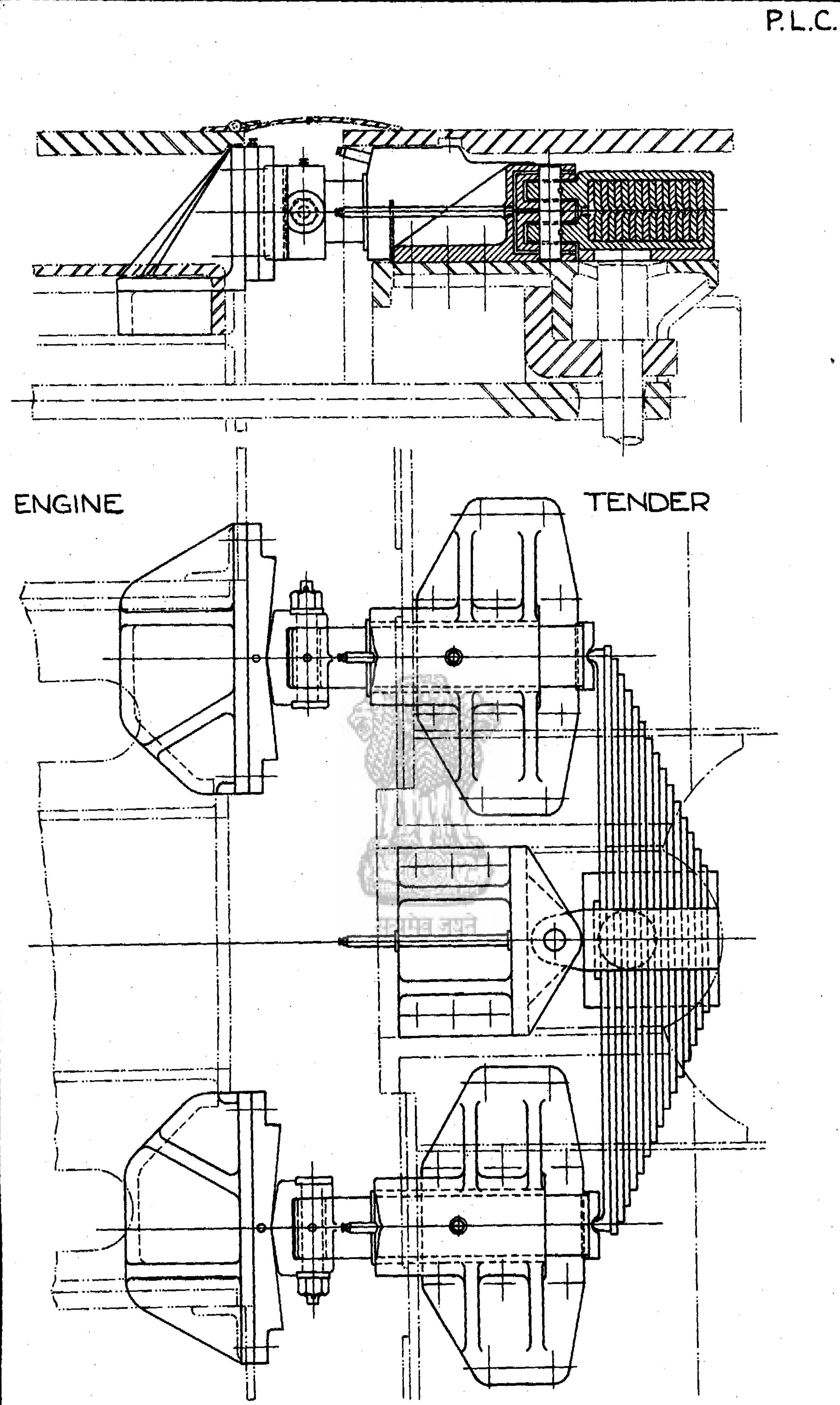
FIG. 22.

P.L.C



CLEARANCE BETWEEN FLANGE & RAIL.

FIG. 23



ARRANGEMENT OF GERMAN TYPE INTERMEDIATE BUFFING GEAR.

FIG. 24.