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IRRIGATION BY TANKS

Specially with reference

TO

GWALIOR STATE

BY

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GWALIOR.

PREFACE.

The object with which these short Notes are composed is to make them useful to subordinates in the Irrigation Department. I want to make these Notes, brief as they are, as complete as possible. It is therefore submitted to the professional readers for criticism, suggestions and corrections. The 1st edition will be brought out after necessary corrections are made in the light of criticism from qualified men.

SABALGARH,
Dated th March 1903.

S. K. GURTU.

CHAPTER I.

INTRODUCTORY.

SECTION 1.

Sources of Irrigation in the Gwalior State.

Most part of the Gwalior State is hilly, and abounds in Nalas and ravines, in which the water flows during the rains, and which run dry at the end of the wet season. There are no perennial streams; even Sindh and Chambal dry up, or hold very little water, in summer. Thus irrigation by canals is impossible. The only two remaining sources of irrigation are—irrigation by wells, and irrigation by tanks Well sinking is not always resorted to in this State owing to the sub-soil water level being at considerable depths, and to reach to that level boring in hard rock is necessary, the cost of which is often prohibitive. Most of the wells sunk are not, for this reason, carried to sub-soil water level, with the consequence that they dry up in summer,—just at the time when they are most needed. Only here and there rich land-holders spend large sums of money in carrying their wells to the sub-soil water level.

Irrigation by canals being impossible, and the construction of wells not bringing proportionate return for the money expended, people find it very much cheaper and easier to bund up Nalas and store up supply of water sufficient for their purposes. Upto very late tanks were constructed in a very crude and unscientific way. People contented themselves with bunding up Nalas and providing outlets for drawing off water, when necessary. It often happened that a heavy and brisk downpour was sufficient to fill the tank to the brim, after which the water overflowed the earthen Bund, doing it great damage and sometimes breaching it badly. No mathematically calculated escapes were provided for the surplus water to run off from, without heading up to the top of the Bund and overflowing it. It was Sir Michael Filose who first inaugurated the construction of tanks on a sound basis. A regular Irrigation Department, however, was organised only very lately, and method introduced in the construction of Bunds.

It will thus be clear that Irrigation by tanks in this state, is the cheapest means of Irrigation, proved by long experience. Moreover the configuration of the ground lends itself very easily to the construction of tanks. Suitable sites for Bunds are to be met with everywhere, and if money and attention are devoted to this branch of Irrigation it will be found that Irrigation by tanks is as cheap, if not cheaper, than canal irrigation in the Punjab and the United Provinces.

The cost of constructing and maintaining Bunds is considerably less than that of canals, only the Bunds should be constructed on a grander scale and with greater factors of safety than allowed heretofore. If the construction of tanks goes on actively, the whole of the State will in course of time, be covered by a net work of tanks, which will protect large areas from drought and famine, leading to the prosperity of the State and the ryots.

SECTION 2.

Functions of Irrigation Works.

In his admirable work on Irrigation Colonel Clibborn, late Principal of Roorkee Engineer College, gives the following 9 functions of Irrigation *viz* :—

(1) PROTECTION.
(2) IMPROVEMENT OF CROPS.
(3) ADDITION TO THE WEALTH OF THE COUNTRY.
(4) INCREASE OF POPULATION.
(5) EFFECT ON HEALTH AND CLIMATE.
(6) PLANTATION.
(7) NAVIGATION.
(8) BATHING.
(9) WATER POWER.

(1) PROTECTION.

Of all the considerations which lead to the extension of irrigation works this is the most important. To a person who has been an eye-witness to the harrowing misery of the people in times of drought, the importance of Irrigation works admits of no question. The more extensive the irrigation the larger the area which would be protected from the ruinous effects of water-famine. Relief works in times of famine are mere make-shifts; they very inadequately meet the difficulty, and provide no security against the recurrence of famine. It is too sanguine optimism to take refuge in the belief that famines will not recur, without taking effective measures against their possible visitation. Years of plenty should be regarded as breathing spaces allowed by wise Providence for us to guard against the recurrence of famines. The only means of combating a famine is by the extension of irrigation. Under the liberal administration of our present ruler, irrigation has received an impetus unknown before, and it is to be hoped that by further extension of irrigation, it will be possible to see famine pass over the land without affecting it seriously.

(2) Improvement of Crops.

Crops which depend upon rain-fall for growth and nourishment are not so good as those which receive a regular supply of water. Rain-fall does as much injury sometimes by its excess as by its scarcity, not so the water in tanks which can be regulated according to need.

(3) Addition to the Wealth of the Country.

This is evident. If there were more irrigation works than at present, the land-holder could bring greater area under cultivation, thereby reaping greater profit himself, and giving larger sums to the State in the shape of revenue.

(4) Increase of population.

From the vestiges of ancient greatness, which are yet to be seen in the Surwaya Taluqa of His Highness's Dominions, it is patent to even a casual observer that this District must have been highly populous in times gone-by. Now it is all desolate. Prior to the construction of Irrigation works—Tanks and Wells—by the Land Records Department, there was hardly any water to be met with for miles around. Those who have read the ancient history of the migration of Aryans, and of other races in recent times, with any care, must have noticed that the immigrants always chose that spot for settlement which was fertile and had some perennial supply of water, as a river, in its vicinity. The Aryans settled down in the Panjab and Upper Hindustan in preference to the arid lands of Rajputana.

Supply water in any particular locality and you are bound to attract settlers in course of time: of course productiveness of the soil is a *sine qua non.*

(5) Climate and health.

Excessive heat is too distressing an element in the climate of Lashkar. Add to this the heaps of putrid and putrifying rubbish lying ensconced in the depths of the Nala which intersects the city, causing miasmatic exhalations, and you have a simple explanation of the insalubriousness of the climate of Lashkar. The mosquito pest also is due to the filthiness of the town. With the outbreak of monsoon these symptoms are greatly heightened. With the bunding up of the Nala, introduction of irrigation works, and proper conservancy arrangements, it is possible to improve the climate of Lashkar, hemmed though it is on all sides by hills, which irradiate heat in the scorching days of summer. Of course strict measures shall have to be taken to prevent any rubbish or filth being thrown into the Nalá, as is now the practice. Some might object to this scheme as likely to breed disease by water-logging the soil. I can, in refutation, only cite the example of the Naddi at Indore which passes through the Residency limits, but its bunding up has not evoked any cry from the medical authorities, in respect of its affecting the health of the people injuriously. No water-logging need be feared here as the moisture of the Nala would serve to absorb the excessive heat—one would nullify the other.

(6) Plantation.

No special attention has yet been bestowed upon the Conservation of Forests, though the beginnings of it are to be seen in the creation of a Dang Department, but the proper conservation of forests requires efficient and qualified supervision. The British Government have a regular institution where Forest Conservators are trained and educated. Only an expert can say what trees are to be preserved and what rooted out. If trees yielding fruit and good timber are planted in and around all big tanks, they will, in time, be a source of income to the State. Lac, Gum, Catechu, Chironji seed, Mhowa and other things can be raised in forests, yielding good revenue.

It is a meteorological phenomenon that places which are thickly covered with forests, attract more rain than those denuded of trees. Sir John Malcolm says, in his "Malwa" that prior to the destruction of forests in Central India the average rain-fall stood at about 55 inches annually and now the average does not go beyond 35 inches or so.

(7) Navigation.

This is quite out of question in this State, having no big navigable rivers like the Ganges or Jamna.

(8) Bathing.

This item too has its recommendation in big towns like Lashkar. If large tanks can be constructed in the vicinity of large cities, apart from adding to their picturesqueness, they would be highly appreciated by the urban population as bathing places. To a Hindu it is a real treat to have a tank near the city for bathing and morning prayers.

(9) Water-Power.

This has not yet received the attention it deserves. Syed Jafer Husain, who prepared the Sindh Project, told me once that the Sindh had several sites favorable for the construction of falls, and thereby giving water-power sufficient to work mills. No doubt the Chambal too must have many good points of this character.

CHAPTER II.

TANKS

All the tanks in this State fall under three heads *viz* :—

(1) SUBMERGING TANKS. (2) SUBMERGING TANKS WITH OUTSIDE IRRIGATION. (3) RESERVOIR TANKS.

SECTION I.

SUBMERGING TANKS.

Submerging tanks are constructed to submerge large tracts of land within the tanks, the land outside not being of such a character as could be brought under cultivation. Cases, however, sometimes occur when the land outside the tank is of a good quality, but the tank can not impound water sufficient to submerge the land inside and leave some surplus for the land outside. Such tanks are constructed merely with the view of storing sufficient quantity of water to keep the land submerged wet till the season for *Rabi* crop comes, when water is let off through scouring-sluices, and the moist land is brought under cultivation, yielding good harvest of wheat or gram. Submerging tanks serve the following 3 useful purposes:—

(*i.*) They bring a large *Parat* area under cultivation, leading to a direct return to the State in the shape of land-revenue.

(*ii.*) The rain-water brings with it rich manure from places it passes over, in the shape of dissolved cow-dung and other rotting and rotten vegetable matter which serve to fertilise the soil and render it more productive. It not infrequently happens that the land which formerly yielded *Tilli* or some other inferior crop, begins to yield wheat and gram, after the construction of a tank !

(*iii.*) The uneven land around the Nálá across which the Bund is thrown becomes, in course of time, one level piece of ground. Gwalior being notably a hilly country the rain water flows off the land with an eroding action, with the result that, year by year, the ground round about the hilly Nálás or ravines is cut slowly into *Behur*, and much productive soil washed off to the sea, leaving the land barer and poorer ! Traces of earthy crust having been washed away, leaving bare rock behind, are to be found every where in this State.

Kaitha, Soujna and other Mouzas in the Gird District are examples of this denudation going on from times immemorial. Bunding up such Nálás arrests this havoc, and turns an enemy into a friend, in that the earth brought down by the Nálá in flood settles in the tank, and the Nálá gets silted up in course of time.

Naunan'a ká Tál may be cited as a very good example of a submerging tank. The designer has been very happy in his choice, as by throwing a small Bund across a Nálá, he has been able to submerge a large tract of land, which yields nice wheat in the *Rabi* season. The water of this tank is drawn off in the month of October and wheat grown. It is a typical example of a submerging tank.

SECTION 2.

SUBMERGING TANKS WITH OUTSIDE IRRIGATION.

These tanks, as their name implies, serve two ends, *viz.* they submerge and fertilise the land within the tank, and also irrigate the land under the command of the tank outside, often as much as that submerged. They are by far the most useful tanks in the State. Many tanks of this description lie scattered in different parts of this State.

The water of such tanks is let out about *Dewali* for bringing the land within the tank under tillage for *Rabi* crop, some having been utilized for irrigating outside rice-fields. Sometimes the escaping water serves to moisten such lands outside the tank as have, for want of having been ploughed up in the rainy season, become hard and dry. Such land can not produce wheat, but grows gram very well.

It will not be out of place here to give a short account of how rice fields are irrigated, which will help in rightly estimating the quantity and depth of waterings required for rice crops.*

* On Syed Jafar Hosain's authority.

Just at the commencement of the rainy season when the tanks are full of water and there is further hope of rain falling and re-filling the tank if it is once emptied or partially emptied, rice is grown in the land outside the tank, and water carried to them through sluices, along the ridges of the fields. The land is flushed with water after being ploughed up and the water is allowed to soak into the earth for two or three days. Water is constantly poured into the fields—they are not allowed to dry up. Thus all the vegetable matter in the fields gets rotten and serves as manure. These fields are then again brought under the plough and seed thrown. Fresh water is poured into the fields. When the seed sprouts, the ridges are cut through and the standing water let out. The water which is kept in the fields till the seeds sprout, serves the two-fold purpose of helping the seed to sproit and keeping off birds etc. from picking off the seed thrown. It is a peculiarity with rice that, unlike other seeds, it is much benefited by standing water instead of being injured. Of all the other crops, rice requires the greatest depth of watering.

SECTION 3.

Reservoir Tanks.

Reservoir Tanks are supply tanks *i.e.* keep stored up a large supply of water, which is meant to last for the whole year. From their very nature they can only be constructed in hilly tracts where favorable sites for the construction of Reservoir tanks abound. In designing Reservoirs these two conditions should not be lost sight of :—(i) That sites should be selected where there is a great dip between two hills to permit of a very deep tank being made at a comparatively small expense, (ii) That the soil where Reservoirs are designed should be impervious, as great loss of head is occasioned by the absorption which goes on constantly and very actively in sandy soils The most desirable soil is rocky, next to which is *Màr* which refuses to absorb water beyond a certain amount. Such tanks need not cover large areas, the great point in them is that they should be deep to minimise percolation and absorption, as the greater the surface, the more active are the percolation absorption, and evaporation.

In Reservoir Tanks submerged area is not taken count of, as the tanks are never intended to run dry leaving a wetted area for cultivation. Reservoirs can be useful in the following 7 ways, *viz.*—

1. For watering cattle. 2. For irrigating *Rabi* crops below the tank. 3. To fill other submerging tanks below them, through channels or escapes. 4. Reclamation of *Behur* or broken ground. 5. Raising of subsoil water level and thereby reducing the cost of sinking wells in their vicinity. 6. Providing a resort for water-fowls and other beasts of prey. 7. Boating and other aquatic amusements.

1. *Watering Cattle.*

Reservoirs are a desideratum in His Highness's Forests and Dang villages, where there is no permanent provision for watering the cattle of the villagers living in Dangs. *Saharyas*, who lead a sort of nomadic life and live in great squalor and poverty, can not afford to sink wells, the cost of which is considerable owing to subsoil water level being too deep down. Living in the most rude manner, without any worldly possessions they shift from place to place for want of water. Thus absence of water encourages, or rather forces them to live a life of vagabondism! If plenty of water is available on all sides these wild *Saharyas* are likely to settle down in one place and turn peaceful cultivators in time. The occupation of well-to-do *Bunias* and *Telis* in the Dang villages is to trade in *Ghi* (clarified butter) got from cattle which graze in the forests. Occasionally they till small bits of land where water is obtainable and land productive. Under the present circumstances in the years of drought, and in the latter days of summer, before the outbreak of rains, the cattle-owners in Dangs have to carry their cattle as much as 10 to 12 miles daily, or alternately, to places where water is obtainable! Scarcity of water in Sheopur District is too well known to require any comment. There is plenty of grass in the Dangs, and if water were obtainable with as much facility, most depopulated districts are likely to attract settlers, who would not only rear cattle but will also bring under tillage land which is lying barren for want of water.

2. *Irrigation of Rabi crops below the Tanks.*

There are no hard and fast rules about the time for the sowing of *Rabi* crops. It extends from October to January. In the Gwalior State operations for the raising of *Rabi* crops are commenced in October. twenty-one days after the casting of the seed irrigation begins, which goes on from time to time according to the requirements of the crops. The 1st of March is about the time when the *Rabi* season is considered to terminate and no more irrigation is required till the next cold season, the *Kharif* crops mainly depending on rain water for their nourishment and growth.

Duty of water.

The duty of water, as applied to tanks, is the area which can be irrigated by a discharge of one cubic foot per second through a sluice-hole, working continuously throughout the year. Colonel Clibborn gives 300 acres or about 600 Gwalior bighas per cubic foot per second as a "fair figure." A duty of 300 acres is equal to a depth of 2·41 feet* all over the area and ignoring the loss in water-courses, which is, however, sometimes as much as 20 to 40 per cent. of the total discharge. Taking 30 per cent. as an aervage figure to work by 2.41 gets reduced to 1·7.

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* How this figure is arrived at—

$$1'' : 1 \times 365 \times 24 \times 360'' :: 1 \text{ cft.} : x \text{ cft.}$$

$$\therefore x = 365 \times 24 \times 360.$$

Dividing this by 300 acres, we get the depth of watering,

$$= \frac{365 \times 24 \times 360}{300 \times 4840 \times 9} \; 2 \cdot 41 \text{ ft.}$$

Depths of waterings.

"The numbers of waterings given to each crop differ so widely according to soil, climate and season that it would not be of any practical use to specify them for general use".* He gives the following table to work by roughly (P. 27. Irrigation Manual.)

No	Crops.	Depths in feet. First watering.	After watering.	Total.
1	Wheat	·250	·186	·436
2	Barley	·186	·186	·372
3	Tobacco	·186	·125	·311
4	Opium	·186	·125	·311
5	Carrots	·186	·125	·311
6	Potatoes	·186	·125	·311
7	Gardens	·093	·093	·186
8	Sugar-cane	·250	·250	·500

Another authority gives the following depths of waterings for different crops.

Tobacco.	Potato.	Sugar-cane.	Opium.	Gardens.	Wheat.
1·9	1·2	1·1	1·0	1·0	0·7

† In Rajputana, a naturally dry country, 1,20,000 cft. of water are sufficient for 3 waterings of one acre *i. e.* about 3 feet depth of watering in 3 waterings, which is sufficient to meet all demands of leakage, evaporation and irrigation.

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* Colonel Clibborn.

† Extract from the Memo. laid before the Irrigation Commission by the Jaipur State.

On this point Molesworth says:—

"In India mean duty per cubic foot per second is: 189 acres, Ganges canal, 215 acres Jamna canal. Sugar-cane and rice 60 acres, wheat 180 acres, Maize and Millet 250 acres." This arranged in a Tabular form gives the following depths of waterings for different crops.

Name of crop.	Sugar-cane.	Rice.	Wheat.	Maize.	Millet.
Total depth of waterings.	12	12	4	2·9	2·9

By comparing the above 3 tables all by eminent authorities it will be seen how very different are the conclusions arrived at, by careful investigators! This discrepancy is mainly due to the character of the soil, and the climate in which the experiments were made. In making calculations, however, it is always safe to take the highest figure, unless there are cogent reasons to the contrary. Molesworth's figures evidently apply to arid soils, where loss by evaporation and absorption is considerable. Colonel Clibborn's figures apply to soils in Upper India where the yellow soil is mostly to be met with, and the climate is more equable and mild than in Rajputana and other arid tracts, and hence the loss by evaporation and absorption is considerably less.

Depths of damp. The mean of a number of measurements of the depth to which these waterings damp the soil below the surface = 0·83.*

*Colonel Clibborn.

3. *To fill other submerging tanks below the Reservoir through channels or escapes.*

There are, in the Gwalior State, many favorable sites for the construction of good tanks, but owing to smallness of catchment basins, it is not considered profitable to construct such Bunds, and many an otherwise good tank is left unconstructed. Reservoir tanks can supply this deficiency and serve as large catchment areas to such tanks. In hilly districts where there are many suitable sites for the construction of large Reservoirs, big supply tanks should be constructed, water can then be conveyed to tanks having poor catchment areas.

Rechera Reservoir has specially been constructed by Syed Jafar Hosain to serve as a feeding tank to two other tanks below it. A move has not, however, been taken in this direction by the Irrigation Department yet. Up till now the aim of constructing all irrigation works has been to make something which would yield a direct return in the shape of revenue. It is a trite saying that failures are more instructive than successes, and some margin should be allowed for enterprises of this kind, which yield nothing directly, but sometimes result in immense advantages both to the ryot and the State. As Colonel Clibborn well observes, when a Public Works Department Engineer makes out his estimates for grand buildings, which give no adequate monetary return, but on the contrary entail a yearly expense on account of Repairs and Maintenance, it is not considered necessary to ask "What is the return for such a large outlay?" but if an irrigation project is brought on the tapis, the first question, every person thinks he has a right to ask, is "What would it yield?" and the project has a very poor chance of sanction if its percentages are not satisfactory. Thus the Irrigation Department labours under a disadvantage, from which other Departments of the P. W. D. are free.

4. *Reclamation of Behur or broken ground.*

This has already been touched upon. By gradual deposition of silt brought down by floods a level and fertile piece of land is obtained within the tank. This reclamation is not peculiar to Reservoir Tanks—it applies equally to all the 3 kinds of tanks.

5. *Raising of subsoil water level.*

In some places where the subsoil water level is very much deep and the cost of constructing wells is prohibitive, construction of a Reservoir not only raises the water level, thereby rendering the construction of wells cheaper, but all the waste of water by absorption is nullified by sinking percolation wells below the tank which yield water as long as the water in Reservoir does not dry up.

The great point in Reservoirs, as already observed, is not breadth so much as depth, the deeper the tank the longer it will hold water. No fear need be entertained of the water, which has passed under ground by absorption, travelling to a great distance from the tank, as the rate of travelling of the underground water is only one mile per year.*

* Col. Clibborn.

6. *Providing a resort for water-fowls and other beasts of prey.*

This item can only be appreciated by sportsmen who wearily wait for the outbreak of monsoon to begin their sporting excursions. Wherever there is a permanent supply of water, water-fowls flock in thousands, and multiply in a wondrously short time. Large Reservoirs, thickly surrounded by jungle, afford a refuge to the beasts of prey, which always like to live in quiet sequestered corners in a thick jungle. In times of yore large sums were spent by sport-loving monarchs to preserve the game and encourage their breed. Construction of Reservoirs in Forest villages, has these collateral advantages, in addition to utility for irrigation purposes.

7. *Boating.*

This sort of amusement is wholly unknown in India. Though in India all the big rivers have many boats, they are only plied by professional rowers, for transshipping passengers from one bank to another or conveying goods, like other means of transit. Boating has not been taken up by the higher classes as a means of amusement and exercise! Even where this has been introduced, few people enter upon it with a zest and animation known at Oxford and Cambridge! Our large tanks and Reservoirs offer exceptional facilities for this kind of amusement; it only remains for persons in the higher walks of life to take the lead, the middle classes will, of course, follow suit.

CHAPTER III.

SOILS.*

In a small treatise on irrigation, it will be out of place to give an account of the geological formation of soils, or supply other technical information about them, but as so many blunders are committed daily in the construction of tanks unsuited for them, it will not be amiss to give a short account of the soils to be met with in this State and to point out what sort of tanks are suited for different soils.

There are 8 kinds of soils to be met with in the Gwalior State *viz.* (*i.*) Black cotton soil or *Mâr* (*ii.*) Yellow soil (*iii.*) *Parwa* (*iv.*) *Dumat* soil (*v.*) *Usar* (*vi.*) *Moram* (*vii.*) *Bhur* or sandy (*viii.*) Rocky soil.

(*i.*) *Black cotton or Mâr soil.*

This is by far the best soil for cultivation; it is most productive and retains moisture most. It is of a dull grey color and is, when dried up, badly cracked. It does not, beyond a certain limit, absorb any water, and that is why, when rain falls excessively over black cotton soil, it absorbs as much water as would moisten it and then refuses to have any more, which collects on its surface, rendering the

* For much information in this Chapter I am indebted to Syed Jafar Husain.

ground impassable for days and weeks after the cessation of rain. The earth when wet is of a sticky character and is most troublesome to walk on in the rainy season. Most of the soil in the Surwaya *Taluqa* of His Highness's Dominions, is of this character. *Már* soil grows wheat and gram of a very high order, as also opium. Malwa is noted for its good wheat and good opium—it is all due to this soil. In *Már* soil large submerging tanks are indicated. The depth of water is not so much a point as a large submerged area. Very little depth of waterings suffices for this soil.

(*ii.*) *Yellow soil.*

This soil is protean in character and color. It has different varieties, from the yellow soil which is hardly at all inferior to black cotton soil to the yellow soil which partakes of the nature of sand and is utterly useless for the purposes of cultivation. A kind of ferruginous soil, sometimes met with in the Gwalior State and which contains a great deal of oxide of iron, also belongs to this class. Yellow soil from its numerous varieties is most difficult to distinguish and is therefore most treacherous. Particular attention should be devoted to finding whether a so called yellow soil is good for cultivation, whether it can retain water or is of a porous character.

(*iii.*) *Farwa soil.*

Farwa soil is properly a kind of yellow soil; it is more or less sandy. It yields good crops. The soil of Panyar belongs to this class. From observations made last year the loss of head by evaporation and absorbtion in the three months of August, September and October was six feet. Evaporation is not very active in these months, so all this loss should be put down to absorbtion. Submerging tanks are indicated for this kind of soil ; the land submerged is brought under cultivation as soon as water recedes from it.

(*iv.*) *Dumat soil.*

This is a cross between black cotton and yellow or *Parwa* soils and partakes of the properties of both. Reservoir tanks can be constructed in such soil, as loss of water due to absorption is not very great.

(*v.*) *Usar.*

Usar proper is a name given to a soil having *Reh* or efflorescent salt which can hardly grow any thing, except perhaps inferior rice. This name is also given to those *Banjar* lands which are not capable of yielding any thing and are so hard that water does not seem to penetrate them, but after submersion for a long time and when the *Reh*, if any, is washed off by mechanical means, it begins to grow ordinary crops. The process of reclaiming such soils is very tedious and need not be described here

(*vi.*) *Muram.*

It goes without saying that there is no use in constructing a tank on such soil, as it can neither serve as a storage tank, in that it can not retain any water, nor as a submerging tank as it would not grow any cereal. Manyar tank in Sipri is constructed on a bed of Morum; it will be interesting to see how it works.

(vii.) Bhur or Sandy Soil.

This is all sand and nothing but sand. All remarks about Morum apply to this. This is rarely to be met with in Gwalior.

(viii) Rocky.

Rocky soils admit of no cultivation but being impervious are most suited for the construction of Reservoirs.

CHAPTER IV.

MISCELLANEOUS.

SECTION 1.

Evaporation and absorption.

The loss of water in tanks and reservoirs by evaporation and absorption is very considerable, and varies in different localities according to the nature of soil, climate etc. Some engineers failing to put a stop to percolation have suggested the lining of tanks with some impervious clay or other substance. This is an Utopian and impracticable idea, as it would entail a great expense and even then its success would be problematic. Loss by evaporation can not be stopped but it can be minimised by thick plantations around the tanks. In his Natural Philosophy Ganot gives the following about evaporation (see *p.p.* 279 to 281, eighth edition) :—

> "The term evaporation is assigned to the slow formation of vapor on the surface of a volatile liquid when it is exposed in the open air. It is in consequence of evaporation that the level of the water in a pond gradually sinks, and the pond ultimately dries up, if it is not fed by a spring * * * Several causes influence the rapidity of the evaporation of a liquid : its temperature, the quantity of the same vapor in the surrounding atmosphere, the renewal of this atmosphere, also the extent of the surface of the liquid.

Influence of temperature.—Heat being the agent of all evaporation, the higher the temperature, the more abundant is the formation of vapor.

Influence of pressure.—The pressure of the atmosphere is an obstacle to the disengagement of vapor.

Influence of the renewal of air.—In order to understand the influence of the 3rd cause, it is to be observed that no evaporation could take place in a space already saturated with the vapor of the same liquid, and that evaporation would reach its maximum in air completely freed of this vapor.

The effects of the renewal of this atmosphere are easily explained, for if the air or gas which surrounds the liquid is not renewed, it soon becomes saturated and evaporation ceases. Thus it is the wind removing the layers of air which are in contact with the earth, that soon dries up the roads and streets.

Influence of the extent of surface.—The greater the extent of surface which a liquid presents to the air the more numerous are the points from which vapor is disengaged."

Thus evaporation is more active in broad shallow tanks than in deep and narrow reservoirs. Absorption is most active in Nalas with sandy beds and tanks in porous soils. It is the least in Mar soil, and none, or next to none in rocky ground. There are some soils so porous that they absorb water like a sponge. It is evident that it will be unprofitable to construct tanks in such soils.

The following is a table showing loss of water in tanks in Rajputana, on the authority of Culcheth.

Period.	By evaporation.	By absorption.	TOTAL.
	Feet.	Feet.	
October to March, 182 days	2·32	·75	3·07
April to June, 91 "	2·21	1·31	3·58
July to September 92 "	1·51	1·53	3·12
Total No. of days 365	6·15	3·[illegible]2	9·77
Average per day in feet ...	·017	·01	·027
Average per day in inches ...	·202	·11[illegible]	·321

In Deccan the loss by evaporation, absorption, leakage etc. from October to March was found to be 3·51 feet in 182 days *i. e.* ·0193 feet per day. From April to May 2·03 feet in 61 days=·0333 feet per day.

*Loss by evaporation only, in feet.**

Name of Country.	October.	November.	December.	January.	February.	March.	April.	May.	Total 8 months.
Rajputana	49	·35	·29	20	·35	·55	·73	·81	3·86
Bombay	·65	·19	·37	·44	·31	·44	·60	·90	4·41
Nagpur	·50	·42	·37	33	·32	48	·76	59	3·77

These figures, however, do not apply to all classes of soils. From my own observations in Panyar, the loss of water from the beginning of August to the end of October was 6 feet. This was due to the porosity of the soil more than to evaporation. In ordinary soils, however, which are not sandy, an allowance of one foot per month, on an average, both for evaporation and absorption, would be a fair figure to work by.

SECTION 2.

How to find the capacity of a tank.

It is most necessary to find how much water a particular tank would impound, and what would remain for irrigation purposes after deducting the loss due to evaporation and absorption. In submerg-

* Molesworth.

ing tanks evaporation and absorption for the months of August, September and October only may be considered in the Gwalior State, as after October the water is let out for bringing the land within the tank under cultivation. Thus a loss of 2 feet head may be put down for submerging tanks. For Reservoir Tanks full 12 feet head should be allowed. To find the quantity in cubic feet, find the average of the Reduced Levels (at every chain) of all the cross lines, and then find an average of their sum. The result would be the mean Reduced Level of ground all over the tank. Subtract this from the Reduced Level of the cill of the overflow, the remainder would be the mean depth of water in the tank. Again subtract from this figure the loss of head due to evaporation and absorption and the remainder multiplied by the submerged area would give the quantity of water available for outside irrigation. From this too some deduction should be made for loss of water in water-courses, through which the water would be carried to the fields, which require water. Sometimes as much as ·4 of the whole is thus lost, but as in Gwalior the outside irrigable land begins just from the outer toe of the Bund, this item may practically be ignored.

SECTION 3.

Management & supervision of works under construction.

In appointing Sub-Overseers etc. to look after any work of construction it is not enough to ascertain whether he understands drawing and knows what a subordinate shoul l know, about professional work. It should also be enquired into whether he is a good manager or not. I shall say nothing here of persons who, though good managers, purposely and fraudulently connive at the bad work of contractors from dishonest motives. Such persons, it is a matter of regret, are but too common in the Public Works Department all over the world. They are the black sheep, which lower the dignity of the profession and bring discredit upon the Department. Such men should unsparingly be weeded out and replaced by better paid and honest men. I would speak only of those who, though they have the best intentions, can not manage a work from incapacity, or do not possess enough knowledge of human nature to be able to guide and control the persons who work under them. Some subordinates have the vicious habit of ordering the dismantling of masonry or stopping the work altogether, on trivial pretexts. This is most reprehensible! What a sensible subordinate ought to do is to thoroughly disabuse the contractors of the idea that he could demean himself by accepting any thing in the way of bribe or would wantonly stop a work when all is being done according to specifications. When a contractor is assured that the supervising officer is above corruption and that he need entertain no fear of being fleeced by office hands, he has every motive to give good work. Contractors have recourse to dishonest tricks only when they have to distribute their "percentages" among the corrupt executive and ministerial staffs. If perfect immunity from such black-mailing is guaranteed to the contractor it becomes possible to induce him to accept lower rates than those in vogue in the Department. It is a matter of wonder to the corrupt, how coursed rubble masonry laid in lime mortar can be done @ Rs. 10/- per % cft., or concrete @ Rs. 8/- per % cft., without any way allowing the quality of the work to suffer!

Undue harshness towards contractors, and treating them with discourtesy is most to be deprecated, specially in lower subordinates. Dismantling of masonry or stoppage of work should only be resorted to when inferior work is given by the contractor, and if he does not pay any heed to repeated warnings, he should be turned out.

CHAPTER V

HOW A TANK PROJECT IS PREPARED.

SECTION 1.

RECONNOISSANCE AND CHOICE OF SITE.

It is quite possible that there may be a suitable site for the construction of a Band in a particular locality, but owing to there being other works of irrigation in the vicinity it may be quite a waste of money to construct a Bund. The designer should not look to the site of a Bund alone as an isolated fact, but should, by making local enquiries and riding or walking over the country, assure himself that a Bund would be advantageous, before beginning survey operations.

The opinion obtains wth some people that. Districts officials are the best judges of sites for Bunds, being cognizant of the wants and requirements of their ryots. The data on which the decision of the District *auothorities* rests are—

(*i.*) scarcity of water in a particular locality.

(*ii.*) and the presence of a local dip, as indicating the site for a Bund.

Now these two factors, however commendable can not by themselves carry very great weight with the engineer. The engineer would look to other factors besides these, before coming to a decision. The following are the considerations, which lead to the choice of the site of a Bund in a particular locality:—

(*i.*) Necessity of constructing a tank owing to scarcity of water.

(*ii.*) Soil.

(*iii.*) Catchment area.

(*iv.*) Configuration of ground.

(*v.*) Consideration of expense and the class of tank that can be constructed.

(*vi.*) Absence or presence of circumstances which stand in the way of constructing a new tank.

(*vii.*) Estimation of yield.

Necessity of constructing a tank owing to scarcity of water.

The District officials can supply this information, as by constantly touring about in the districts in their charge, and by personal contact with the ryots, they come to know of their wants. If water is scarce in any locality the Tehsildar is the likliest person to hear of it. It is likewise known to him how much irrigable land is under cultivation and how much is lying useless for want of irrigation. A sympathetic Engineer would like to have his information first hand from the zemindars. The Mehta, or the head zemindar of the village where a Bund is said to be required should be called and by a judicious cross examination and sympathetic treatment much useful information can be gleaned. Having received all availabe information from the District officials and the zemindars, the Engineer should personally see how far the want manifested is real. Satisfying himself on this score he should look to the next point.

(ii.) Soil.

This has already been treated of at length in the chapter on soil (*q. v.*) The designer should satisfy himself that the soil is of a character as would retain water and is productive.

(*iii.*) *Catchment area.*

If a 1″ survey map is available the catchment area of the proposed tank can be roughly measured. In the absence of such a map it can be ascertained in the following 3 ways, *viz.*:—

(*i*) If great accuracy is desired, it should be found out by actual survey—this, however, is very tedious and expensive, and should only be done for very large tanks.

(*ii.*) By walking or riding over the natural ridges the surveyor should look for the watershed and thus form a rough idea of the basin.

(*iii*) A more rough way and that usually adopted by the subordinates in the Irrigation Department is to make enquiries from the villagers about it, and accept their views! This practice is most objectionable, as it gives most unreliable results.

The designer should not lose sight of the fact that if it is not possible to find out the exact catchment basin, it is better to err on the safe side; greater drainage area should be assumed for calculations than appears from a bird's eye view of the country or the report of the villagers.

If it is found that the catchment area of a tank is too small to bring necessary supply of water it would be useless to sink money in its construction, as it would never fill, and will not serve the purpose it is meant for. If the drainage area is sufficient we should next look to.

(iv.) The configuration of the ground.

We can not construct a tank in a flat piece of country. However large a catchment basin may be, unless the configuration of the land is of a character that admits of a tank being constructed, it is of no avail. A dip in the middle with a gentle rising of ground on both the sides is an indication of a very good site for submerging tank. Again, a deep hollow between two hills would point to a Reservoir tank.

(v.) Consideration of expense, estimation of yield and the class of tank that can be constructed.

There are many splendid sites for the construction of tanks, but the cost of constructing them would be prohibitive. Having satisfied himself as to the above 4 points the designer should next devote his attention to the item of cost. He should make rough calculations about the probable cost and return in the shape of land revenue, and judge whether there is any margin of profit for the money invested. He shall also have to decide, at this juncture, as to what kind of tank is suggested by the natural features of the country. If the construction of one kind of tank appears to be expensive another kind may not be so. As for instance it may be found that to construct a Reservoir Tank with a large pucca waste weir would be necessary to stand the immense pressure of the impounded water, and the cost would naturally therefore be very great. The funds at the disposal of the Irrigation Department may not allow of undergoing the expense. The engineer would probably then see whether a submerging tank with moderately high banks would be less expensive. Or it may happen that the abandonment of a particular site may lead to the selection of another site higher up or lower down, which might considerably curtail the expense. The cases are so varied that it requires great common sense and forethought on the part of an engineer to choose a good site. No hard and fast rules can be laid down—all questions as to site have to be considered on the merits of a particular case.

(*vi.*) *Absence or presence of circumstances which stand in the way of constructing a new Tank.*

The five foregone conditions may be fulfilled and still a tank may have to be abandoned for what are termed 'Obligatory' points. As for instance if the construction of a tank endangers the safety of a village or a Railway line, it may have to be given up. There are many places in Surwaya Taluqa, in the Isagadh Prant, where if a Bund is thrown across two hills it will submerge the whole Taluqa upto Sipri, but the construction of such a large Reservoir would be undesirable for the following considerations :—

(*i.*) There is not sufficient catchment area for this Titanic tank.

(*ii.*) The cost of constructing it would be something fabulous.

(*iii.*) All the villages in the Taluqa shall have to be abandoned, and the whole Taluqa depopulated and turned into a big lake or inland sea.!

(*iv.*) The safety of all the cities and villages lying below it would be endangered. When full, the Reservoir will be hardly less formidable for Jhansi and the adjoining districts, than was the Gohana Lake for cities situated on the banks of the Ganges !

(*v.*) This gigantic Bund will be of no practical utility. Submerged area is quite out of the question as this Reservoir with an enormous head would never run dry. The outside irrigable area is insignificant. It may be one of the wonders of the world and attract curious globe-trotters to see it; beyond that its utility does not go !

Of course all possible impediments which come in the way of constructing tanks do not admit of ready and off hand enumeration. Every case has its attendant circumstances and has to be decided on its own merits.

SECTION 2.

FIELD WORK.

The Bund line having been proposed, a line of levels should be run along it and Longitudinal section plotted; the formation level may next be marked, and the sites of sluices, escapes (or in case of a big tank overflows or waste weir) etc. marked out. Cross lines should then be run across the tank to set out the natural contours of the ground on the plan, with a view to ascertaining how much area would be submerged by the tank. If there is an old Bund or there is too much slope in the ground at the site of the Bund cross sections should be taken at every chain and at places where there are breaches, to find out how much more earth is to be added to the old to bring it to the required level.

If the ground at the site of the escape or overflow be too rapidly sloping, cross lines should be run at right angles to the proposed overflow to ascertain the condition of the ground and to decide whether it would not be advisable to cut a sort of channel on both sides of the overflow to permit of the water flowing over the cill in a rectangular prism. It is self-evident that if the ground rises from one wing of the overflow to the other, the flood water would flow in the form of a wedge and the overflow will not have full play.

SECTION 3.

BUND AND THE ESTIMATE OF EARTHWORK.

The formation level should always be 3 feet above the High Flood Level. Though this entails some extra expense the Bund is perfectly safe and there is no fear of the flood water overflowing the earthen portion.

The following note in Molesworth is worthy of attention (See his Pocket Book p. 316) :—

"Width at the top in high dams from 7 to 20 ft.
Width at the top in low dams is equal to height.
Breast slope (inner slope) 3 to 1.
Back slope (outer slope) 2 to 1.
Height above surface of water not less than $3\frac{1}{2}$ft."

The earth-work is to be estimated by the trapezoidal formula, if there is no old Bund. The following is the form :—

Chainage.	Height.	Top width.	Bottom width.	(Top width + bottom width) ÷ 2	Sectional area = Column 2 × Column 5.	Sum of sectional area at equal distance.	(1st Sec. + Last Sec.) ÷ 2.	Balance.	Cubical contents.	Total.

Abstract Form.

Unit.	Item.	Rate.	Quantity.	Amount.	Total.

If there is an old Bund and it is to be raised and improved, the form is slightly different. It is as below :—

Chainage.	Sectional areas.	Sum of sectional areas at equal distances.	(1st section + last sec.) ÷ 2.	Balance.	Cubical contents.	Total.

The usual rate allowed for earth-work in Gwalior is from Rs. 3-8-0 to Rs. 4-8-0 per o/oo cft. In excavation of foundations Rs. 5 per o/oo cft. are allowed. When the earth is brought from a distance some lead is allowed.

Specifications for Earth-work.

(1.) Before starting the Earth-work the bottom breadth of the Bund should be marked on each chain, *Sutli* stretched between the pegs and Daghbel nicked out.

(2.) All Jungle and small growth should be rooted out, and loose materials, like pieces of stone, removed.

(3.) Where the ground is soft the upper crust should be removed and where hard, scraped a little.

(4.) All white ant, rat and other holes dug down to their depth and well tamped with earth and water.

(5.) A berm of at least 30 feet inside and 20 outside should be left, and borrow pits dug beyond that.

(6.) The borrow pits must, as far as possible, run parallel to the Bund and all of unifom width and depth, to make it easy for the man in charge to measure the Earthwork. This should be enforced strictly, as it is very tedious and vexatious to have to measure irregular and unshapely pits.

(7.) The pits should as far as possible be only 1 foot deep. It is better to allow some lead than injure culturable land. The pits should on no account, be more than two foot deep, unless special reasons point to the contrary.

(8.) To avoid any mistake being made by the contractor or his laborers, the borrow pits should be marked by the sub-overseer, in parallel lines with a partition wall, 1 foot wide, between the two rows of pits. (See Figure 1 Plate 1).

(9.) The earth is to be thrown in layers of six inches, and well rammed with a little sprinkling of water before another is added. The Bund should be raised, layer by layer, throughout its length.

(10.) The Bund is to be raised 1/10 higher than its proposed height to allow for its settlement.

(11.) When the Bund is near its completion, and the last layer is to be added, the Sub-overseer in charge should level it to find out how much more earth is required in different chains and to guide the laborers accordingly.

(12.) The last layer is to be rammed thoroughly. The edges should be well marked, and the slopes regular.

How a slope is tested. To test the 3 to 1 slope :—From the edge take 3 feet or any multiple of 3 feet and at the end of it raise a stick 1 foot, or the same multiple of 1 foot as was taken before, at right angles to the line measured and stretch a cord or any other thing between the top of the stick and the point on the edge. If its prolongation goes along the slope, the slope is all right. Any deviation from this line points to the extent of the filling or cutting required. (See Figures 6 and 7 Plate 2).

Another method is to prepare wooden templets showing 3 to 1 and 2 to 1 slopes. (See Figures 8, 9 and 10 Plate 2).

(13.) If the estimate permits *Dúb* grass may be planted on the top and slopes to render the earth firm and to confer upon it some immunity from the scratching action of the surface drainage.

(14.) In Nálá portions or where the lashing action of the waves is to be guarded against, the slope may be protected by dry-stone pitching. The pitching need not be carried higher than the High Flood Level.

(15.) One laborer, with a good rammer, can ram up about 1,000 sft. working 8 hours a day.

SECTION 4.

PUDDLE WORK.

When it is deemed fit to construct a submerging tank in soils of a sandy nature, it is necessary to provide puddle wall in the core of the Bund, to obviate percolation from underneath it.

The puddle wall should not be raised above the flood level. It will be sufficient if it is raised to the level of the cill of the overflow, as floods, though violent, are of short duration; the highest level of water in the tank after the subsidence of flood is only the cill level.

As to the dimensions of the puddle wall, its base should be rectangular, and carried at least 3 feet below the ground. Above the ground it should rise with a batter of 1 in 16 on both sides. The top width need not be more than 3 feet. Thus when the height of the Bund at a particular point is known, we can ascertain the height to which the puddle wall will have to be carried and then the width of the base can be easily found. Suppose, for instance, the height is 10 feet, the top is 3 feet. By a batter of 1 in 16 the extra width at bottom would be $\frac{20}{16}' = \frac{5}{4}'$ on both sides, or $7\frac{1}{2}''$ on either side. Thus the total width at bottom $= 3' + \frac{5}{4}' = 4\frac{1}{4}$ feet. Now the rectangular portion will go 3 feet below the ground. (See Figure 2 Plate 1). Thus cross sections at every chain can be plotted and estimate made out like that ' r Earthwork.

It is no use constructing a Puddle wall of sandy as that would not stop leakage. It should be ; of *Mär*, some other clay or fat earth, even ugh it may have to be carted from a little distance, xed with a little sand.

The following is a very suggestive note by Colonel Rundall on Puddle work (Earthwork P. 6):—

"There are soils so porous that they are unable to sustain any pressure of water without leaking, which must, therefore, in course of time produce such a settlement of the bank as would bring its crest, below the water level, and thus ensure its destruction. But in such a case my own opinion and experience would lead me to place a clay lining on the interior slope, in preference to adopting a puddle core, for this obvious reason that the object of an Engineer is, or should be, not to let any water at all find its way into the mass of the bank. * * * * * It is also urged that in cases of porous soils it is necessary to carry the puddle wall down to a water-tight stratum, in order to prevent the water percolating through the soil and under the seat of the embankment; but supposing such ever to be necessary, it would, in my opinion, be better to place the puddle trench at the toe of the interior slope and so effectually prevent the possibility of any water finding its way into any part of the embankment seat."

The foundation of Puddle wall below the ground is technically called Puddle Trench.

If the water is within 3 chains of the Bund, and can be brought to the site by gravitation, Rs. 10 per o/oo cubic feet is a fair rate for puddling. Of course with the increase or decrease of lead this rate is open to modification. The following are the—

Specifications for Puddle work.

(1.) Before the Puddle work is started the Sub-Overseer in-charge should *see* that the trench is carried 3 feet deep, and that its width is as given in the estimate. Of course the width will vary with every chain.

(2.) When the Sub-Overseer in-charge has satisfied himself about the foundation of the Puddle wall having been excavated rightly, the trench should be filled with water 6″ deep for 3 hours, to make the ground moist and to allow its well joining up with the Puddle.

(3) The soil should be fat or clayey, on no account sandy. Morum is also to be discarded.

(4) Puddling should be done in layers of 1 foot throughout the length of the Bund, the depressed portion being puddled up first.

(5.) It is much better if the earth for puddling is mixed and made into *gonda* outside the trench, but this should not be insisted on, as it considerably adds to the cost. When thrown in the trench the earth should be well mixed up and stirred with a *Phaora*, and then kneaded by men treading over it.

(6.) Excess of water in mixing up the earth is as much harmful as paucity—enough water should be used to bring the *gonda* to the right consistency.

(7.) When a day's puddling is done it should be covered over with earth to prevent the surface drying and giving cracks.

(8.) The Sub-Overseer in-charge should personally see to all these details and *not depend upon the reports of mates or coolies.*

SECTION 5.

Maps and Designs.

The following is a list of maps and designs required in a Tank Project :—

(1) Index Map. (2) Contour map with plan and site of the Bund marked on it. (3) Longitudinal section of the proposed Bund. (4) Cross sections at each chain. (5)* Plan of the escape, overflow or waste-weir. (6) Plan of sluices. (7) Cross lines at the site of the waste-weir, if necessary. (8) Survey of the Nala, if necessary.

(1.) INDEX MAP.

This map is meant to show the catchment basin or drainage area of a particular tank. The natural water sheds of the country are marked on it, with the Nala or Nalas which drain the basin. The drainage area is found out by an actual survey of the area, the position of the water-shed being ascertained by running lines of levels in all directions. This, however, involves great expenditure of time and money. A more expeditious and economical method is to ascertain the drainage area from the 1″ survey or topographical maps of the Government of India, which are very accurate, and to all intents and purposes, answer as well as a map prepared by actual survey. This map is the basis of all calculations, as

* Under this head are given all calculations required in designing an overflow.

on its accuracy depend the accuracy of calculations for discharge and length of the cill, and indirectly the stability of the whole Bund.

(2.) Contour Map.

The levels of the Bund line having been taken, lines of levels are run across it, generally parallel to each other. (See Figure 3 Plate 1).

When these lines are plotted and R. L.'s written at every chain, we get what are called Contour Lines by joining all such points on these lines as have the same Reduced Level, from which we can find out how much area would be submerged by a particular R. L. being fixed as the Reduced Level of the cill of the overflow or waste-weir. From this we can also see, at a glance, whether the slope is gentle or abrupt, as the closer the Contour lines the steeper the slope and *vice versa*.

(3.) Longitudinal Section.

This is the most important. It is from this that the depth of filling can be found, chain by chain, estimate of Earthwork made out and sites of irrigation and scouring sluices, and waste-weir determined. It is not considered necessary to show here how it is plotted, as every subordinate is supposed to know it.

(4.) Cross Sections.

When the ground is not of an even character, but slants rapidly, and in old Bunds, when we want to find out how much more earthwork is required, it is necessary to take cross sections at each chain, and specially at breached places. Thus a more accurate estimate of earthwork is made out, than would otherwise be possible.

(5.) Escape, Overflow or Waste-weir.

All the three names imply one and the same thing having the same function *i. e.* providing a *pucca* waterway for the escape of the superfluous water from the tank. The differences of nomenclature is arbitrary. Very small passages or vents for water are termed escapes, larger ones overflows. A Waste-weir is a more pretentious thing. It indicates a big *pucca* masonry work providing waterway for the escape of flood water and at the same time a more solid wall across some Nala or River, than a mere earthen Bund which would not stand the force of sudden and impetuous flood. In designing an escape it is sufficient to see that the waterway allowed is sufficient for the superfluous water to pass through without giving rise to any afflux and consequent overflowing the top of the earthen Bund.

While designing big overflows or waste-weirs the following points are to be kept in view :—

(1.) That the length of the cill is sufficient *i. e*, with the proposed head all the water which is *ever* likely to pass over the cill, even in exceptional floods, like those of last year, will pass over it without rising above the proposed High Flood Level, much less overtopping the Bund.

(2.) The designer should see that architectural effect is not wanting. It will not do to look to strength only and construct a big, uncouth and clumsy structure which, however well it may answer its purpose, is an eyesore to all observers. Two such clumsily built overflows are to be seen from the Railway Train, between Lashkar and Panyar. A good design is that which is calculated to resist all possible forces it is likely to be subjected to, and to catch the eye.

(3.) In designing waste-weirs across Nalas or Naddis, it should be a very serious point for consideration to provide against the cutting-back action (for want of a better term) of the flood water discharged over the cill. If the ground below the waste-weir is not sufficiently protected for some distance against the eroding action of water, the flood water will, in course of time cut the ground backwards upto the apron of the waste-weir, undermine it upto the foundation of the crest wall, which is bound to topple forwards, having no legs to stand upon, under the immense pressure of the moving water from behind. The cases of Tonga and Kuloli Tanks are instances in point*. Both of these waste-weirs gave way not because they were not strong enough to resist the hydraulic pressure but because no provision was made against what I have called the cutting-back action of water.

* Syed Jafar Hosain supplied me with necessary information about these.

In big tanks with long waste-weirs a water cushion should be designed below the crest to break the fall of the flood water, beyond that a *pucca* apron, followed by a long talus of dry stones set on edge, and well grouted, after setting. As an extra precaution against the cutting back action a retaining wall may be designed at the end of the talus, going 4 to 8 feet below the Nala bed. In short an ingenious designer will find one means or other for guarding against the slow-working but tremendous effects of the flood water rushing impetuously through the Nala.

(4.) When the length of the waste-weir is over a chain in length intermediate buttresses or counterforts should be designed to support the crest wall from outside. About $\frac{1}{8}$th of the masonry of the crest wall may be thrown in the shape of counterforts, which not only add to the strength of the structure, but also to its look. Allowance should, however, be made to the obstuction of a part of the waterway by the projections of these buttresses.

(5.) An earthen cushion (top width 2—4 feet and slope 3 to 1) should be provided behind the waste-weir to serve as a buffer to the force of water. This will also stop up all leakage through the masonry of the crest wall.

Formulæ and Calculations.

Discharge formulæ.

(1.) Dicken's formula—

Colonel Dickens R. E. gives the following simple formula for finding out the discharge of a given drainage area :—

$D = 825\ M,^{\frac{3}{4}}$ assuming rain-fall at one inch per hour. In designing irrigation works in the Gwalior State 2 inches per hour should be taken in calculations. The formula therefore stands as—

$$D = (825\ M^{\frac{3}{4}}) \times 2$$

Where D = discharge in cusecs.

M = drainage area in square miles.

This formula takes no count of the nature of the ground and the diminution in discharge due to largeness of area. So for large areas and flat ground the discharge given is considerably in excess of the actual discharge. It errs, however, on the safe side.

(2.) Mr. Strange, M. I. C. E. gives the following table for finding the run-off from a particular basin, assuming rain-fall at 2″ per hour.

Table of waste-weir run-off.

Catchment area in square miles.	0—5	5—10	10—25	25—75	75—150	Over 150
Runs-of in inches per hour	2·0	1·5	1·25	1·00	0·75	0 5

From the above table it is clear that for finding the total discharge or run-off of a drainage area, its area (in square miles) is to be multiplied by the corresponding coefficient given in the table. As for instance if the drainage area is from 0—5 miles, the area is to be multiplied by 2·0″ and so on.

This table provides for diminution in total run-off due to area, but takes no count of the nature of the ground over which the rain water passes. The flatness or otherwise of a ground makes a great difference in the amount of discharge. With the same rain-fall the run-off in mountain gorges is more than twice that in a flat country, over which the water passes with a very small velocity, with the result that much water is lost by evaporation and absorption.

(3.) A third authority gives the following empirical figures which have been tested by long experience and give the most reliable results. Run-off from one square mile, when rain-fall is taken at 2″ per hour, is as below, according to the nature of the country :—

(*i.*) Flat country	$2 \times 220 =$	440	Cusecs.
(*ii.*) Undulating country	$2 \times 350 =$	700	,,
(*iii.*) Near Hills	$2 \times 450 =$	900	,,
(*iv.*) Mountain gorges	$2 \times 550 =$	1,100	,,

When the catchment area increases beyond 5 square miles, the discharge decreases as per Strange's table given above.

The discharge is inversely proportional to the catchment area *i. e.*, if the catchment area increases the discharge (per square mile) decreases and *vice versa*.

(4.) *Discharge formula**—

$$Q = 440 \times R \times C \times M.^{\frac{3}{4}}$$

Where Q = Discharge in cusecs.

R = Rain-fall per hour in inches.

C = Constant depending on the fall of the ground, from 0·33 for flat country to 0·67 in mountain gorges.

M = Catchment area in square miles.

This formula is calculated to give very reliable results. It makes allowance for both the factors—diminution in discharge due to area, and nature of the ground which the flood has to traverse.

(5.) The following note† by Mr. George Chamier on Discharge is very valuable.

"Elements upon which calculations for discharge are based :—

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* From Mr. B. C. Mukerji I. C. E.'s Note Book

† *Vide* Minutes of the Proceedings of the Institute of Civil Engineers Vol. CXXXIV. P. 313.

(*i.*) Catchment area. (*ii.*) Rainfall. (*iii.*) Surface discharge. (*iv.*) Diminution in flood discharge due to area.

The average rate of precipitation (of rain) is found every where to vary inversely as its duration *i. e.*, the longer the duration the less the precipitation and *vice versa.* Only a part of the (total) rainfall passes through a given waterway. There is diminution in the surface discharge of water from the following causes :—

(1.) Absorption. (2.) Evaporation. (3.) Percolation. (4.) Natural obstructions.

By "Coefficient of discharge" is to be understood that portion of the rainfall which immediately flows off the surface and finds its way in running streams. As a general rule the "Coefficient of discharge" may be taken to be between $\frac{1}{3}$ to $\frac{2}{3}$ of the total rainfall in times of flood*

Table of Surface Discharge.

	Class of country	Percentage of run-off.
1.	Flat country, sandy soil or cultivated ground ...	0·25 to 0·35
2.	Meadows, gentle declivities, absorbent ground...	·35 to ·45
3.	Wooded hill slopes, compact or stony ground ...	·45 to ·55
4.	Mountains, rocky or non-absorbent surfaces ...	·55 to ·65
5.	Naked, unfissured mountains, very steep ground or paved streets	·80.

* It may be noted here that this "Coefficient of discharge" in times of flood is quite distinct from the rain-fall off a given catchment area, available for storage. On the authority of Binnie it ranges, according to the nature of soil, from 20 to 25 per cent. of the total rain-fall throughout the year.

Flood volumes are inversely proportional to the extent of catchment areas. The diminution in flood volume due to area must not be confounded with the diminution in the rate of rainfall on account of its duration.

All, lakes, swamps etc., act as "flood moderators.

(5.) *Discharge formula.*

$$Q = A \times R \times C \times \frac{M^{\frac{3}{4}}}{M.}$$

Where Q = Discharge in cusecs.

A = Catchment area.

R = Average rain-fall per hour.

C = Co-efficient of surface drainage, as given in the above table, which depends on the nature of the country.

$\frac{*M^{\frac{3}{4}}}{M.}$ = The factor of diminution in consequence of area."

Of all the formulæ quoted above this seems to be most reliable, in that it takes count of all the circumstances which affect the discharge through a given waterway.

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* Here M = Catchment area or A.

Formulæ for determining the length of the cill from a given discharge.

$$(1)\quad L \times \sqrt{H^3} \times 3{\cdot}5 = D.$$

Where L = Length of the cill.
H = Head of flood in feet.
D = Discharge.

This is a very useful formula and gives very reliable results.

(2) Mr. Strange's Table of waste weir discharges per lineal foot.

Head over cill or depth of flood in feet	1	2	3	4	5	6	7	8	9	10
Discharge for drowned channel	2 38	7 20	13 7	22 22	32 55	43 02	57 01	71 87	87 02	106 06
Discharge for clear overfall . .	3 57	[illegible]0 05	18 53	28 33	39 87	52 13	66 05	80 72	96 30	112 73

NOTE.—Drowned channel means the channel in which the level of water is higher than the crest level (See Figure 4 Plate 1), while a clear overfall means a weir whose crest is higher than the level of water in the channel (See Figure 5 Plate 1).

Small escapes etc. should be designed as drowned weirs, while large weirs should evidently be clear overfalls.

The above table is used to find out the length of the waste weir in this way: Suppose the discharge off a catchment area has been found out by one of the formulæ noted above, also the head determined. Now by consulting the table you will find the discharge *per lineal foot* under the chosen head, for drowned weir or clear overfall, according to your choice. Dividing the calculated discharge by this figure we get the length of the cill. Suppose the discharge off a catchment basin is 800 cusecs. The head we decide to have 4 feet in height; weir——clear overfall. The length of the cill will be $\frac{8000}{2853}$ or 300 feet nearly.

Determination of Head.

It will not be out of place here to mention what considerations lead to the determination of head :—

(1.) The head should be as small as possible (apart from any other consideration) in order that the capacity of the tank may not suffer.

(2.) But if the lessening of the head gives a very great length of cill and consequent increase of expense, the head should be so determined as to strike a balance between the two considerations.

(3.) In designing flank overflows or escapes expense is not generally a consideration, as flank overflows being low, often the cill being flush with the ground, cost very little. Accordingly when flank overflows are designed the cill may be made as long as possible to allow of a small head being given over the cill.

(4.) In waste weirs across Nalas and Naddis large heads are allowed to shorten the length of the weir and reduce expense.

(5.) Generally a head of 1 to 3 feet is considered fair for small escapes or overflows and for larger weirs from 3 to 6 feet.

Hydraulic pressure against crest-wall.

Before giving formulæ for finding out pressure against weirs, it is necessary to give some definitions and elementary notions about the Hydrostatic Laws.

Hydrostatic Laws, or Laws of water at rest.

(1) The pressure of water on any plane surface is equal to the weight of a column of water whose base is the area of the surface and whose height is the depth of the centre of gravity of the surface below the surface level of the water. The pressures at any two points at the same level in a liquid are evidently equal.

(2.) The direction of pressure on a surface is perpendicular to that surface.

(3.) The resultant pressure of water on a body immersed or partly immersed in it acts vertically upwards, and is equal to the weight of the water displaced. If the body floats it follows that the water displaced is equal to the weight of the body.

(4.) Water transmits its pressure equally in all directions.

Hydrodynamic Laws.

(1.) If the motion is rectilinear and uniform, and if the effect of eddies produced by the roughness of the boundaries of the stream be neglected, the pressure at any point is the same as if the fluid were at rest.

(2.) If the fluid particles take the same accelerations which they would have if independent, the pressure is uniform.

The moment of a force about a point is the product of the force into the perpendicular from the point on the direction of the force. (Figure 41, Plate 8).

Stability of a wall is the power of the wall to resist the pressure brought to bear on it.

The centre of gravity of a body is the point around which the weight of the body is equally balanced in all directions and the body is in equilibrium.

The centre of pressure in a body is a point around which the pressure of a mass is supposed to be concentrated. Thus the centre of gravity and centre of pressure are not necessarily the same thing. The centre of gravity and the centre of pressure coincide only in one position, *viz.* when the plane surface of the body is horizontal or parallel to the level of water.

Formulæ for calculating pressure.

1. Pressure of still water, against a wall the surface of the wall being at right angles to the water level. (See Figure 11 Plate 2).

$$P = \frac{h^2}{2} \times L \times W.$$

Where P = Hydraulic pressure in lbs.

h = Height of the water or the wall.

L = Length of the wall.

W = Weight of a cubic foot of water = $62\frac{1}{2}$ lbs.

2. Pressure of water flowing over the wall with a head of H feet, the wall being at right angles to the surface of water. (See Figure 13 Plate 2).

$$P = \left(\frac{h + 2H}{2}\right) \times h \times L \times W.$$

Where

P = Hydraulic pressure in lbs.

$\left(\frac{H + 2h}{2}\right) \times h$ is the area of trapezoidal lamina A B C D.

L = Length of the wall.

W = Weight of a cubic foot of water = $62\frac{1}{2}$ lbs.

3. Pressure of water against a wall at an angle, (other than a right angle, with the water.) (See Figure 12 Plate 2).

$$P = \left(\frac{A\ B \times h}{2}\right) \times L \times W.$$

Where as before,

P = Hydraulic pressure in lbs.

A B = Slanting length of the wall.

h = Height of the water perpendicular to the horizontal plane.

L = Length of the wall.

W = $62\frac{1}{2}$ lbs.

For more detail see Love's Hydraulics.

The following are the weights per * cubic foot of different kinds of masonry from which the weight and stability of a crest wall may be determined:—

Brick work ...	112 lbs.	per	cubic foot.
Rubble masonry	125	,,	,,
Concrete ...	125	,,	,,
Granite or Lime stone ...	170	,,	,,

In designing sub-marine works, it should be remembered that every cubic foot of masonry will lose the weight of its own bulk of water *i. e.*, $62\frac{1}{2}$ lbs. It should, therefore, be proportionately stronger.

As a rough method in designing small irrigation works it is sufficient to make a wall ·7 of the height at the base, ·5 in the middle and ·3 at the top for hydraulic pressure, and ·4 at the base and ·3 at the top for earth pressure. But in designing large works the following calculations should be gone into.

Stability of walls against water pressure†.

(See Figure 38 Plate 7).

H = Height of wall in feet.

h = Height of centre of pressure above base in ft. = $\frac{1}{3}$ H for still water.

L = Length of wall in feet.

* Dry sand, 90—110 lbs. Clay 120 lbs.

† See Molesworth P. 86.

W = Weight of wall in lbs.
y = Horizontal distance of centre of gravity from toe of wall in feet.
P. = Pressure tending to overturn the wall in lbs.
m = Overturnig moment.

$$= P \times h = \left(\frac{H^2}{2} \times L \times \frac{125}{2} \right) \times \frac{H}{3}$$

$$= 10{\cdot}4\,H^3 \times L \text{ for water.}$$

M = Moment of stability = W† − y.

If M exceeds m the wall is stable, provided the materials of the wall and of the foundation are strong enough to resist crushing,

NOTE—The crushing strenth of different materials are as below.

Crushing strength of brick 800–1,100 lbs. per square inch.

,,	,, Granite		5,000–11,000 lbs.
,,	,, Sandstone		2,003—5,000 lbs.
Cast Iron		,,	1,12,000
,, Wrought Iron*		,,	3,36,000
Steel			38,080
Mortar(lime)			80

Stability of retaining walls against earth pressure.‡

(See Figure 39 Plate 2).

W = Weight of a lineal foot of the wall in lbs.
w = ,, ,, cubic ,, of the soil retained in lbs.

* For finding out P. see Formula (1), (2) and (3) P. P. 58 and 59.
† W = Weight of the wall.
‡ See Molesworth P. 86.

H = Height of the wall in feet.

a = Angle of repose of the soil
= 36° for dry sand; 39,° for gravel or stringle; 47° for dry earth and 54° for moist earth.

B = Angle of slope, if any, retained.

P = Pressure in each lineal foot of the wall in lbs.

$$(1)\quad P = \frac{w\,H^2}{2} \times \frac{1 - \sin a}{1 + \sin a} \text{ when } B = o.$$

$$(2)\quad P = \frac{w\,H^2 \times \cos a}{2} \text{ when } B = a.$$

$$(3)\quad P = \cos B \times \frac{\cos B - \sqrt{\cos^2 B - \cos^{2a}}}{\cos B + \sqrt{\cos^2 B - \cos^{2a}}} \times \frac{w\,H^2}{2} \text{ for any other slope.}$$

"To determine the stability of the wall draw the horizontal line of the centre of pressure AD at $\frac{2}{3}$ H from the top of the wall, cutting the vertical line, that passes through the centre of gravity of the wall, at C. Then with any convenient scale make CD = P and CF = W; complete the parallelogram CDEF; draw the diagonal CE, and if, where it cuts the level of the base of the wall, it should fall outside the base the equilibrium will be unstable. In practice the diagonal should fall within the middle third of the base, as shown in the diagram."

Retaining walls.

E = Weight of earthwork per cube yard.

W = Weight of wall " " "

H = Height of wall.

T = Thickness of wall at top.

T = H X Tabular No.

Batter of wall*	E : W :: 4 : 5		E : W :: 1 : 1	
	Clay.	Sand.	Clay.	Sand.
1 in 4 ...	·083	·020	·115	·051
1 in 5 ...	·122	·065	·155	·092
1 in 6 ...	·149	·092	·183	·118
1 in 8 ...	·182	·125	·218	·153
1 in 12 ...	·221	·160	·256	·189
Verticle ...	·300	·289	·336	·267

Surcharged walls.†

Surcharged walls are those which have not only to bear a horizontal pressure of earth which they have to support, but also the oblique pressure of earth above the level of their top (see figure 40 Plate 8.)

In calculating the strength of surcharged walls subsitute Y for H, Y being the perpendicular at the

* See Molesworth P. 87.

† See Molesworth P 90.

end of a line, L = H, measured along the slope to be retained, (See figure 40 Plate 8).

Y = 1.71 H	in slopes of	1 to 1	
Y = 1·55 H	„	$1\frac{1}{2}$ to 1	
Y = 1·45 H	„	2 to 1	
Y = 1·31 H	„	3 to 1	
Y = 1·24 H	„	4 to 1	

High Dams in Masonry for Reservoirs.

(See figure 34 Plate 7.)

H = Height of dam in feet.

X = Any depth below the surface of water in feet.

Y = Offset from vertical line to outer face of dam at any depath X in feet.

Z = Ditto, ditto to inner face in feet.

B = width of dam at top in feet.

A = width of dam at $\frac{1}{4}$ H from top in feet.

P = Limit of pressure allowed on the masonry in tons per square foot = 9 tons in the dam of La Terrasse.

$$Y = \sqrt{\frac{\cdot 05\ x^3}{P + (\cdot 03\ x)}} = Z\left(\frac{\cdot 09\ x}{P}\right)^4$$

B = 0·4 a ; Y = 0·6 x as a minimum.

* See Molesworth P. 315.

To keep the resultant pressure within the middle third use T, (see below) in place of 0·6 x.

*Minimum Thickness of Masonry Dams**

T = Minimum thickness of dam at any depth below the surface of water.

g = Specific gravity† of the masonry for
light masonry = 2·08
,, ordinary ,, 2·24
,, heavy ,, 2·4

d = depth below surface of water.

$$T = \frac{d}{\sqrt{g}}$$

Limit of pressure per square foot, 6 tons in light, 9 tons in heavy masonry.

To find the centre of gravity of walls of different sections.‡

(See Figures 35 and 36 Plate 7)

Triangle.

Bisect two sides of the triangle and join the points of bisection with the appices, the point of intersection of these (joining) lines would give the centre of gravity of the triangle. D E is always ⅓ of A D. (See Figure 35 Plate 7).

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* See Molesworth P. 314.

† Specific gravity of a body means the ratio of the weight of the body with the weight of its own bulk of water.

‡ See Molesworth P. 366.

Any irrigular four-sided figure.

(See Figure 36 Plate 7).

Join the diagonals A C and D B and let them intersect at E. Make D F = E B. Join A F, F C. The centre of gravity of the triangle A F C will be the centre of gravity of the whole figure.

Co-ordinates of the centre of gravity. (See Figure 37 Plate 7).

$$x = \frac{1}{3}\left(A + B - \frac{A\ E}{A+B}\right)$$

$$y = \frac{C}{3}\left(\frac{2\ A+B}{A+B}\right)$$

Squares, rectangles, cubes, equilateral triangles, rings, regular ploygons, circles, cylinders have their centre of gravity in their geometrical centres.

To find the centre of gravity by experiment.

Suspend the body successively in two or more positions, the intersection of the vertical lines from each point of suspension will pass through the centre of gravity.

(*6.*) *Sluices.*

Sluices are of two kind *viz.*—

Irrigation sluices or scouring sluices. Irrigation sluices are those which dischafge water for purposes of irrigation. These are opened or plugged up according to the requirements of the cultivator. The orifices of these sluices are generally 9″ in diameter.

Scouring sluices are generally located at the lowest level in the Band to permit of all water being withdrawn from the tank. There is no essential difference in the design of these two kinds, though their shapes vary considerably at the whim of the designer. The orifice of a scouring sluice should be greater, say, 1 foot in diameter to allow of the tank being drained quickly.

Discharge from Sluice holes.

$$Q = C\ A\ V, \text{ where.}$$

Q = Discharge in cusecs.

C = Co-efficient of discharge = ·62 in a thin plate.

A = Cross section (or area) of the sluice hole in superficial feet.

V = Theoretic velocity due to head = $\sqrt{2\ g\ h}$, where $g = 32$, and h = head from the surface of the water to the centre of the orifice.

---:o:---

Specifications for Concrete and Masonry.

Concrete.

(1). The ballast (brick or stone) should pass through a sieve, with meshes $1\frac{1}{2}''$ in diameter.

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* See Lyne's Hydraulics.

(2.) In case of the stone ballast being used, it should be broken of a hard stone.

(3.) For every 100 cubic feet of concrete the proportions of ballast, Kunkar lime and gravel or sand should be as below :—

Ballast 113 cubic feet.

Lime 40 cubic feet.

Sand or gravel 50 cubic feet.

Lime and gravel after being ground together assume one-half of their original proportions.

(4.) The concrete should be laid in layers of six inches and well rammed. The test of a layer having been well rammed is that if water is freely sprinkled over it, it would not soak into the concrete, but would remain on the surface. As a rough rule for practice two men with good substantial rammers can consolidate 100 superficial feet in about 8 hours.

(5.) The ballast and mortar should be well mixed up on a platform outside the foundation to prevent dry ballast being thrown in the foundation. The concrete should be carried in baskets and thrown into the foundation with a whirling motion of the hands.

Masonry.

(1.) In tanks all masonry should be of rough hammer-dressed stones laid in lime mortar, in courses.

(2.) The face masonry should be of chisel dressed stones.

(3.) No stone should be less than $1' \times \frac{1}{2}' \times \frac{1}{2}'$.

(4.) The joints should not be more than $\frac{1}{2}$ apart.

(5.) Plenty of mortar should be used in the joints and pressed with a trowel.

(6.) In walls wider than 1 foot, filling in the middle should be done most carefully and of as large pieces of stones (called *guttas*) as possible, thoroughly grouted with lime morter. Unless this is done stones will not hold each other firmly and will be liable to displacement under any shock or pressure.

(7.) Every 4th course should be of binders *i.e.*, pieces of stone not less than $1\frac{1}{2}' \times 1' \times \frac{1}{2}'$ to overlap the lower courses and to bind them in one homogeneous whole.

(8.) Lime of the best quality available should be used (See Note on lime.)

(9.) The top of masonry should be covered by slabs or pucca plaster.

(10.) All face masonry should be lime-pointed. All faces of masonry exposed to water should be plastered as all masonry is liable to leakage.

(11.) All masonry and concrete while in the course of construction should be kept thoroughly moist till the mortar sets.

* Moisture is most necessary to allow the Carbonic Acid Gas in the air to mix with lime and transform it into lime-stone.

(7.) *Cross lines at the site of the overflow.*

At the site of an overflow or escape, specially when situated on flank, just where the ground begins to rise higher than the R. L. of the cill, cross lines of level should be run at right angles to the Bund Line, at every chain, on both sides, to such lengths as would give an idea of the natural contours of the ground. From this it can be ascertained whether the flood water would flow in a rectangular sheet, or in the form of a wedge. In the latter case the discharge would be about ½ that of the first.

If the ground is of this character a channel at right-angles to the overflow should be excavated on both sides to give full play to the overflow.

(8.) *Survey Plan of the Nala.*

Where Bunds are thrown across Nalas and specially when waste weirs are designed at places where the Bund Line cuts the Nala, a most accurate survey should be made of it, to devise means to protect the land in front of the waste weir against the cutting back action of the flood water, passing over the apron in the Nala below. This point has already been dealt with at length under the head "waste weir." For evident reasons the survey of the Nala should extend to at least 4 or 8 furlongs beyond where the Bund is placed to give the designer a correct idea of the course and twists and turnings of the Nala.

In choosing the site of a Bund the designer should see that the Bund line cuts the Nala at right angles, in order that the water flowing into the Nala in times of flood, may impinge against the crest wall at right angles. All things being equal a wall at right angles to the direction of moving water is calculated to stand the pressure of flood better.

SECTION 6.

Data for the rates of masonry etc.

It is a bad practice to have fixed rates about masonry or any other work, for all places and all conditions. Conditions so much vary that a rate applying to some one locality can not apply to another. Rates should therefore be fixed for any work in a particular locality after due consideration of the items of expense. As for instance in determining the rate of concrete the following points should be considered:—

(1.) Quantity of ballast required for every hundred cubic feet of concrete. The cost of breaking it and carting it to site.

(2.) The proportion of lime and sand or gravel required for it, with their respective charges. The cost of grinding mortar.

(3.) The cost of laying concrete in foundation, ramming and watering per hundred cubic feet.

(4.) Profit to the contractor, generally $12\frac{1}{2}$ per cent in the Gwalior State.

Data for masonry.

(1.) The cost of breaking and carting to site 130 cubic feet of stone, which yields 100 cubic feet of masonry.

(2.) Cost of lime and gravel required for 100 cubic feet of masonry.

(3.) Cost of grinding the mortar, which includes the charges of constructing mortar mills.

(4.) Cost of constructing 100 cubic feet of masonry, including lift and watering charges.

(5.) Profit to the contractor as above.

Data for puddle work.

(1) Cost of excavation of foundation.

(2.) Lead and lift of earth required for puddling.

(3.) Cost of water.

(4.) Cost of stirring and kneading the puddle.

(5.) Profit to the contractor.

Data for Earth-work.

(1) Cost of earth for embankment.

(2.) Cost of ramming and dressing ~~it~~.

(3) Lead and lift.

(4) Profit to the contractor.

SECTION 7.

Report.

This brings us finally to the preparation of a Report—a comprehensive report for submission to the authority which sanctions estimates. This report should deal with the following points :—

(1.) General features of the country and the nature of the soil.

(2.) What kind of tank is intended to be constructed.

(3.) Reasons for the choice of site.

(4.) Probable cost.

(5.) Probable income.

(6.) Calculations and designs.

(7.) Data of rates.

(8.) Summing up and reasons shown whether a tank should be constructed; if not, for what considerations.

Finis.

APPENDIXES.

APPENDIX No. I.

Glossary of terms alphabetically arranged.

A.

Afflux—Means the heading up or rising of the water level due to obstruction.

Alignment—Means the marking out of a line, as that of rail, road or canal.

Anicut—A term for dam in the Madras Presidency.

Absorption—Means the underground percolation of water.

Angle of repose (of a soil)—Is the angle which the soil makes with the horizontal line when heaped loosely. This angle differs with different soils. The greater the angle the more the frictional stability.

Apron—Means the flooring of *pucca* masonry or stone on edge, below a waste-weir or overflow over which the water falls.

Assessment—Means the valuation of the yield of a particular land and the revenue fixed for it by the Settlement Officer.

B.

Backwater—Stagnant water. Also water forced back by some obstruction.

Ballast—Means pieces of stones used in concrete or covering Railway embankments.

Batter—Means the slope, one in sixteen or more or less, in walls (See Figure 2 Plate 1).

Berms—Mean the banks on both sides of the road. The term also means the spaces left on both sides of a Bund, within which no borrow-pits are allowed to be dug.

Bench Mark—Means a permanent mark whose height and position do not vary and from which survey or level work is started or at which terminated, and which serves to check the accuracy of the work. In long surveys or level lines B. M's should be set up at every 2 miles.

Borrow-pits—Pits from which earth is excavated for embankment or other purposes.

Breast wall—A wall to protect the sides of a cutting from weather and consequent disintegration and slipping.

C.

Catchment area (also called catchment basin or drainage area)—As much area as is drained by one system of water-courses, or the piece ~~of land whose~~ collected rain-fall passes through the same drain which is hence called Catchment Drain.

Culingulah—Overflow or waste-weir—a term in vogue in the Madras Presidency.

Capillarity—Is that force which raises water above its level *e. g.* in sugar, earth, sponge etc.

Cill—Top of the crest wall.

Clearance (of silt)—Removal of silt deposit in channels or wells.

Contour—Outline; as referred to tanks it means a line joining those points in a tank which have the same R. L.

Collimation (line of)—Is the line which passes through the centre of the object glass and the intersection of the cross hairs. Error in this occurs by the displacement of the diaphragm.

Counterfort—A buttress or a projecting piece to support a wall. (See Figure 44 Plate 8).

Co-efficient—A factor or multiplier which is affixed to certain quantities to modify their condition, as co-efficient of discharge, of friction etc.

Core-wall—A wall of masonry in the core or heart of an earthen Band with a view to giving greater stability to it. Such core-walls are designed in places where the Band crosses a Nala or a stream.

Crest-wall—Is the wall over which the flood water flows.

Clear overfall—A weir whose level is higher than the level of the water flowing over the apron and beyond. (See Figure 5 Plate 1).

Cutting—Means removal of stone or earth by blasting or excavation, for a channel, roadway or railway ; also the opening thus made.

Coping—Is the protection of masonry work at the top by slabbing or plastering. It is designed in a manner to add to the effect of the wall as an ornament, in addition to its utility.

D.

Data—Facts or figures known or given from which unknown quantities etc are calculated.

Debarred area—Is an area which is debarred from being irrigated by a tank, depending on a well for its irrigation.

Depth of watering—Means the total depth of water required by different crops from the time of sowing the seed to their maturity. Depths of watering differ for different crops and soils and climate.

Discharge (run-off)—Means the quantity of water which passes through a given waterway, off a particular catchment basin, after making allowance for evaporation and absorption.

Drainage area—See catchment area.

Drowned weir—A weir the level of whose top is lower than that of the tail water. (See Figure 4 Plate 1).

Duty of water—As applied to tanks is the area which can be irrigated by a discharge of one cubic foot per second, through a sluice hole or outlet, working continuously throughout the year. Duty of water varies with different soils and different crops.

E.

Embankment—Heaping of earth in some regular shape, either for a Band, road or railway.

Erosion—Means the scratching scouring or cutting action of water.

Escape—Means a *pucca* masonry waterway to let off surplus water of a tank during the time of flood.

F.

Factor of safety—Is the allowance made, over and above what is got by calculation, with a view to provide some extra margin of safety against climatic effects, and unlooked for shocks or pressures. As for instance large bridges are made 10 times as strong as warranted by mathematical calculation of all the stresses they have to sustain! In old works of architecture the factor of safety is something considerable. The modern Engineer, however, calls it a waste of money! Waste or no waste the greater the factor of safety, of course within a limit, the greater the stability of a structure.

Fallow—parat or *parti*, arable land not under cultivation, either for want of tillers, or for rest. When any piece of land is tilled, season after season, and allowed no rest it loses, to a great extent, its fertility and productiveness. Professor Bose the famous Indian scientist has lately proved that "Responsiveness" is not the peculiar characteristic of what we called the living creation. Thus metals and what was hitherto considered inert matter, have some sort of life and get exhausted by over-work in the same way as animal and vegetable creation!

Filling—The filling up of a depressed place with earth or any other material. Also an embankment.

Formation (or Formation Level)—The level or top of a proposed embankment. In Railway the level of the embankment below the ballast.

G.

Grout—Mortar or any cement reduced to a liquid state, with water, and used in filling the interstices in masonry work or stone pitching,

H.

Head—Means height or depth of water. As applied to tanks it means the depth of waterway allowed over the sill.

Headers—tSones or bricks laid lengthwise across a wall; also through stones covering the whole width of the wall.

H. F. L.—Means High Flood Level *i. e.* the level to which the highest flood is calculated to rise.

H. W. L.—Means High Water Level *i. e.* the highest level of water a tank can retain. This is evidently the cill or crest level.

Hydraulic—Pertaining to water, as hydraulic pressure; hydraulic mortar.

I.

Inundation Canal—As applied to a tank means the channel through which the flood water of a reservoir is intended to pass on to other tanks below, having poor drainage areas.

Inertia—Is the incapacity of matter to change its state of motion or rest. When a carriage is shunted into a siding you see it moving on for some distance after it is released from the Engine. This is due to inertia. The carriage stops when the inertia is overcome by gravity.

J.

Jack Bund—Small or subsidiary Bund in a tank.

K.

Kiln—A furnace for burning lime or bricks.

L.

Lamina—Thin plate (or section) of any thing.

Lead—See Note 3 Appendix 2.

Lift—See Note 3 Appendix 2.

Lime-pointing—Is the filling the face joints of masonry with fine plaster and pressing it in a neat and regular form. There are generally 3 ways of pointing. (See Figures 26, 27 and 28 Plate 5).

M.

Mason's level or Tilanti—A templet used by masons to test the level of masonry work or to lay off a right angle. (See Figure 43 Plate 8).

Moment—(Of a force about a point) is the product of the force and the perpendicular distance of the point on the direction of that force. (See Figure 41 Plate 8).

Motor or motive power—Means the moving force, also the machine moved by that force.

N.

Newel—The upright post about which the steps of a circular staircase wind.

O.

Optical axis of a lens—Is the line which joins the centres of the spherical surfaces by which the lens is bounded.

Overflow—See escape.

P

Parallax—Is the apparent angular motion of an object (seen through the telescope) arising from the change of the point of view. This motion disappears when the image of the object is made to coincide with the plane of the cross hairs, by the use of the eye-piece.

Percolation—Means the oozing of water through earth or masonry *c. f.* seepage ; leakage.

Perennial (as applied to a river or spring)—Means a river or spring which does not dry up even in summer, having water all the year round.

Perimeter—Means the sum of all the sides of a figure. " Wetted perimeter " is the line in a cross section of a river or Nala which shows the wetted section. (See Figure 14 Plate 3).

Pitching—Stones on edge laid regularly to protect the surface of a thing from the eroding action of water.

Porous (noun, porosity)—A substance is called porous when it easily absorbs and lets out water.

Potential area—Means the largest area which can be irrigated by a well in times of drought.

Protection—In the technical sense means the immunity afforded by irrigation works to certain tracts under their command in the years of drought.

Puddle—Means the mixing of earth with water into "slush," by well kneading and treading, to prevent leakage *c. f.* puddle wall, puddle trench.

Q.

Quadrangular—Having 4 angles

R.

Ravine—Means a Nala or a gorge cut by the scouring action of water in mountainous or hilly country.

Reclamation (*of ground*)—Restoring to cultivation such land as has remained untilled for any cause.

Reconnoissance—Means the cursory inspection of a country as a preliminary step to actual survey.

Regulator—Is the head of a channel through which the supply of water can be regulated *i. e.*, increased, decreased or stopped, according to requirements.

Revetment—A term indifferently used for retaining or breast walls (*Quode Vide.*)

Retaining wall—A wall which supports a made up embankment of earth or any other substance.

Rotation of crops—Frequent change of crops on any piece of land.

S.

Saturation—Means the absorption of water by a substance, as earth or sugar, to a point beyond which it can absorb no more.

Seepage—Oozing out of water.

Site—The place or position of a thing. "At site" means at the place where construction is going on.

Specifications—Means the memo of directions about the quality and quantity of materials to be used by a contractor in building a structure.

Specific gravity—Means the relative weight of a substance as compared with that of water, bulk for bulk.

Splay —Any turn given to a wall.

Stability—Means the power of a structure to resist the pressure which it has likely to bear.

Surcharged wall—Are retaining walls which have also to sustain the pressure of earth above their top level. (See Figure 40 Plate 8).

Syphon—An underground outlet for water. (See Figure 45 Plate 8).

T.

Taccavi (advances)—Is the money advanced by district officers to cultivators for seed grain etc.

Templet (written also template)—A gauge cut out of a thin piece of a metal or wood to the form of the work to be executed. (See Figures 8, 9 and 10 Plate 2).

Tools and Plant—Mean the implements like phaora, pickaxe, ranging rods, mallets, levelling staves, etc., used in surveying or construction of works. "Tools" refer to imlements made of any metal, while "Plant" to that of wood.

Topography—Is that branch of drawing which gives minute details of the natural features of any part of a country. *c. f.*, Topographical survey.

V.

Velocity—Means the rate at which a thing moves.

Virtual line of sight—Is the locus of the points observed through a telescope. When the instrument is in perfect adjustment, optical axis of the lens, line of collimation and virtual line of sight are coincident.

W

Waterway—The space allowed for the outflow of water.

Waste-weir—A *pucca* masonry dam across a Nala to impound water; also providing water-way for the escape of surplus flood water. It is a more pre-tentious thing than an overflow, though answering the same purpose.

Water-shed—That strip of high ground which divides two systems of water courses or Doabs.

Water-cushion—A reservoir below a waste-weir, instead of a *pucca* apron, which gets filled with water and bears all the impact of the water falling on it. It considerably deadens the shock of the flood water falling over the cill.

Weep-holes (or Weepers)—Are small holes in a wall through which the water passes out.

APPENDIX No. 2.

Useful recipes, hints and formulæ.

NOTE 1—Cement to join or repair a stone*.

Fuse sulphur in some earthen pot or trough, and mix with it finely powdered stone of the same quality and color with the piece to be repaired and make the paste of thick consistency. The pieces to which this cement is to be applied should be heated first and then joined together and allowed to cool down.

NOTE 2—Preservation of iron.

There are four ways of protecting iron from the disintegrating and oxidising effects of climate *viz* :—

(1.) Boiling in Coal Tar.

(2.) Heating and smearing with linseed oil.

(3.) Painting.

(4.) Galvanizing.

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* From Syed Jafar Hosain.

NOTE 3—Lead and lift.

Lead is the extra distance a material has to be carted or carried and which has to be paid for @ rates agreed upon. Also the extra money which is thus paid. Lift is the extra height a material has to be lifted. "As a general rule the cost of lifting earth or any other material each additional foot is equal to the cost of carrying it an extra lead of 10 feet"—Colonel Clibborn.

NOTE 4—Water Cushions* (Dyas).

(See Figure 15 Plate 3).

" *Depth of water cushions for weirs.*

d = Depth of fall from surface to surface (of water.)

H = Height (head) of water over top of weir.

x = Depth of water cushion (required).

$$x = H + \sqrt[3]{H} \times \sqrt{d}$$

But prior to finding out x, we have to determine d. In channels "d" can be easily found but in tank waste-weirs where there is no channel beyond the apron the following will do as a rough and safe approximation :—

$$d \simeq h - \left(\frac{L \times H}{L'}\right)$$

* See Molesworth P. 298 (24th Edition.)

Where d = Is as above.

h = Difference of H. F. L. and Ground Level.

L = Length of the cill.

H = As above.

L´ = Distance between the toes of the outer wings of a weir (in tanks).

(See Figure 14 Plate 3).

NOTE 5—Ferrotype or Blue Process.

" By this process prints are produced in Prussian Blue and White, a print taken direct from an ordinary tracing in Indian Ink,* giving white lines on a blue ground.

Sensitizing Solution.

A	... Citrate of Iron and Ammonia .	100 grains.
	Water	1 ounce.
B	... Red Prussiate of Potash...	70 grains.
	Water	1 ounce.

These solutions will keep indefinitely before mixing, but, when mixed they should be used at once or left in the dark.

Preparing the paper.

Mix equal quantities of A and B, and apply to one side of the paper with a sponge. The sponge should be as full as it will hold of the solution which

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* See Molesworth P. 119 (24th Edition.)

should be liberally applied to the paper for about two minutes. Then squeeze out the sponge and wipe off all the solution from the surface of the paper, care being taken to use the sponge lightly, without abrading the surface. The paper, which is now of a light yellow color on the prepared side, should be hung up to dry in the dark.

Printing.

The printing is done in every respect in the same manner as for ordinary photographic silver prints, the tracing representing the negative. Behind the glass of the printing frame lay the tracing, face next the glass, behind the tracing the prepared paper, prepared surface next the tracing. Put out in the sun or diffused day-light from 9 A. M. to noon; the time required (for exposure) will be from 8 to 10 minutes. In the afternoon a somewhat longer exposure must be given.

Fixing.

The print is fixed by simply washing *thoroughly* in clean water.

Additions and erasures.

A white line may be taken out by going over it with a quill pen or brush dipped in the sensitizing solution, exposing to the sun and washing as before. Additions and corrections in white may be made with a quill pen dipped in a solution of 40 grains of

Carbonate of Potash to 1 ounce of water. After using the solution the Potash (solution) must be dried with blotting paper and washed, or the line will spread and become blurred."

N. B—Simple as the process is the great drawback is that the paper deteriorates by the slightest exposure to light—it loses its yellow character, and becomes dark yellow, and if exposed longer turns dull blue-black. The ingredients used should be fresh, and care should be taken to use fresh clean water, if distilled water is not available. All the plates (preferably of China) for washing and fixing should be scrupulously clean, being washed in many changes of water before use. All the processes—sensitizing paper, fixing in frame, washing and fixing—should be done in a dark room under orange or red light. Marion's Candle, costing about a rupee, (to be got from Messrs. Nadkarni and Co., Dealers in Photographic Chemicals, Bombay,) will answer all the requirements of the case. For fixing the prints should be well immersed under and washed in several changes of, water even after it appears perfectly clean, to ensure thorough removal of the sensitizing solution, as, if any the least of it remains on the paper the print gets discolored and blurred. Upon thorough cleanliness and strict adherence to directions depend the brightness and permanency of the prints.

NOTE 6—Gwalior Bighas and Acres.

1 Bigha = 150′ × 150′ or 22,500 sft.
An acre = 4,840 × 9 = 43,560 sft.

Thus an Acre is approximately equal to two Gwalior Bighas.

NOTE 7—Table of Regular Polygons.*

1	2	3	4	5
No. of sides.	Names.	Radius of the inscribed circle.	Radius of the circumscribed circle.	Area.
3	Equilateral triangle ...	·2889	·5773	·433
4	Square	·5	·7071	1·0
5	Pentagon	·6882	·8506	1·7205
6	Hexagon	·866	1·0	2·5981
7	Heptagon	1·0383	1·1524	3·6339
8	Octagon	1·2071	1·3060	4·8284

Working rule.—To find the radius of the inscribed or the circumscribed circle, multiply the length of the side of the polygon by the corresponding numbers in column (3) or (4): but in finding the area, the square of the side is to be multiplied by the corresponding number in column (5). The polygon described about a circle will have that circle as its inscribed circle.

* Quoted from the Mensuration of Dr. Ziauddin M. A., D. S. O., Professor of Mathematics Aligarh.

Example 1.—The side of a pentagon is 10 ft. Find its area.

Area required $= (10)^2 \times 1{\cdot}7205$ sq. ft.

Example 2.— Find the side of a regular octagon described about a circle of 100 ft. radius. Let x = the side required.

$\therefore\ 100 = 1{\cdot}2071 \times x \ \therefore\ x = \frac{100}{1{\cdot}2071}$ ft.

NOTE 8 – Working powers of different motors.*

"To estimate the amount of a force we require to know three things *viz.*, the weight, (of the object) the height it is lifted, and the time in which it is lifted. A British unit of force is the weight of 1 lb. lifted 1 foot in a minute. It is assumed that a horse can lift 33,000 lbs. one foot high in a minute, which are called 33,000 foot – pounds = 1 H. P. or one Horse Power.

Example—Water moves in a channel at the rate of 2 cubic feet per second and falls from a height of 12 feet, find how much power, in terms of H. P. does it generate? When the water moves at the rate of 2 cubic feet per second, its discharge will be $2 \times 60 = 120$ cft. in a minute *i. e.*, $120 \times 62\frac{1}{2}$ lbs. So the power generated in terms of H. P. =

$$\frac{120 \times 62{\cdot}5 \times 12}{33{,}000} = 2{\cdot}72 \text{ H. P.}$$

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* See the Guide (P, 207) of Rai Bahadur Ganga Ram, M. I. C. E., M. I. M. E., Executive Engineer Lahore Division,

Working powers of man and some animals working 8 hours a day.

	Foot-pounds *
Man in rowing a boat	4,000
„ in moving wheels etc. with feet...	3,100
„ turning a handle	2,600
Horse	21,000
Ox	12,000
Donkey	10,000
Ass	3,500

The above, however are the nominal powers, the actual powers are something less."

NOTE 9—Lime Kiln† and Pazawa or Clamp

(See Figure 33 Plate 7).

"Circular Kiln is generally used for burning lime. Figure 1st is the plan; figure 2nd longitudinal section and figure 3rd the cross section of a kiln.

Lime Kankar is burnt with wood and cow-dung in the following manner :—

> First a layer of cow-dung 9" thick is laid, then a layer of 3" of wood, over these is laid a layer of 37½ cubic feet of Kankar, then again a layer of fuel 7" inches thick, followed by a layer of 62½ cubic feet of Kankar. Add another similar layer of fuel, followed by 75 cubic feet of Kankar and so on.

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* Per minute.

† See R. B. Ganga Ram's Guide P. 269.

Thus this kiln contains 6 layers of Kankar ($37\frac{1}{2} + 62\frac{1}{2} + 75 + 100 + 125 + 153$)' = 550 cubic feet of Kankar. In seven layers of fuel 500 cubic feet of wood and 156 that of cow-dung, in all 656 cubic feet of fuel are used. Thus the quantity of fuel is $\frac{1}{5}$ more than that of Kankar. It should also be observed that the layers of fuel decrease from bottom upwards, while those of kankar increase.

The lime thus burnt is considered to be vitiated by the ashes of fuel. Where very good lime is required, coal is used in place of wood, in this way: First a layer of coal 1 foot thick is laid, then the Kankar and remaining coal are heaped up mixed together. Every 100 cft. of kankar require 35 cft. of coal.

(Pazawa or clamp.)

(See Figure 32 Plate 6).

The bottom has four holes at right angles to each other, meeting in the centre. A piece of wood 6″ or 7″ thick is stuck up in the centre, round which the fuel and Kankar are heaped up. This is taken out when the clamp is full to leave some vent for the communication of air with the bottom holes. The clamp is set fire to from the bottom. First a layer of cow-dung 1′ thick is laid, and then Kankar and coal mixed together is heaped up. To burn 1,000 cft. of lime, 350 of coal and 125 of cow-dung are required.

NOTE 10—Rain-gauge or Pluviometer and how to use it.

(See Figure 16 Plate 3).

$\{(\frac{6}{2}'')^2 \times \pi \times 1''\}^{c\ in.}$ = the cubic contents of 1″ rain at the mouth of the funnel. $\{(\frac{3}{2})^2 \times \pi\}^{s\ in.}$ = area at the mouth of the gullet or cross section of the tube. So 1″ rain on the surface of the funnel will rise $\{(\frac{6}{2}'')^2 \times \pi \times 1''\}^{c\ in} \div \{(\frac{3}{2}'')^2 \times \pi\}^{s.\ in.} =$ 4″ in the tube.

The dotted line inside the tube is a stick in which 30″ are divided into 30 × $2\frac{1}{2}$ = 75 divisions (cents.) *i. e.* each inch = $2\frac{1}{2}$ divisions. When 1″ of rain falls the stick rises in the tube 4″ or 4 × $2\frac{1}{2}$ = 10 divisions (or cents.) on the stick. To find out how many inches the rain has fallen during a given time we have to read off the divisions on the stick, and divide it by 10, the quotient is the rain fall in inches.

NOTE 11—Foundations.

It is hardly necessary to say that on the strength of the foundations depends the stability of all the superstructure. Great care should therefore be taken in designing foundations. The following points should be kept in view, while designing them :—

(1.) They should be strong enough to bear the permanent pressure (the weight of the masonry and all other superstructure.)

(2.) They should also have some margin of safety against accidental or occasional pressures, as for instance, the concourse of people in a hall or over the roof of a building.

(3.) They should be carried deep enough to be secure from wind and rain.

(4.) Their surface should be normal to the pressure.

(5.) The foundations should be unyielding or uniformly yielding.

(6.) In treacherous soils means should be adopted to prevent the lateral displacement of the material which supports the foundation.

(7.) It is a mistake to design concrete in steps, as it can not be properly consolidated unless supported on all sides by firm earth. Evidently the foundation can not be dug in regular steps, decreasing upwards.

(8.) In deep foundations it is advisable to give a little batter (See Figure 17. Plate 4). to obviate any slipping of earth over the laborers working in the pit. The batter should be increased in loose soils. Ordinarily a batter of 1 in 16 will be quite sufficient. The last 3 or 4 feet of the foundations should be dug straight.

(9.) All foundations should be carried to hard firm soil, whose depth can be ascertained by sinking trial-pits (5′ × 3′) before making out estimates.

(10.) As far as possible the whole of the foundation should be dug to the same level, unless the ground is in a sharp slope when it can be properly stepped.

NOTE 12—How to roughly estimate the number of stacks (of stone) and quantities of lime and gravel required for any given piece of masonry work.

The following is the formula for finding the number of stacks.

$$\frac{M \times 162}{120 \times 162} = Q$$

$$\text{or} \quad \frac{M}{120} = Q$$

where M = Total masonry in cubic feet

and Q = The number of stacks required.

One stack (or *chatta*) of stone = $9' \times 9' \times 2'$ = 162 cubic feet. When one stack of stone is dressed for masonry it yields approximately 120 cubic of masonry and hence the above formula. Every 100 cubic feet of masonry require 30 cubic feet of kankar lime and 40 cubic feet of gravel.

NOTE 13—Points to be kept in mind to insure accuracy in chain surveying.

(1.) The length of chain should be tested daily and any shortness or elongation removed.

(2.) All knots, after spreading the chain, should be removed by giving a strong shake to the chain, while the other end is held firmly.

(3) All lines from station to station should be ranged straight very carefully and the chain run exactly along the line thus ranged.

(4.) The chain should be held firmly but neither too tight nor too loose.

(5.) When the 11th chain is spread out the follower should make over the arrows to the leader and draw the attention of the surveyor to this. The surveyor, before proceeding further, should make an entry of having surveyed another 10 chains, in his Field Book.

(6.) To ensure that the exact length of the chain is taken and no more, the follower should always put the interior of the loop touching the arrow and the leader, the exterior.

(7.) In dragging the chain along the ground a cant should be given to it to one side, to make it clear of the arrow.

(8.) It goes without saying that all entries in the Field Book should be written very clearly, as ambiguous or indistinct figures occasion great and sometimes, serious error.

NOTE 14—Points to be kept in mind to insure accuracy in levelling.

(1.) As a first step it should be seen whether the permanent adjustments of the instrument are right.

(2.) The temporary adjustments too should be done most carefully.

(3.) The instrument should be set up midway between the staves to obviate any error due to collimation.

(4.) In chaining along with levelling all the directions about chain surveying should be followed.

(5.) The staves should be set up on wooden pegs driven firmly into the ground and projecting from it not more than $\frac{3}{4}$ of an inch.

(6.) The staves should be held truly vertical and to obviate any possibility of mistake the cooly should be told to move the staff, very gently, backwards and forwards, the least reading being the right one.

(7.) At every change of direction the Back Bearing of a line should also be taken to ascertain whether the Fore Bearing has been taken rightly. The Back and Fore Bearings of a line should differ by two right angles.

(8.) In reading from the staff the feet should be read off first and recorded, and then the bubble seen to, and feet, tenths and hundreths read off together. *Any mistake in tenths and hundreths does not matter so much as that of feet.*

(9.) Different staves are differently marked. The leveller should, prior to starting level work, see how the staves are divided, and how the feet, the tenths and hundreths are to be read. This, though a trifling matter, leads to serious error sometimes.

(10.) The leveller should try to level the instrument by legs first and then by the foot-screws, having brought all the screws in the middle of their pitch This not only prevents the wear of the screws, but renders the work of levelling easier. Of course dexterity is acquired by practice, in this as in all other manual operations.

(11.) As an extra precaution against possible error, where great accuracy is desired, the instrument should be taken up and set up again. If the difference of Back and Fore readings tallies with that obtained before, the readings are right.

(12.) Where great accuracy is desired levelling should not be done when the wind is high or glare of the sun excessive.

NOTE—For ordinary levelling error due to refraction and curvature may be neglected.

NOTE 15—To protract angles with any scale

This is a modification of the Scale of Chords.

Working rule—Stretch the compass to exactly 60 divisions of any scale and from the end of a line

A B, limited at one end A and unlimited at the other B, as centre draw an arc B C cutting A B in B and from B as centre and as many divisions (of the scale used before) as there are number of degrees in the angle required to be protracted (minus* $\frac{1}{18}$ of these divisions) draw another arc P C E cutting B C in C. (See Figure 18 Plate 4). Join C A. C A B will be the required angle. If the angle required to be protracted contains minutes as well, the minutes should be reduced to the fraction of a degree and the same fraction of a division on the scale may be added to the whole numbers (minus, of course $\frac{1}{18}$th of the angle, as before.)

This method of protracting angles is of inestimable value in Ground Tracing, as any angle can be protracted by means of the Measuring Tape.

Example—(See Figure 18 Plate 4). Required to protract an angle of 15°-30′. Take a line A B equal to 60 division of any scale. From A as centre and A B as radius describe an arc B C. Now 15°-30′ $= 15\frac{1}{2}^\circ = \frac{31}{2}^\circ$; $\frac{1}{18}$ of $\frac{31}{2} = \frac{31}{36}$. Now take in the compass $15\frac{1}{2} - \frac{31}{36}$ divisions $= \frac{31}{2} - \frac{31}{36} = \frac{558-31}{36} = \frac{527}{36} = 14\frac{3}{4}$ divisions, and with B as centre and these divisions as radius describe the arc P C E cutting the arc B C in C. Join A C. B A C is the required angle. In ground tracing this approximation gives as correct results as an angular instrument.

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* The reason of this is that if a right angled isosceles triangle be drawn with its base and perpendicular each = 60 divisions of a scale, the hypotenuse of the same is = about 85 divisions. So for 90° we have to take 85 divisions i. e $\frac{5}{90} = \frac{1}{18}$ less than the number of degrees required to be protracted In the *same proportion* for other angles.

NOTE 16—Prismatic Compass.

In the Prismatic compass owing to the prism being placed at the reverse side of the graduated ring for the convenience of the observer every thing seen through it is reversed and hence the zero or North point of the ring is placed in the South and the degrees begin from zero to 180° from right to left, like the clock work motion (See Figure 46 Plate 9).

NOTE 17—Plaster for lime-pointing.

Burnt lime of of the best kind (preferably stone lime)	40 cft.
Gravel or sand very fine ...	10 cft.
Jaggery or molasses	1 seer.
Hemp (finely cut)	1 seer.
Belgri or Imlora root ... (well boiled and strained.)	3—to 5 seers

All these to be finely ground in hand-mills or on edge-stones.

NOTE 18—How to cancel mistakes due to collimation.

It must be known to the reader that by placing the instrument midway between the staves, any error of collimation is cancelled. When, however, any obstacle, like a sudden rise or dip in the ground occurs and it is not possible to place the instrument exactly in the middle, the instrument should be removed to some convenient place, exactly at right angles to the chain line at the point where the instrument ought to have been set up and the readings taken. (See Figure 19 Plate 4).

Another method is that the instrument may be set up at some convenient place, at unequal distances from the two staves and readings taken. Any mistake will get cancelled by reversing the distances in the next setting up. (See Figure 20 Plate 4).

NOTE 19—Ellipse.

Area of an ellipse.

$$\text{Area} = \frac{\text{Major Axis} \times \text{Minor Axis} \times \pi}{4}$$

$$\text{or } \frac{\text{Major Axis}}{2} \times \frac{\text{Minor Axis}}{2} \times \pi$$

NOTE.—This formula is thus analogous to that for finding the area of a circle.

The volume of a Prolate spheroid or the volume of a solid whose longitudinal section is an ellipse.

$$\text{Volume} = \frac{\text{Major Axis} \times (\text{Minor Axis})^2 \times \pi}{6}$$

NOTE 20—Given the bearings of the lines of a circuit to find the interior angles.

(See Figure 29 Plate 5).

This is the formula which can be verified from the figure.

From the Fore Bearing of the second line containing the interior angle subtract the Fore Bearing of the 1st line containing the interior angle, add or subtract 180 according as the result is less or greater than 180, the result will be the interior angle required. Or briefly,

$$2\text{nd F. B.} - 1\text{st F. B.} \pm 180 = \text{Int. Angle.}$$

When the 2nd F. B. is less than 1st F. B., their difference is taken prefixed with the sign minus, and 180 added to it.

NOTE 21—Given all the interior angles and the bearing of one line to find the other bearings.

To the bearing of the line preceding that of which the bearing is sought add the interior angle formed by these two lines, and the sum increased or diminished by 180, according as it is less or greater than 180 will be the bearing of the next line. (See Figure 29 Plate 3).

APPENDIX No. 3.

Theodolite.

It is not clear why the Theodolite is considered such a bugbear by the lower subordinates. It is no doubt a very delicate instrument and requires very careful handling and presupposes some knowledge of Trigonometry, in addition to Arithmetic and Mensuration, but once understood it is as simple as any thing. What I mean to say is that there is nothing complex about it. Space forbids any description of the appearance of a Theodolite or its mechanism and adjustments. I will give briefly the uses to which the instrument can be put. They are as under :—

(1.) Reading the Bearing of a line.

(2.) Reading the interior angle between two lines.

(3.) Laying out any angle on the ground.

(4.) Finding out the height of an object.

(5.) Ranging or producing a line indefinitely.

(6.) Laying out a curve.

NOTE—It is not thought necessary to make any reference to the Trigonometrical Survey, as it is not ordinarily required.

Before describing the above some definitions would be necessary, as also an explanation about the use of the Vernier Scale.

Angle of elevation—Is the vertical angle read on the arc of the Theodolite above the horizontal line, originated by the intersection of the cross hairs being directed to the top of the object whose height is to be determined.

Angle of depression—Is the vertical angle read on the arc of Theodolite below the horizontal line, originated by the intersection of the cross hairs being directed to the bottom of the object whose height is to be found.

Slow-motion Screw—called also Tangent Screw or Mecrometer Screw. It is attached to a clamping screw. When any plate *is clamped* and it is required to move it *slightly*, this screw is used.

How to use the vernier.

The degrees and 20 or 40 minutes, according as the case may be, can be read off directly from graduations on the lower plate by a look at the position of the index or the arrow of the vernier, through the eye-piece. Any fraction of 20 minutes* is read by vernier in the following way:—After reading off degrees and 20 or 40 minutes if there are any, if the

* These remarks apply to a Theodolite whose degrees are divided into 3 parts. There are instruments in which degrees are divided into 4 parts.

vernier points to some further fraction of 20 minutes, see roughly what fraction of 20 minutes the arrow points to and then travel your glance along the divisions *on the vernier*, and find out what line on the vernier coincides with a line on the lower plate. This line (on the vernier) will point the number of minutes and seconds to be added to the previous reading, *e. g.* (See Figure 30 Plate 6). By a very look at the graduations we can find out that the arrow of the vernier points to 1° and 20′ and some further fraction of 20′, which to the eye appears about $\frac{1}{4}$th of the minor division of 20′. Now glancing along the Vernier Scale we see that the 1st line (of the minor division) after 4 coincides with a line below, so we are sure that 4′-20″ are to be added to the angle already read off (1°–20′) *i. e.* the angle pointed out by the vernier is 1°–20′ + 4′ – 20″ = 1°–24′–20″ The seconds are unimportant for ordinary work, unless very great accuracy is required.

I. Reading the Bearing of a line from the North.

Bearing of a line from the North means the angle which that line makes with the North line. Bearing is always of a line. When the bearing of a point is spoken of we mean the bearing of the line joining that point to the point where the instrument is set up.

Process.

(1.) Set up the tripod and see that the plumb bob points exactly in the centre of the station peg.

(2.) Level the instrument and focus and remove the defect of the Parallax.

(3). Clamp the vernier at zero (360°).

(4.). Make the magnetic needle point exactly to North by shifting the lower plate (of course the upper plate with it).

(5). Clamp the lower plate removing any slight deviation of the needle from the North line by the Mecrometer Screw attached to the *lower plate.*

(6.) Release the upper plate and intersect the flag or the point whose bearing is required.

(7.) Clamp the upper plate, removing any deviation from the point intersected by the tangent screw of the *upper plate,* and read off the angle pointed out by the *same* vernier which was fixed at zero.

(8.) To test whether a Bearing has been taken rightly, remove the Theodolite to the forward station and from that take the Back Bearing of the line. If these two readings differ by 180°, the readings are right. In removing the tripod the lower plate need not be unclamped, as it would save the processes (3), (4) and (5), but where great accuracy is desired all the processes should be done anew.

2. How to read an interior angle.

PROCESS.

(1), (2) and (3) as above.

(4.) Intersect the back flag and clamp the lower plate, removing any deviation by the tangent screw of the lower plate.

(5.) Release the upper plate and intersect the fore flag.

(6.) Clamp the upper plate, removing any deviation from the intersected flag by the use of the Slow-motion Screw *on the upper plate,* and read off the degrees by the *same* vernier.

3. Laying out any angle on the ground.

Suppose the line or direction A B is given (by pegs) and it is required to lay out on the ground the angle A B C. (See Figure 47 Plate 9).

Set* up the instrument at B and clamp the vernier at zero and intersect the flag at A (the bottom of the flag where it rests on the peg, if possible) and clamp the lower plate. Release the upper plate and set the same vernier at the required angle and clamp the upper plate, removing any deviation by the tangent screw of the upper plate and see through the telescope and bring the flag or rod *exactly* at the point of the intersection of the cross hairs and drive a peg in the ground. Get the cooly or Khalasi to set up the flag again on the peg and if the flag is in position get the man press down the the pointed end of the rod on the top of the peg where it was set up and drive a nail into the point. Cords stretched between A B and B C will give the required angle.

* Of course levelling the instrument etc., etc.

4. To find the height of an object.

(See Figure 21 Plate 4).

(1.) Set up the tripod at the peg with the plumb-bob pointing exactly in the middle of the peg.

(2.) Level and focus and remove the defect of Parallax.

(3.) Fix the vernier of the vertical arc at zero.

(4). Bring the bubble of the telescope in the centre of its run by the two conjugate screws which fasten the pendent piece (containing the clamping screw of the arc) to the projection in the upper plate. This is to make the telescope truly horizontal.

(5.) Unclamp the arc and intersect the top most point of the object whose height is required and read off the angle of elevation on the graduated arc.

(6.) Intersect the bottom of the object in the same way and read off the angle of depression.

(7.) Measure the horizontal distance from the peg to the bottom of the object.

Now $A\,B = A\,C + B\,C$.

$A\,C = C\,D$ (horizontal distance) $\times \tan \angle A\,D\,C$

$C\,B = C\,D \times \tan \angle B\,D\,C$

$\therefore A\,B = C\,D\ \{\tan A\,B\,C + \tan B\,D\,C.\}$

To find out the tangents either Chamber's or any other Mathematical Table of Tangents may be used.

If the bottom of the object is not visible then to A C, found in the above way, add the height of the instrument (from ground to the centre of the eye piece.)

5. Producing a line indefinitely.

(1.) Set up the instrument at any intermediate point in the line which is to be produced, but this point should not be less than 5 chains from the last peg.

(2.) See to all the temporary adjustments enumerated above.

(3.) Clamp the lower plate firmly, but not too tight as that wears out the instrument.

(4.) Release the upper plate.

(5.) Intersect the ranging rod set up by the leader and held truly vertical at the last peg of the line and clamp the upper plate as well, removing any deviation from the rod by the use of the tangent screw.

This gives the direction of the line which can be produced to another 5,000 feet, if the weather is calm and clear and glare not excessive. At every new chain spread out, the leader gets the true position of the peg by putting up the ranging rod and removing it laterally at the signals from the surveyor. Of course none but trained Khalases can perform these operations. Every 1,000 peg should be taken most carefully, and square peg put in.

6. Laying out a curve.

In Railways curves are an absolute necessity, as the train can not change direction without going along a curve. Curves are also necessary at a change of direction in a road, canal or channel. It is possible to turn off a channal abruptly at a corner but this would be unnecessarily exposing the cornor to the pressure of water impinging against it.

There are many methods of setting out curves, but we will consider only 2, *viz.* (1) by Chords and Offsets and (2) by Theodolite.

1. To set out a curve by Chords and Offsets without the aid of any angular instrument.

(See Figure 22 Plate 5).

$$\text{1st offset} = \frac{(\text{chord})^2}{2\ \text{radius}}$$

$$\text{2nd offset} = \frac{(\text{chord})^2}{\text{radius}}$$

If the last length is a full chain, to resume the new tangent line set off as at the first, $\frac{1}{2}$ the offset. If the tangent found occurs at a fraction of the last chord, then set off a proportionate length of the half offset, the proportion of the squares being used. (See figure 22 Plate 5).

2. To set out a curve by Theodolite.

Before showing how a curve is set out by the Theodolite, it is necessary to give some definitions.

Angle of curvature—Is the angle in a circle or curve which is subtended by a chord equal to 100 feet. Thus the larger the radius of a curve, the smaller the angle of curvature and *vice versa.* Or, in other words, angle of curvature varies inversely as radius.

Also the larger the angle of curvature the sharper the curve and *vice versa.* Thus where a sharp curve is intended the angle of curvature is increased.

(2.) The angle which the new direction makes with the old is called the angle of deflection and is symbolically written as $< \delta$. Thus in figure 23 Plate 5 D B is the direction of the new line while B C of the former and the angle C B D is the Deflection Angle.

Before setting out a curve the following information is first to be worked out :—

(1.) Intersection Point (chainage of)
(2.) Deflection (angle of) — right or left.
(3.) $<$. C. = Angle of curvature.
(4.) R = Radius of the curve.
(5.) L. C. = Length of curve.
(6.) Tangent, length of.
(7.) 1st and 2nd tangent points.
(8.) Chord lengths with corresponding tangential angles.

(1.) *Intersection Point.*

This depends on the choice of the surveyor; he fixes this point for manifold considerations (which need not be specified here) which lead to the change of direction. A square peg should be driven at this point with a nail on its top to indicate the exact point of intersection. A *pucca* Bench Mark is to be built about this peg, but the peg is on no account to be disturbed. The chainage of this point should carefully be noted in the Field Book, as it is the basis of all calculations.

(2.) *Deflection.*

Right or left. This is known according as the line turns to the right or left of the original line. The surveyor's rout is marked on the index plan, which it is his duty to follow as far as possible, unless he has cogent reasons to the contrary. If after reaching at a particular point the surveyor sees that any prolongation of the line leads him further from his route he would use his discretion to divert the line—right or left according to the circumstances of a case. As long as the required towns or villages are served, it does not matter how the line is carried, provided it is less expensive than the line marked on the index sheet and no engineering mistakes are made. (See Figure 23 Plate 5).

(3.) *Angle of curvature.*

This the surveyor determines from the consideration, whether the curve would be sharp or light;

which again depends upon, whether the deflection is sharp or easy for light deflections light curves are indicated and for sharp, sharp.

A deflection of from 1° to 20° is light; from 20° to 40°, medium, beyond it sharp.

Likewise, angles of curvature from 1° to 3° give light curves, from 3 to 5° medium and beyond that sharp.

(4.) *Radius.*

This is found simply by dividing 5730 by the angle of curvature.

(5.) *Length of curve.*

(See Figure 24 Plate 5).

The angle at the centre of a curve is equal to the angle of deflection (by Euclid 1·32), and it has already been said that the angle of curvature is the angle subtended by a chord = 100 feet. So the length of curve can be found by simple Rule of Three.

$$100' : \text{Length of curve} :: \text{angle of curvature} : \text{to angle at centre.} \quad (= \angle \delta)$$

$$\text{Length of curve} = \frac{100 \times \delta \text{ angle.}}{\text{Angle of curvature.}}$$

(6.) *Length of tangent.*

This can be found by the formula :—

Tangent = Radius × tan. $\frac{\delta <}{2}$ This formula will be readily intelligible to a person who knows Euclid and rudiments of Trigonometry.

(7.) *Tangent Points.*

1st Tangent Point is found by subtracting the length of tangent from the chainage of the Intersection point.

2nd Tangent Point is found by adding the length of the curve to the chainage of the 1st Tangent Point.

(8.) *Chord lengths with corresponding tangential angles.*

(See Figure 31 Plate 6).

The first chord length is found by subtracting the chainage of the 1st Tangent Point from the next complete chain of 100 feet. After this as many chords of 100 feet as, together with the 1st chord, would be within the length of curve. The last chord length (something less than one chain) is found by subtracting the sum of all the chord lengths (but last) from the length of curve.

Tangential angles.

It will be evident from figure 25 Plate 5 that a tangential angle for any chord is $\frac{1}{2}$ of the angle subtended by the chord at centre. Thus when the chord is 100 feet and the angle of curvature, 6° the

Tangential Angle would be 3°. To find the Tangential Angle of the first chord the following is the proportion.

$$\frac{\text{Angle of curvature}}{2} : \underset{\text{(required)}}{\text{tangential angle}} :: 100' : \text{chord}$$

$$\text{tangential angle} = \frac{\frac{<.\ c \times \text{chord}}{2}}{100}$$

The next tangential angle is found by adding $\frac{<.\ C.}{2}$ to the 1st and so on, till the last but one; the last $= \frac{1}{2}$ the angle of deflection.

When all these details are worked out and *checked*, both the tangent points should be pegged by setting up the Theodilite at the Intersection Point. This done the instrument is removed to the 1st Tangent Point. The upper plate is fixed at the zero and the rod at the intersection point, intersected by the cross hair and the lower plate clamped as well. Then release the upper plate and move the telescope to right or left, according as the deflection is right or left till the required tangential angle is pointed out by that vernier, *which was fixed at zero*. The leader then advances in the direction of the telescope and pegs the 1st chord the telescope is again moved till the required (*i. e* 2nd) Tangential Angle is pointed out by the vernier and the 2nd peg put in at a chain length from the last point, at the intersection of cross hairs, and so on.

The tests of the curve being laid out rightly are :—

(i.) That the last actual chord length on the ground is what is recorded in the details.

(ii.) The tangential angle shown by the rod placed at the 2nd tangent point is what has been arrived at by calculation.

A mistake of 2 or 3 inches in the last chord or 2 on 3 minutes in the last tangential angle dose not signify much.

APPENDIX No. 4.

Lime.

As lime is the basis of all *pucca* work its importance can not be over-rated. Upon a correct estimate as to the quality and ingredients of a particular lime Kankar or lime-stone, the strength and stability of a structure depend. In the natural state lime is to be met with of varying degrees of purity. An engineer must have sure tests of finding out the proportions of different substances found mixed with lime. Upon investigating this, to a certain degree of approximation, will depend his decision sa to how much sand or gravel is to be mixed with the lime to get good mortar. Sand or gravel is added to lime for four reasons, *viz*:—

(i.) For economy, to increase the quantity of mortar, lime costing much more than either sand or gravel.

(ii.) To increase the crushing strength of lime. Lime by itself in its pure state has very little crushing strength.

(iii.) To reduce to a minimum any shrinkage of mortar in the course of setting.

(iv.) To help in and expedite the setting of mortar, as the particles of sand allow some ingress to air charged with carbonic acid gas.

* Crushing strength, means strength to resist crushing.

Jaggery (or molasses, Urdú Gur) also is added to mortar for this purpose, as also to keep the mortar moist while setting. Jaggery being a deliqescent substance, easily absorbs and retanis any moisture in the surrounding air.

When it is desired to increase the hydraulic properties of lime Surkhi* is mixed with lime instead of sand or gravel.

Molesworth gives the following recipes which are worthy of note :—

Mortar.

1 of lime to 2 to 3 of sharp river sand.

Coarse Mortar.

1 of lime to 4 of coarse gravelly sand.

Hydraulic Mortar.

1 of blue lias lime to $2\frac{1}{2}$ of brunt clay, ground together.

Beton or hydraulic concrete.

1 of hydraulic mortar to $1\frac{1}{2}$ of angular stones (ballast.)

Water proof mastic cement.

1 of red lead to 4 of ground lime and 5 of sharp sand mixed with boiled oil.

* Brick-bats reduced to powder.

Portland cement.

It is composed of clayey mud and chalk ground together and calcined at a high temperature, and then ground to a fine powder.

Vicats' classification of lime stones.

(1.) Fat lime (pure lime)—does not set in water.

(2.) Poor lime—mixed with sand, which does not alter its condition.

(3.) Slightly hydraulic lime—containing 8–12 per cent of silica, alumina, magnesia, iron and manganese. Sets slowly in water.

(4.) Hydraulic lime—containing 12—20 per cent of the above engredients, sets in water in 6 or 8 days.

(5.) Eminently hydraulic lime—20—30 per cent of the above, sets in 2 to 4 days.

(6.) Hydraulic cement—containing 30 to 50 per cent of argil (clayey earth) sets in a few minutes and attains the hardness of stone in a month.

Tests of Lime stone and Kankar.

There are two tests for finding out the quality of lime *viz*., Practical and Chemical.

Practical tests.

(1) "They (lime-stones) dissolve wholly or partly in weak acids with brisk effervescence. They are nearly insoluble in water. They can be scratched with an iron point" (Molesworth).

(2.) "Lime-stone, which is of different colors from black to white, when immersed under water for some time does not shine and is velvety to touch" (R. B. Ganga Ram). The test of a good lime kankar is that it should have projecting nodules on its surface. This class is called Bichhwa by Indian masons. When freshly excavated the kankar is found covered with a crust of earth, which should be scraped off, as it vitiates lime. A good lime kankar when burnt should be of dull yellow color and should fall off in flakes on being slaked. Any redness in the burnt lime indicates that the earthy crust with which it is covered in its natural state, has not been scraped off. Such lime should either be rejected or proportion of sand or gravel to be mixed with it decreased. When mixed with gravel and thoroughly ground, lime mortar should have *las*, *i. e.*, should be clammy and sticky to touch. A mortar in which this is absent should be looked upon with suspicion.

The crushing strength of lime should be 80 lbs. per square inch, while the breaking strength 150 lbs. per square inch.

Chemicals Tests.*

1. Take a piece of lime stone and wash it well of all earthy deposits and weigh it. Burn it till it is red hot and allow it to cool down and then weigh it again. The difference in weight is the weight of carbonic acid driven off by heat. From this the proportion of lime in the stone can be found out, as every 100 parts of lime-stone contains 56 of lime and 44 of carbonic acid.

2. Roorkee Building Materials.

(1.) Pound the sample and pass it through a fine sieve.

(2.) Put 150 grains into a tumbler pour gradually in it diluted Hydrochloric Acid, stirring and adding the acid until effervescence ceases.

(3.) Filter through blotting paper and then wash by pouring at least a quart of water through it.

(4.) Carefully collect the remainder, dry and weigh it, its weight deducted from 150 grains will give the weight of carbonate of lime.

(5.) Wash the remainder repeatedly with decantation to remove the lighter particles of clay, then dry and weigh the sedimet, which may be assumed to be sand.

---

* Of course both these tests give rough approximation.

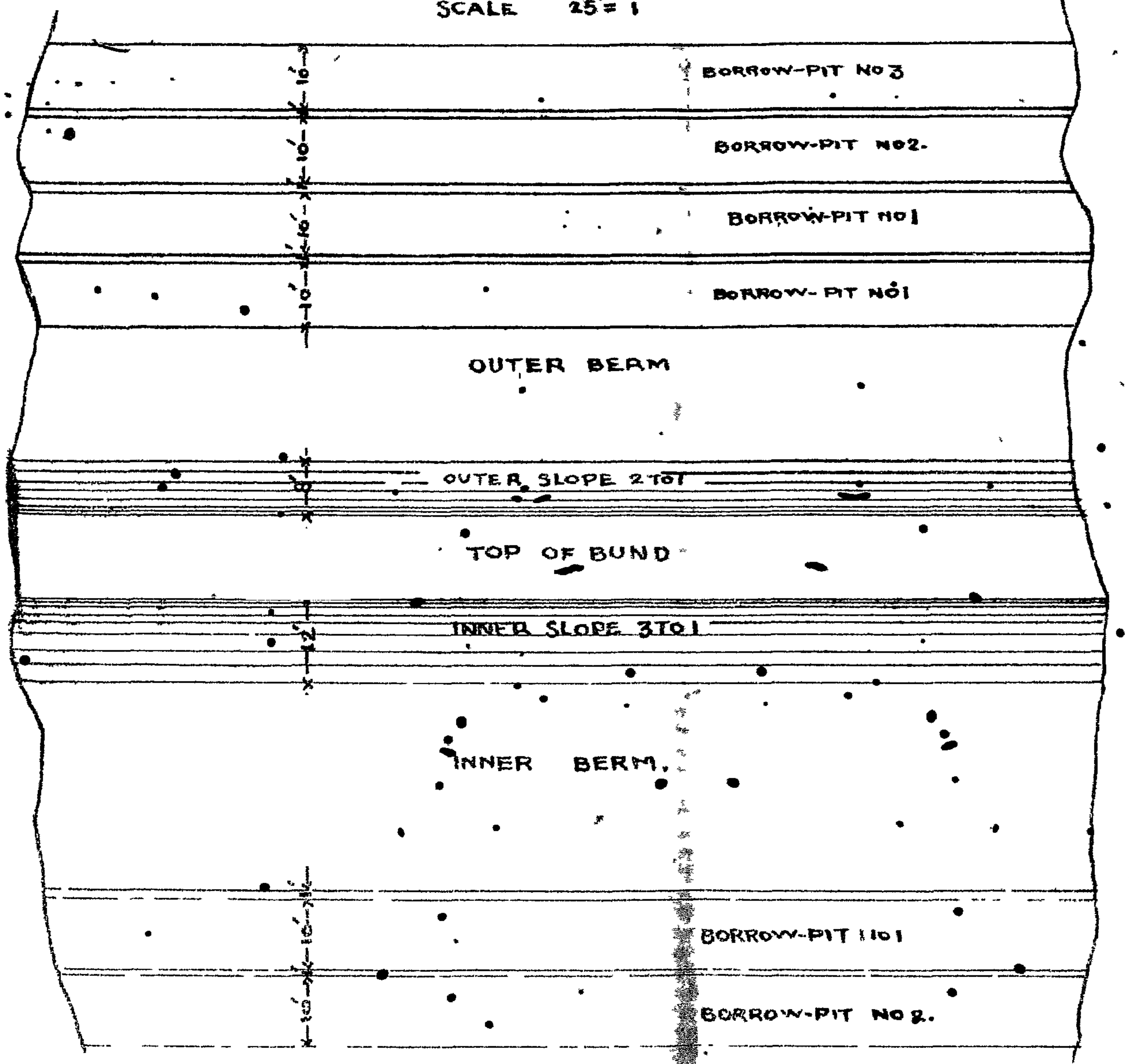
If we find the three ingredients in the following proportions, the lime will be a fair one for general purposes :—

Carbonate of lime	...	112	grains.
Clay ...	...	9	,,
Sand ...	...	29	,,

PLATE. I

Figure 1.

SCALE 25' = 1"



NOTE HEIGHT OF BANK = 4'

Figure 2.

SCALE — 10' = 1"

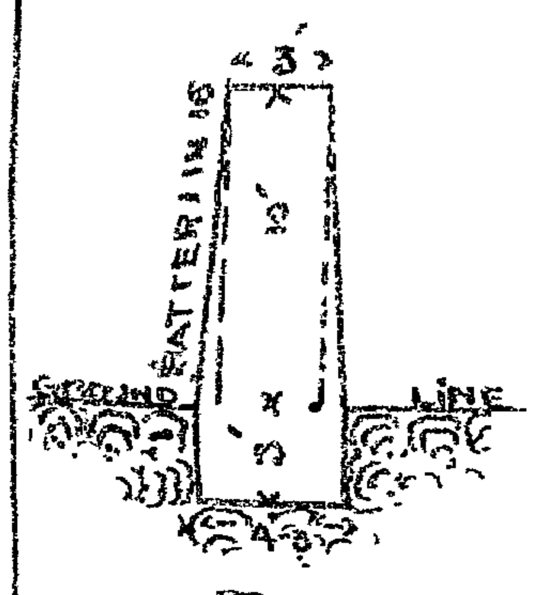


Figure 3.

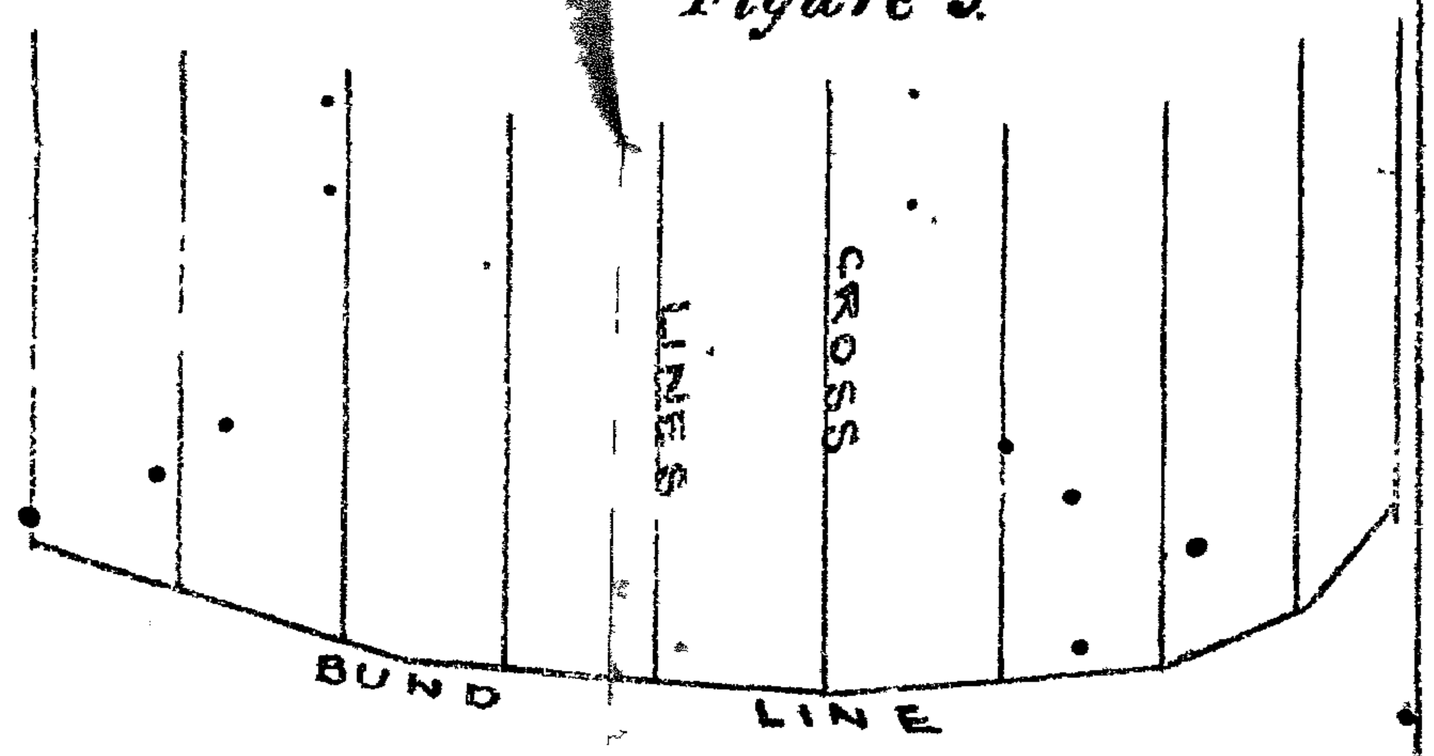


Figure 4.

DROWNED WEIR

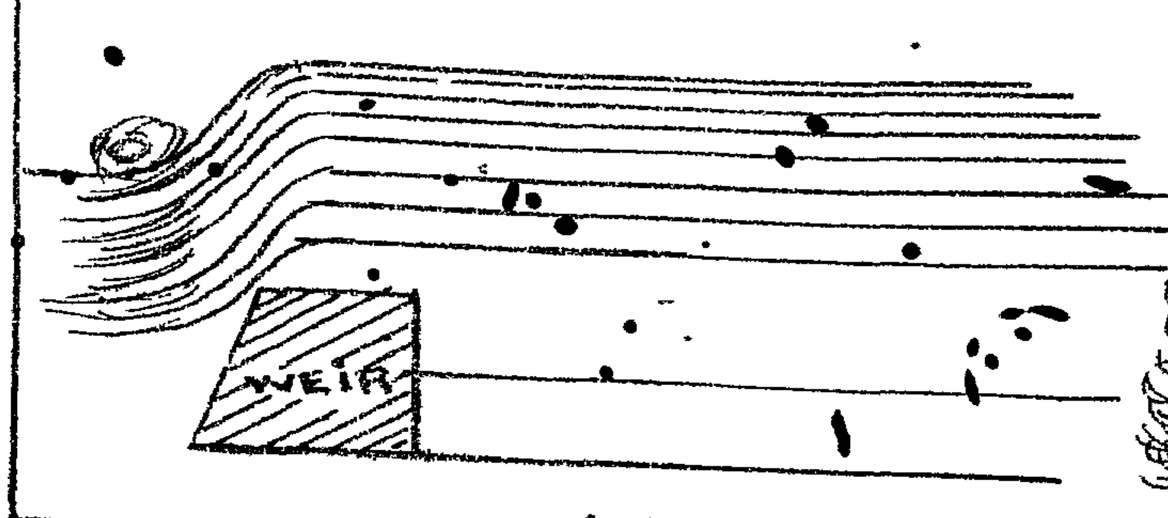


Figure 5.

CLEAR OVER-FALL

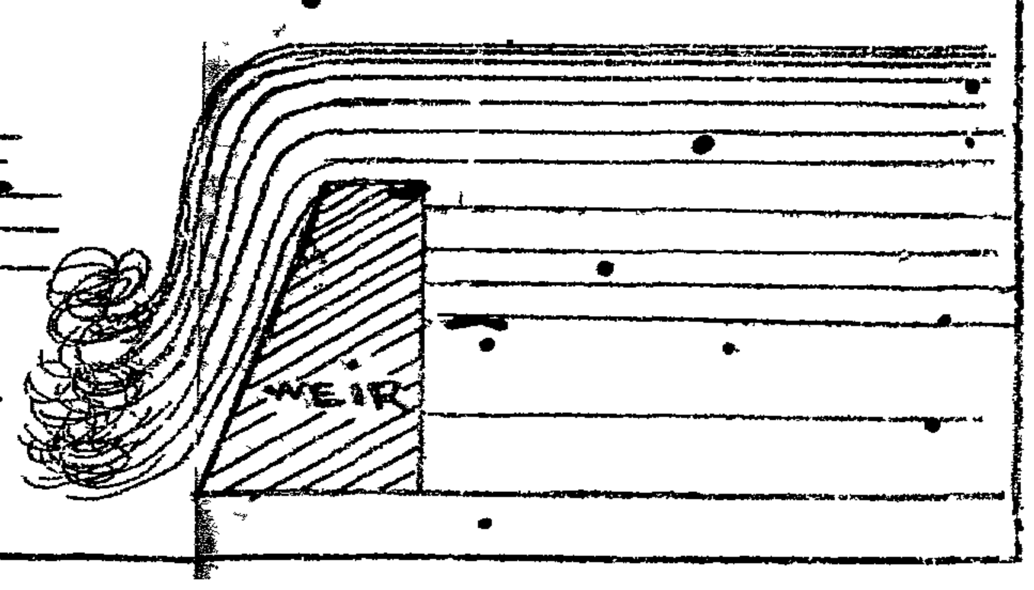


PLATE 2.

Figure 6

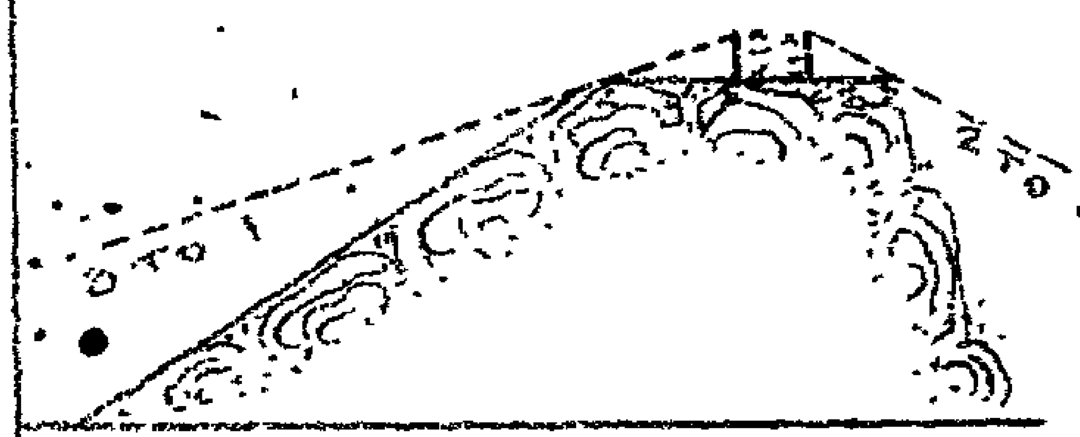


Figure 7.

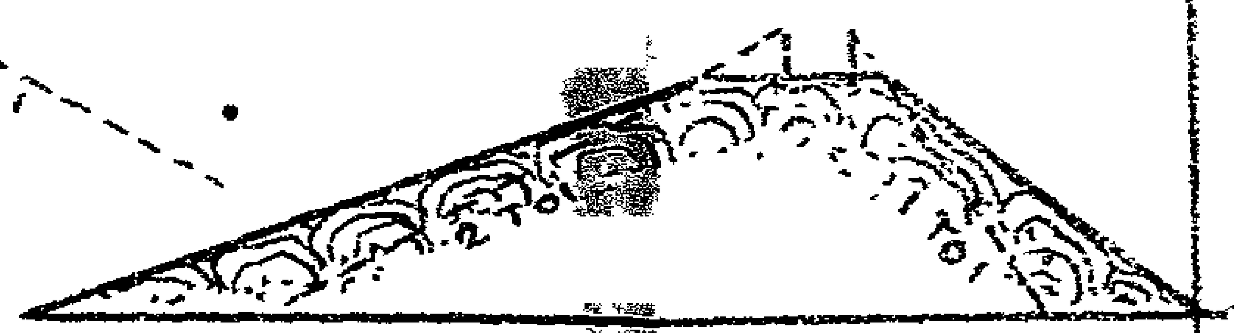
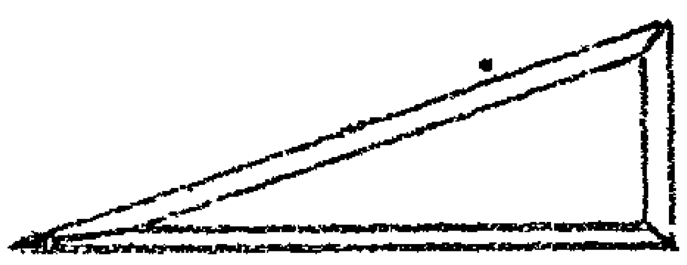
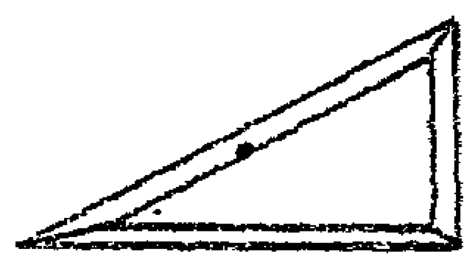


Figure 8 *Figure 9* *Figure 10*

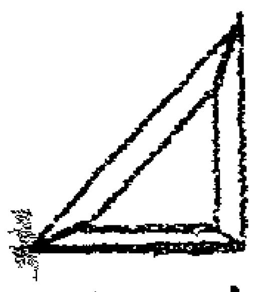
TEMPLETS.



3 TO 1



2 TO 1



1 TO 1

Figure 11

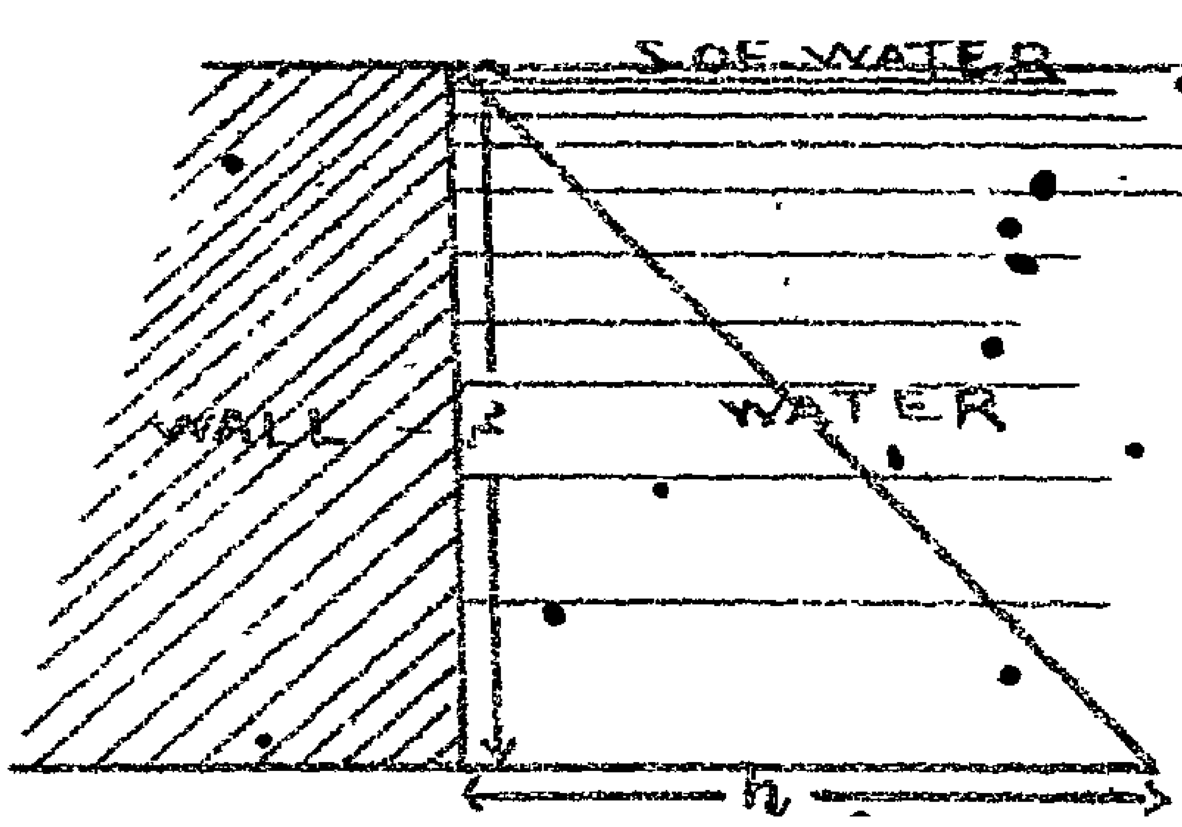


Figure 12.

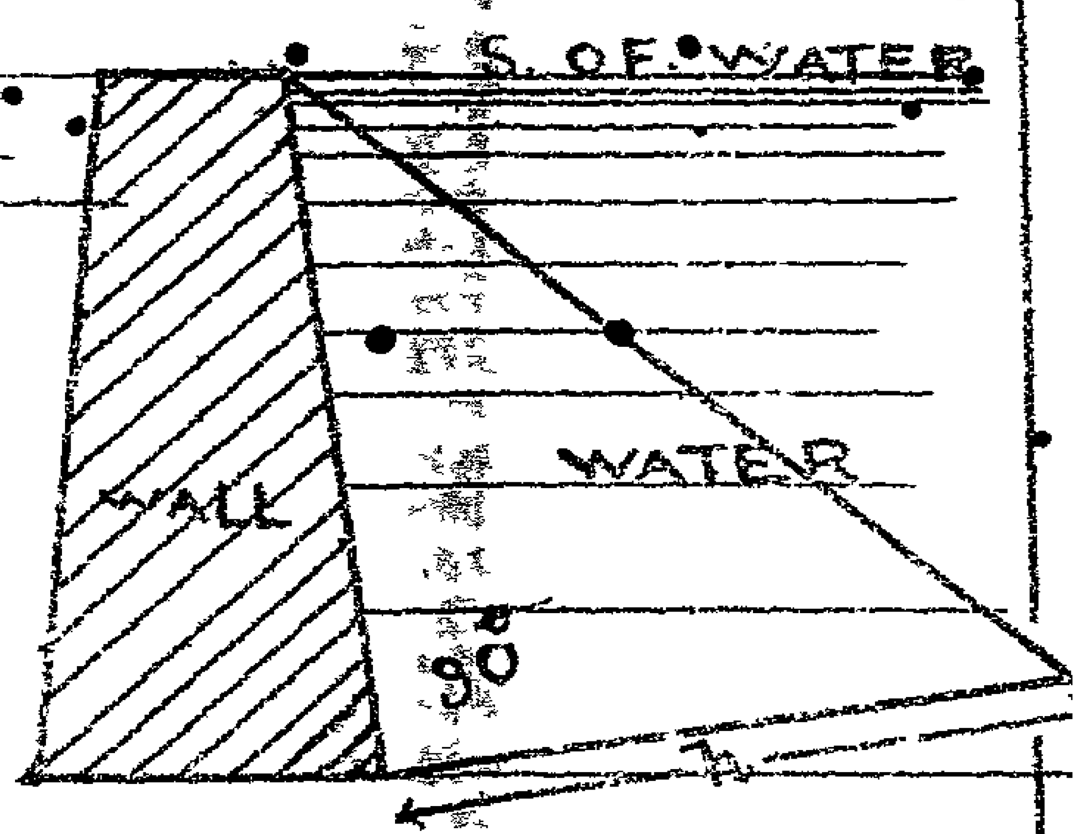


Figure 13.

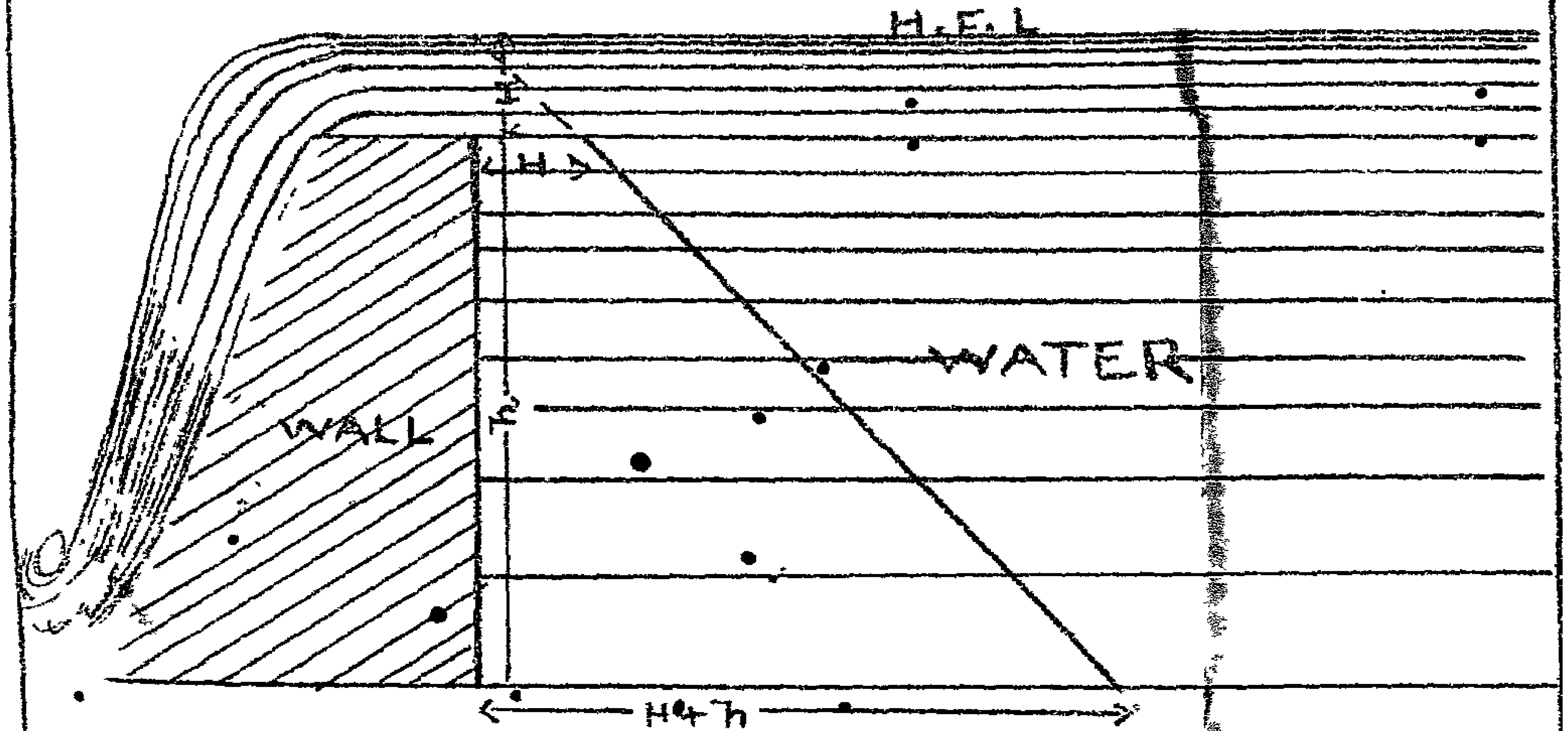


PLATE 3

Figure 14.

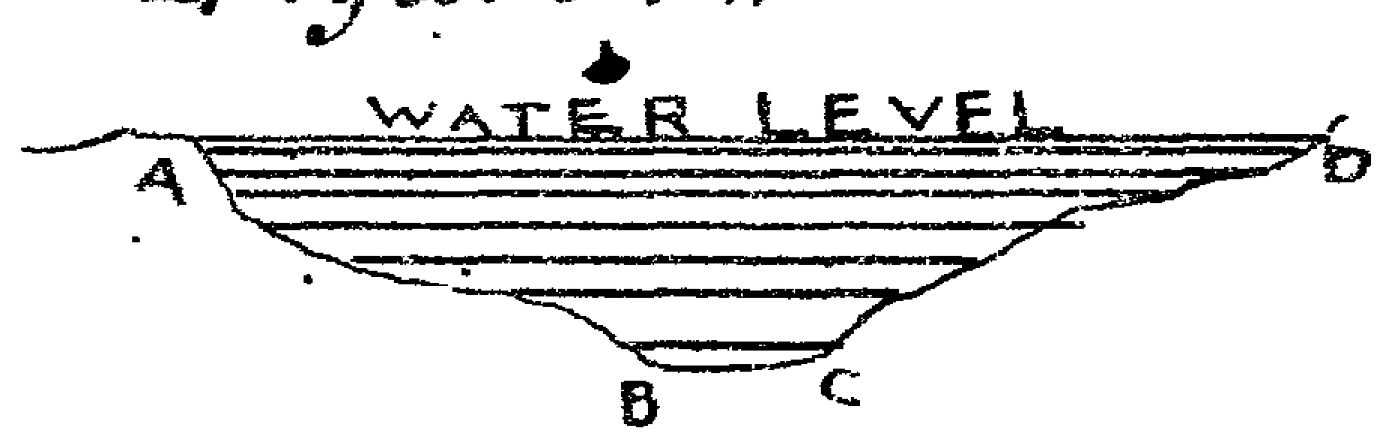


Figure 15

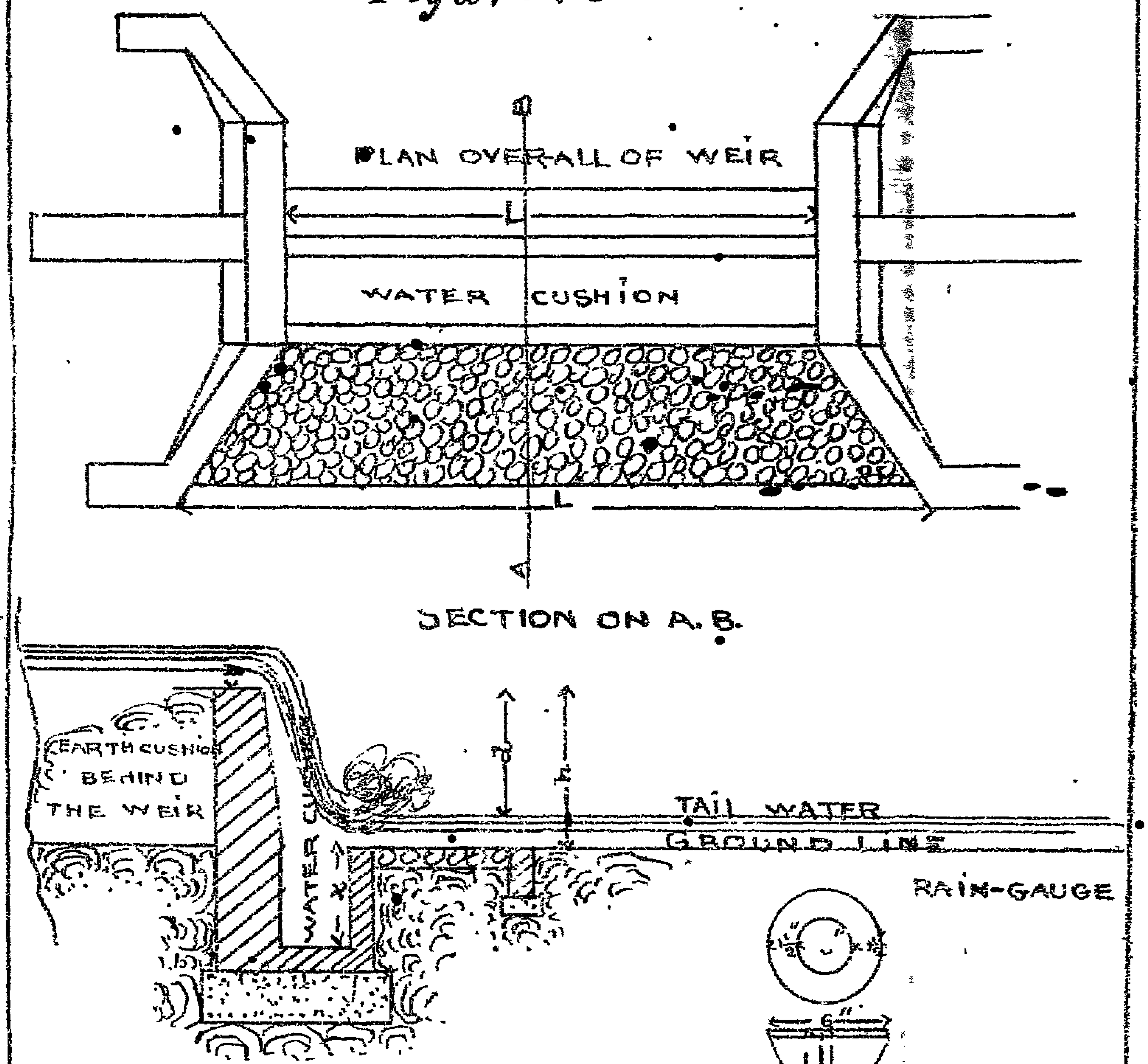


Figure 16

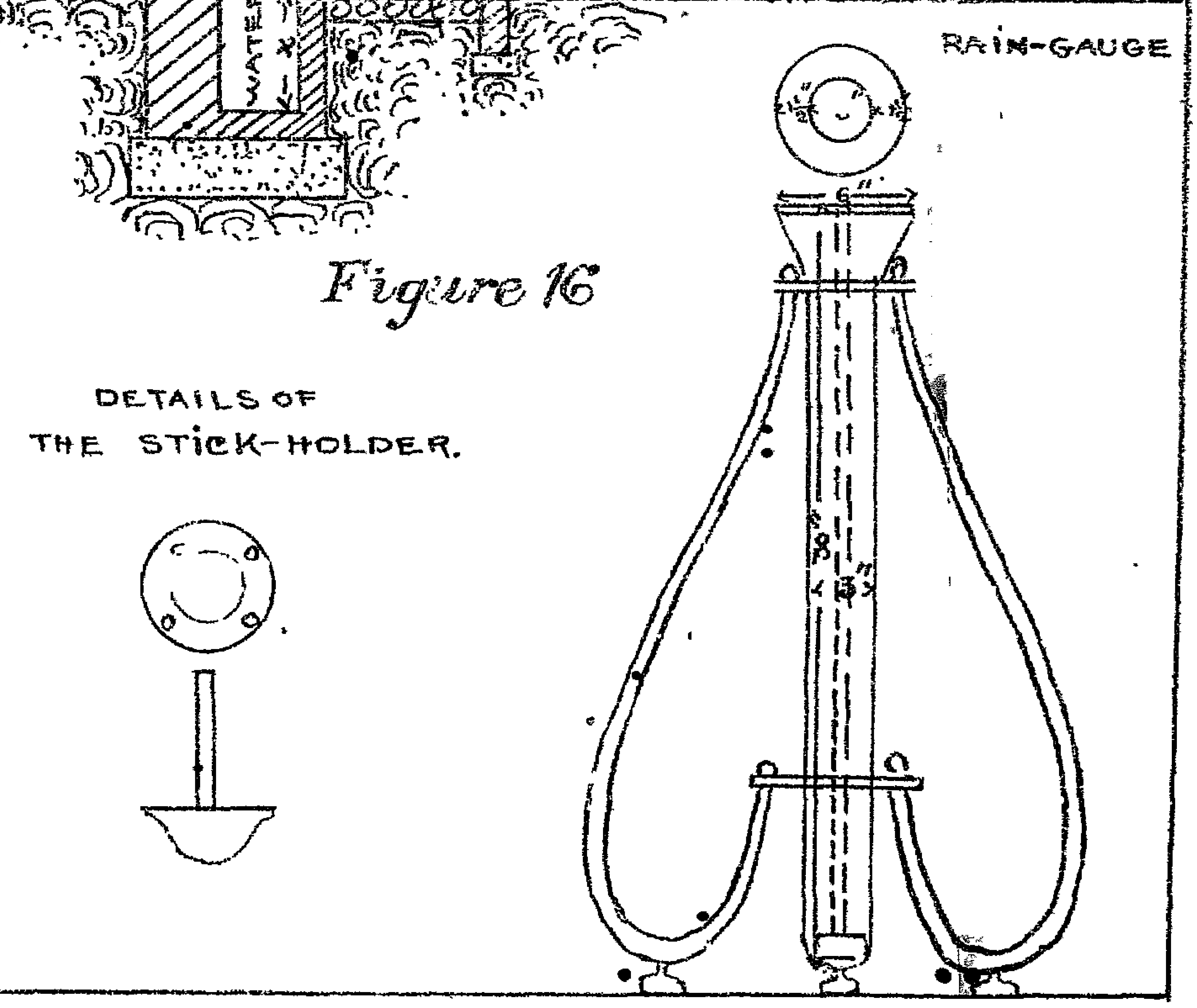


PLATE 4

Figure 17

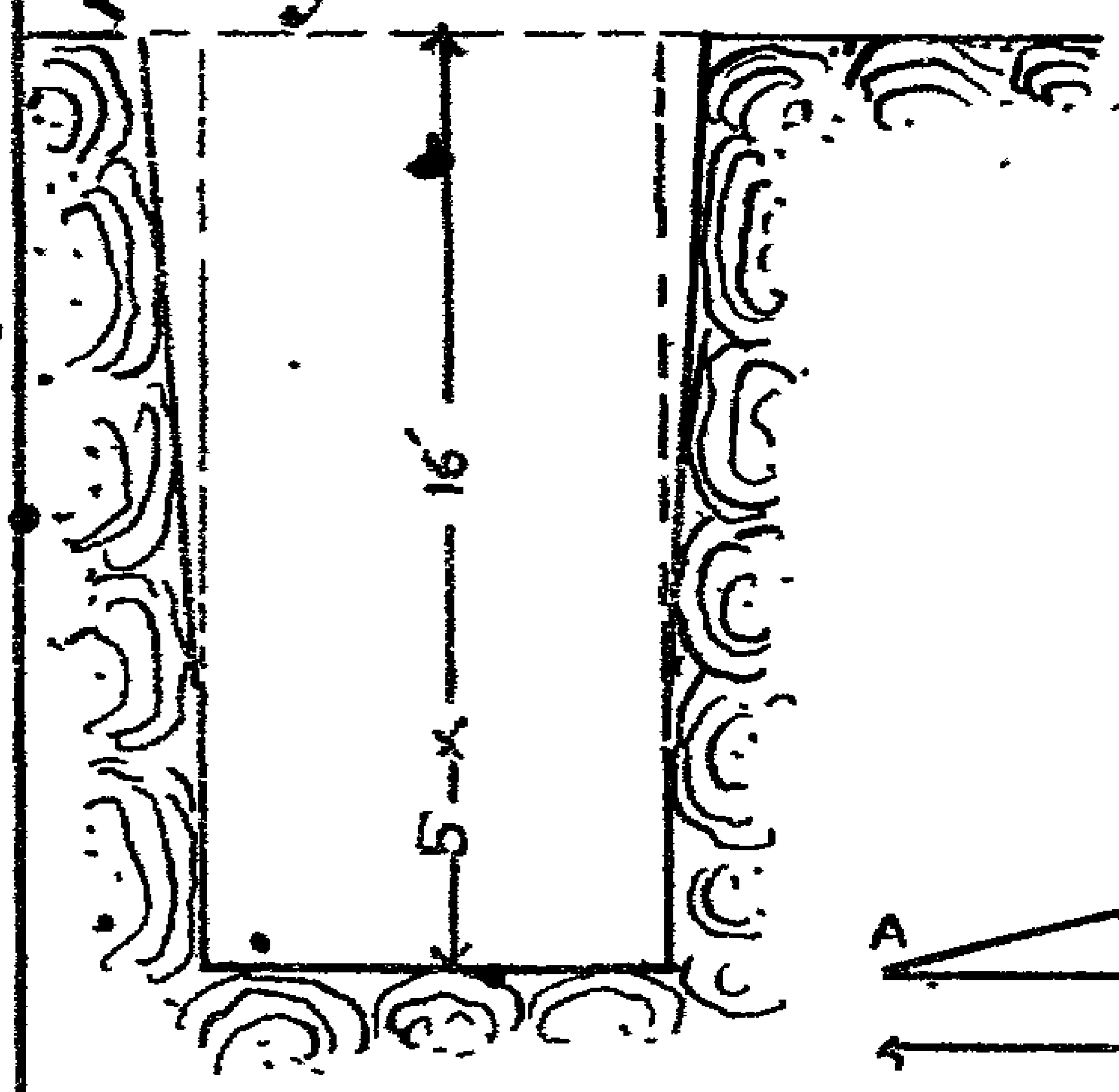


Figure 18

SCALE 20'=1"

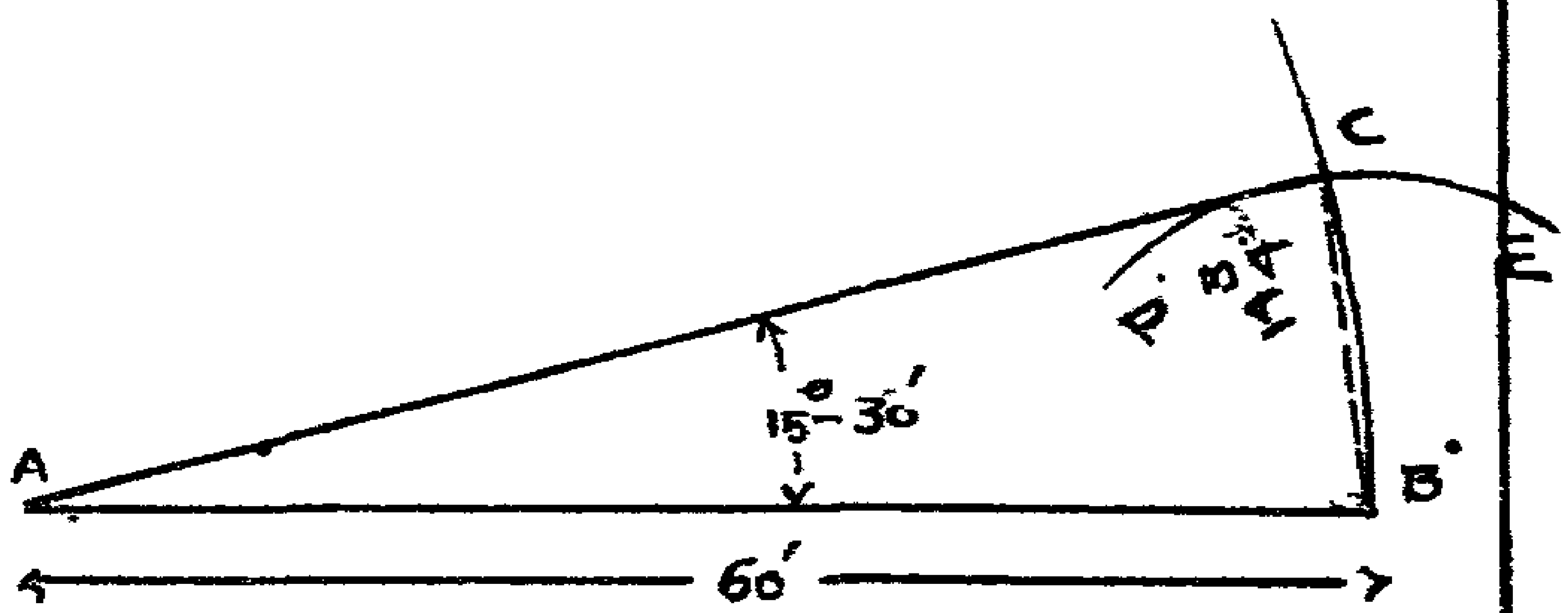


Figure 19

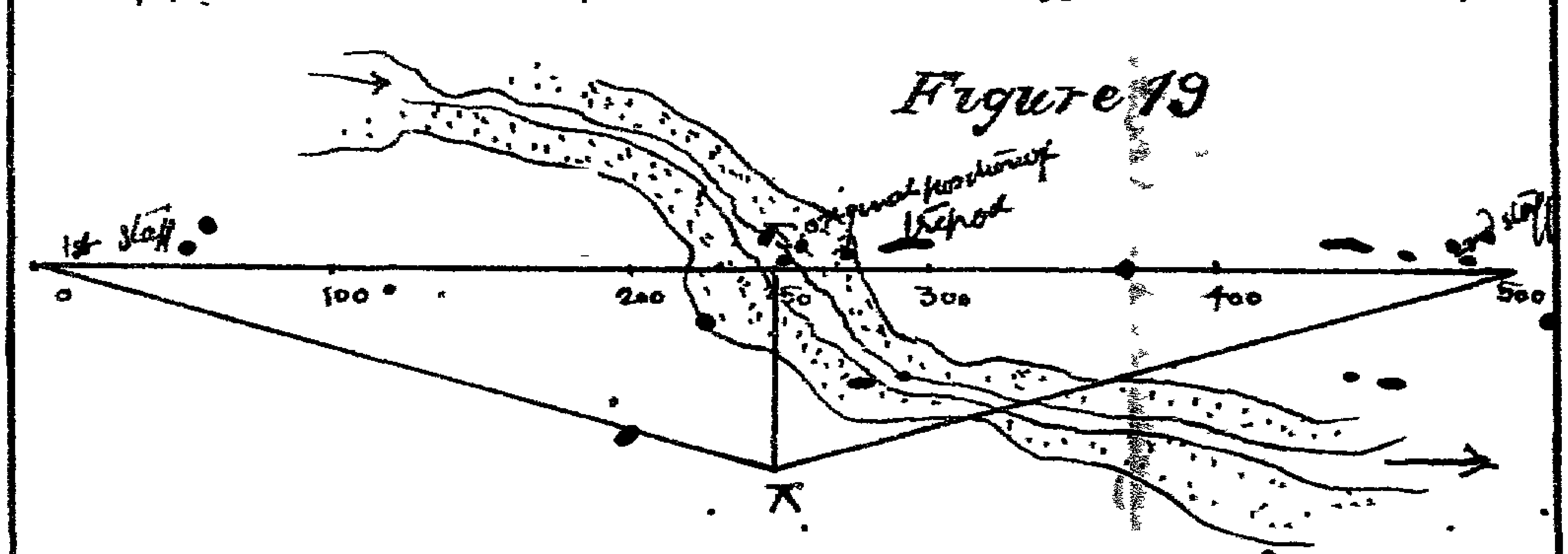


Figure 20

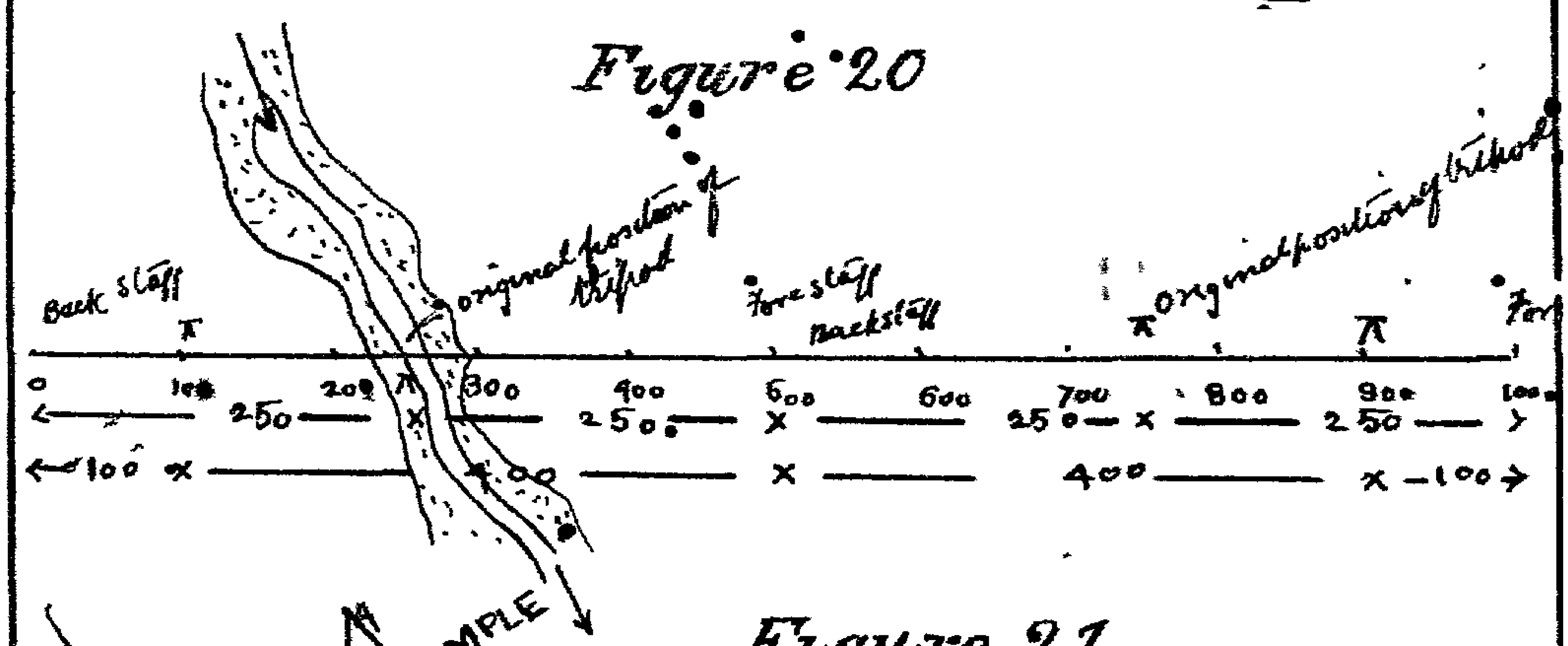


Figure 21

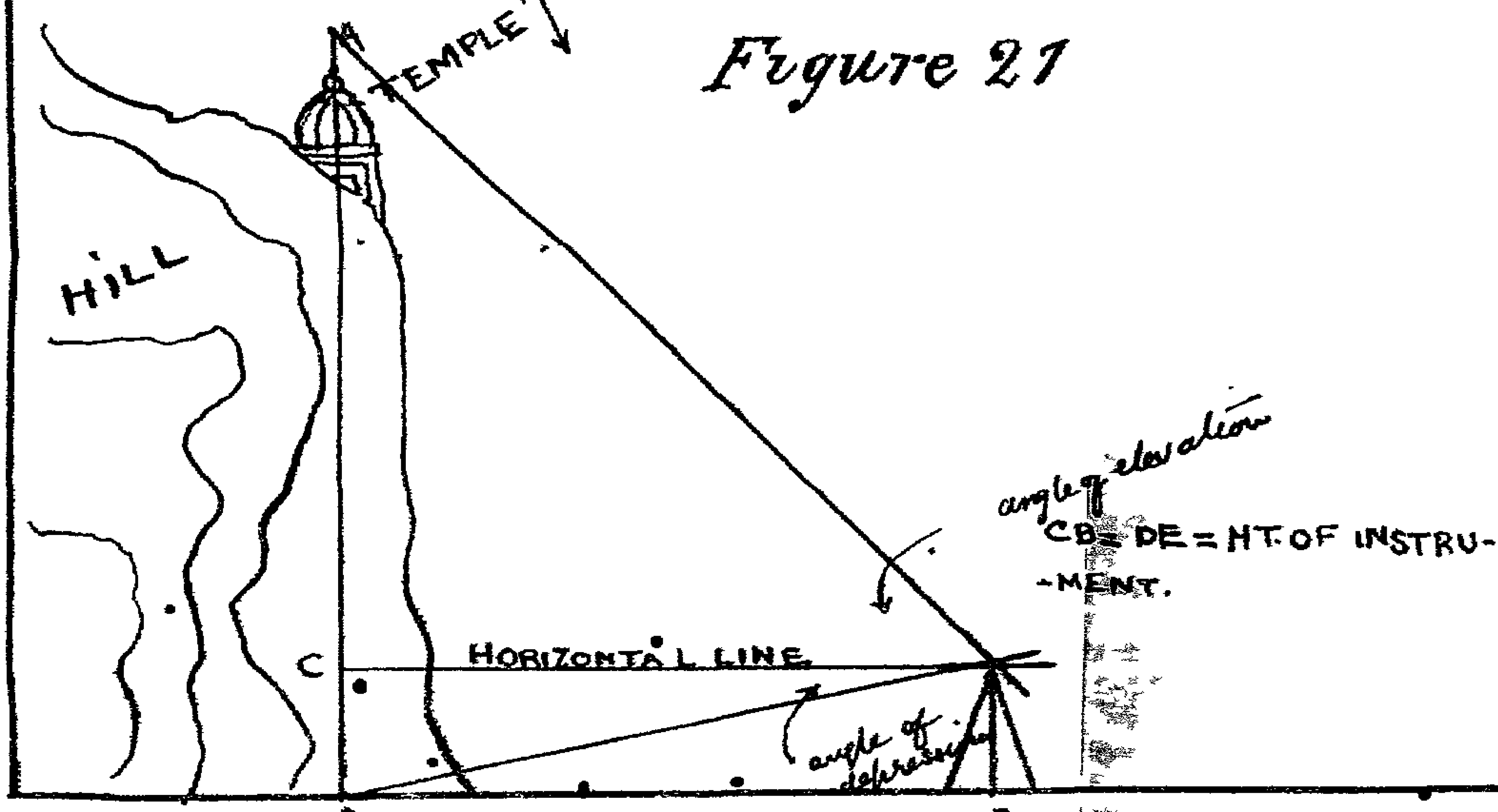


PLATE 5

Figure 22

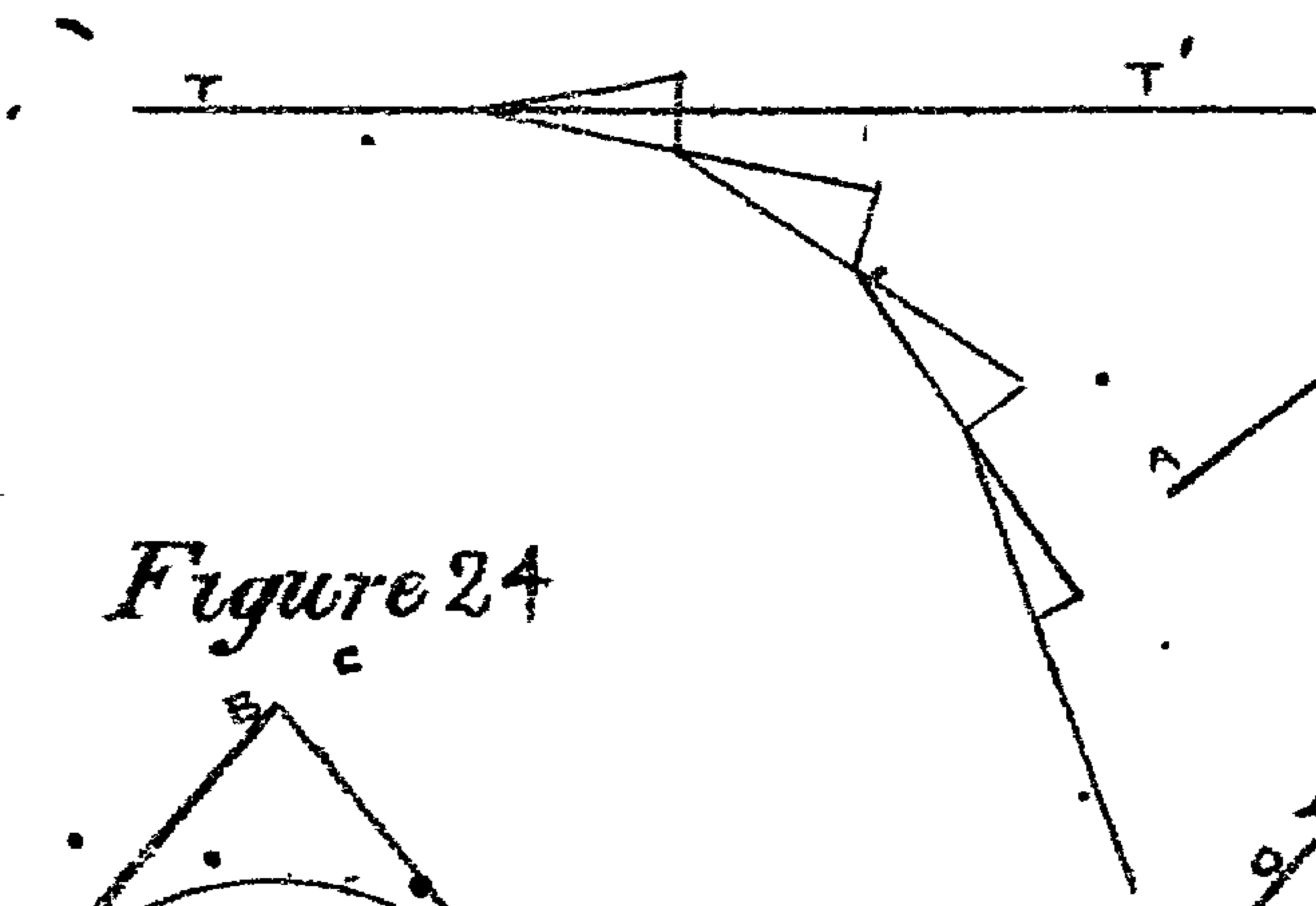


Figure 23

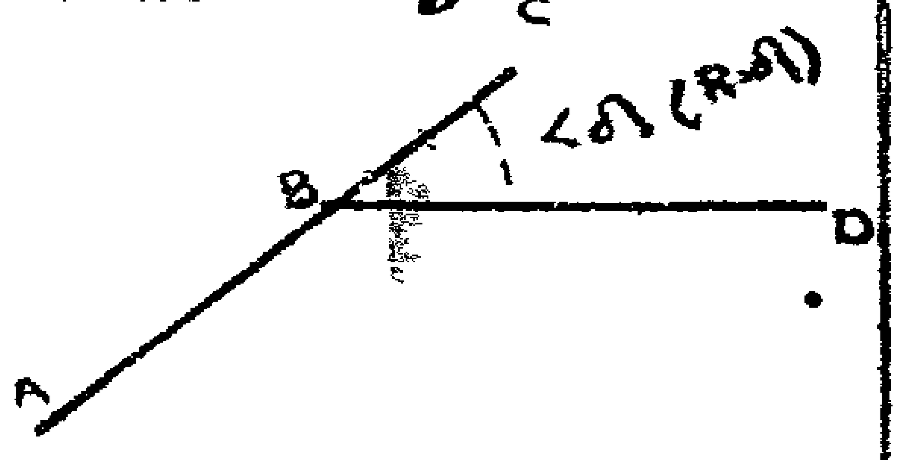
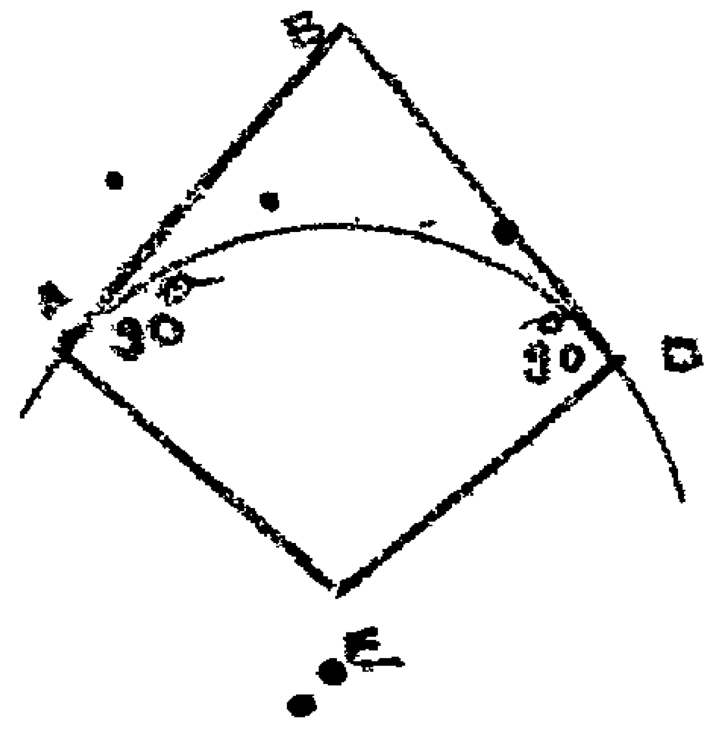
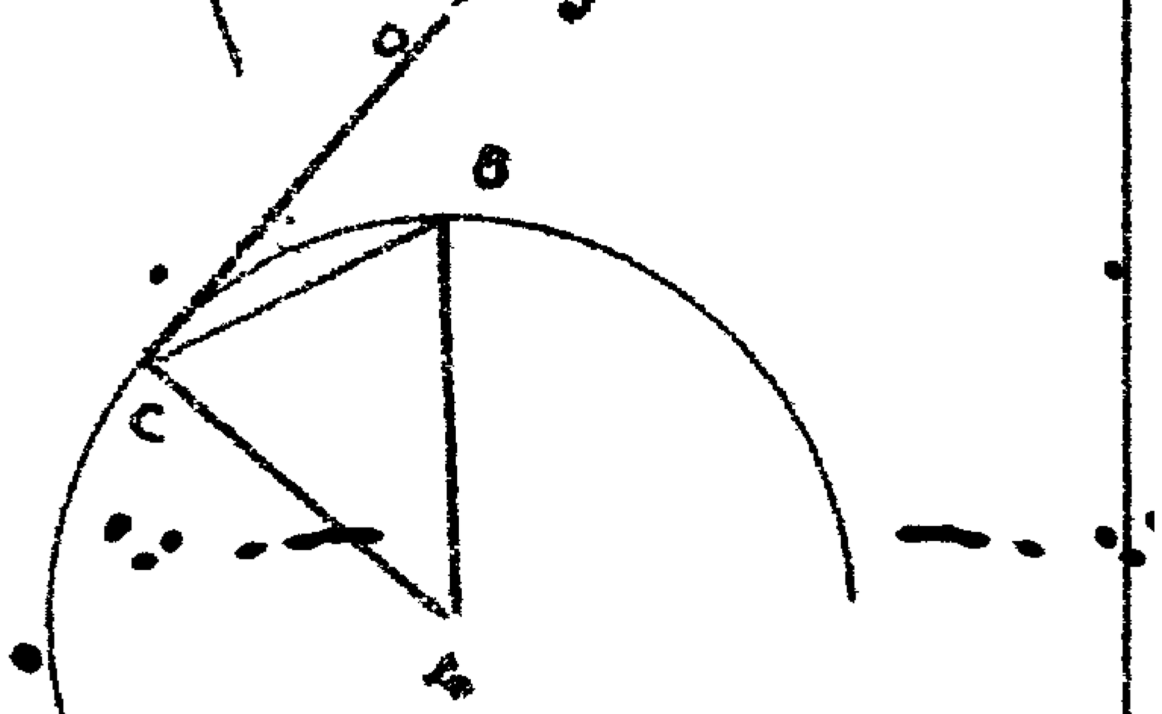


Figure 24



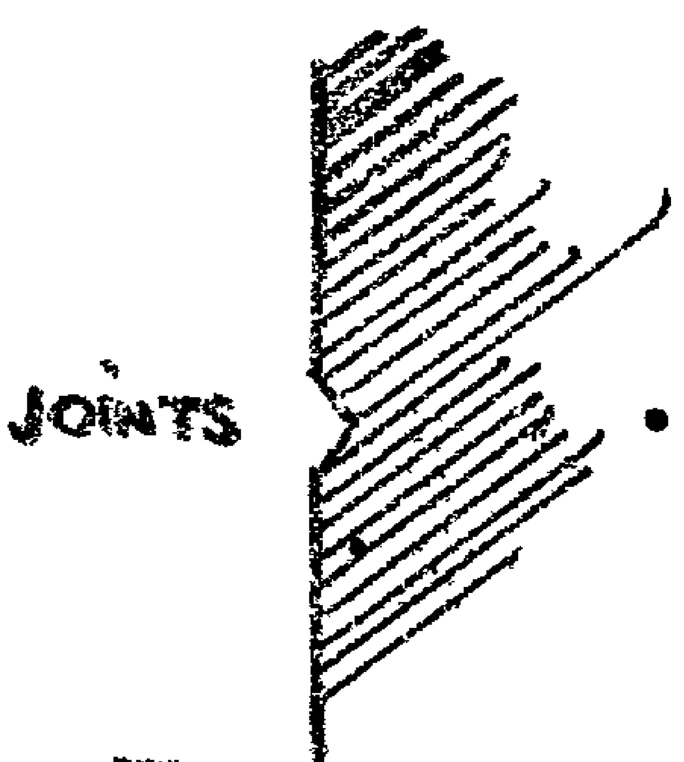
∠CBD = ∠AED

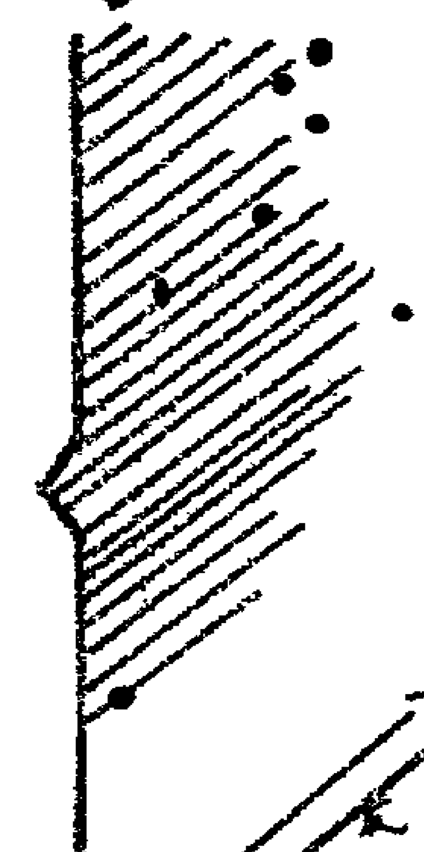
Figure 25



TANGENTIAL ∠ DCB = ½ ∠ OF CURVATURE CAB (BY I·5 & I·32 EUCLID)

Figure 26 *Figure 27.* *Figure 28.*





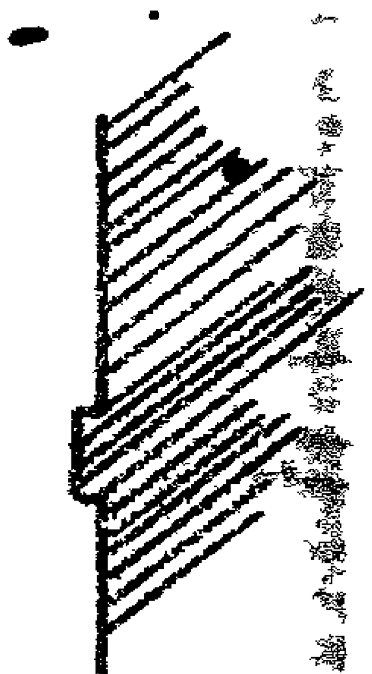
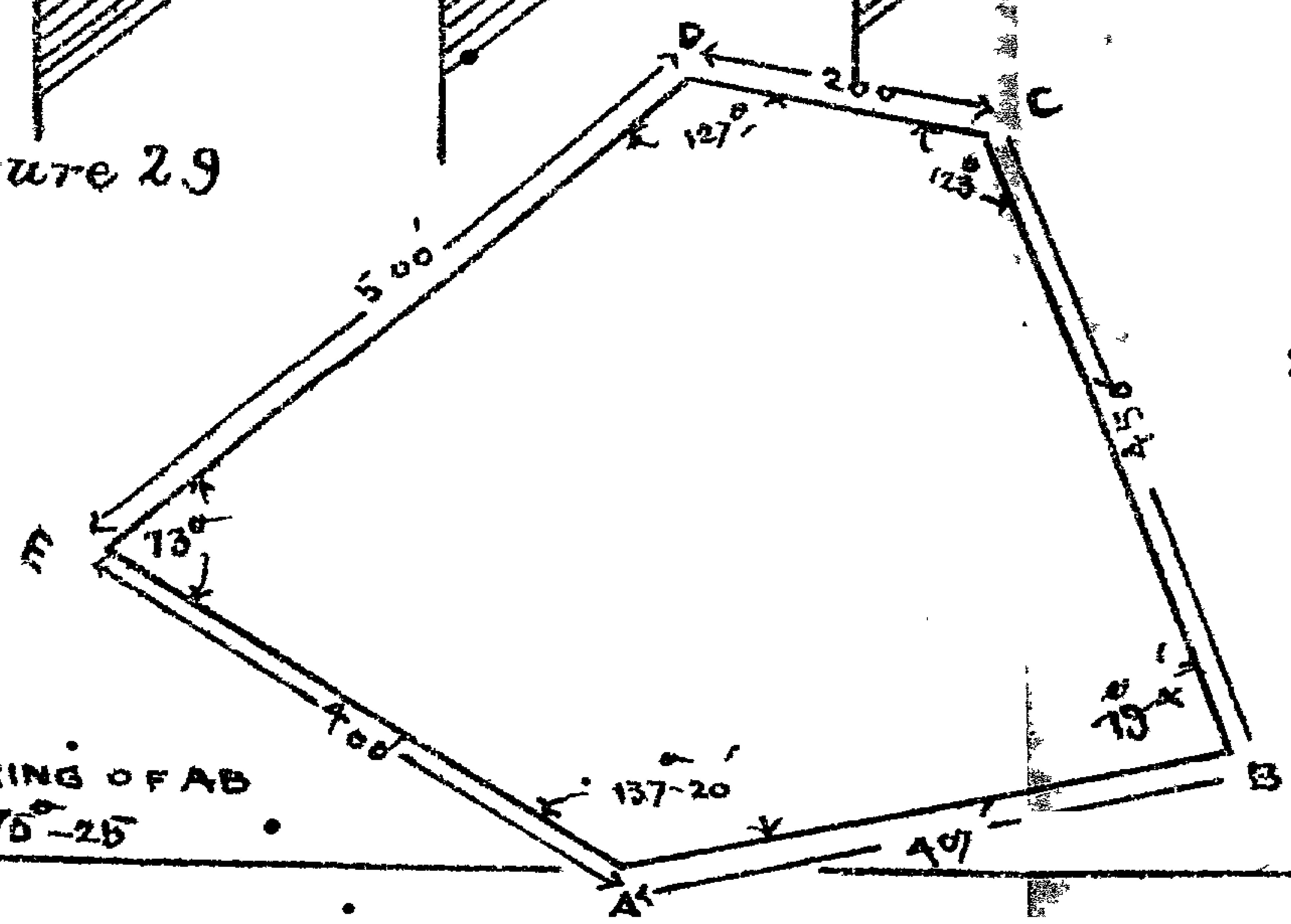


Figure 29



F. BEARING OF AB = 75°–25'

PLATE 6

Figure 30

VERNIER SHOWING UPTO 20"

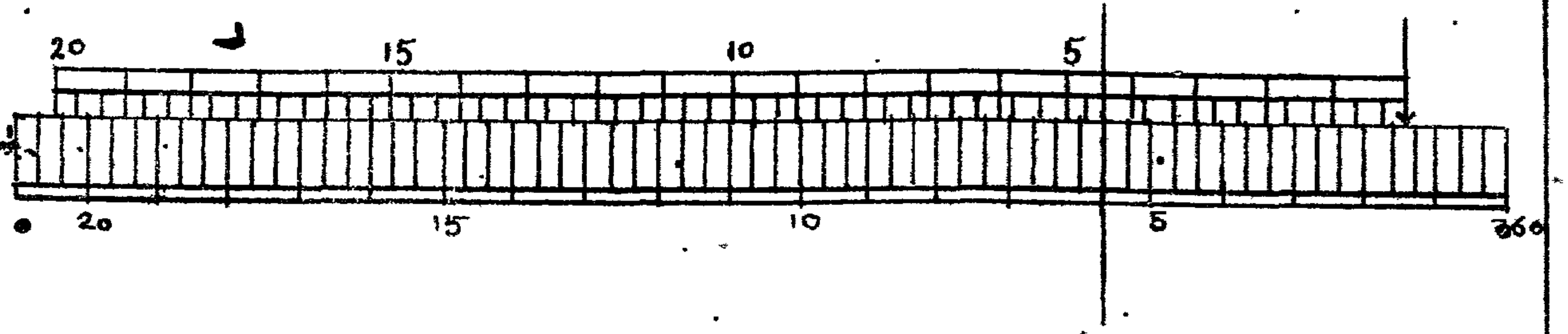
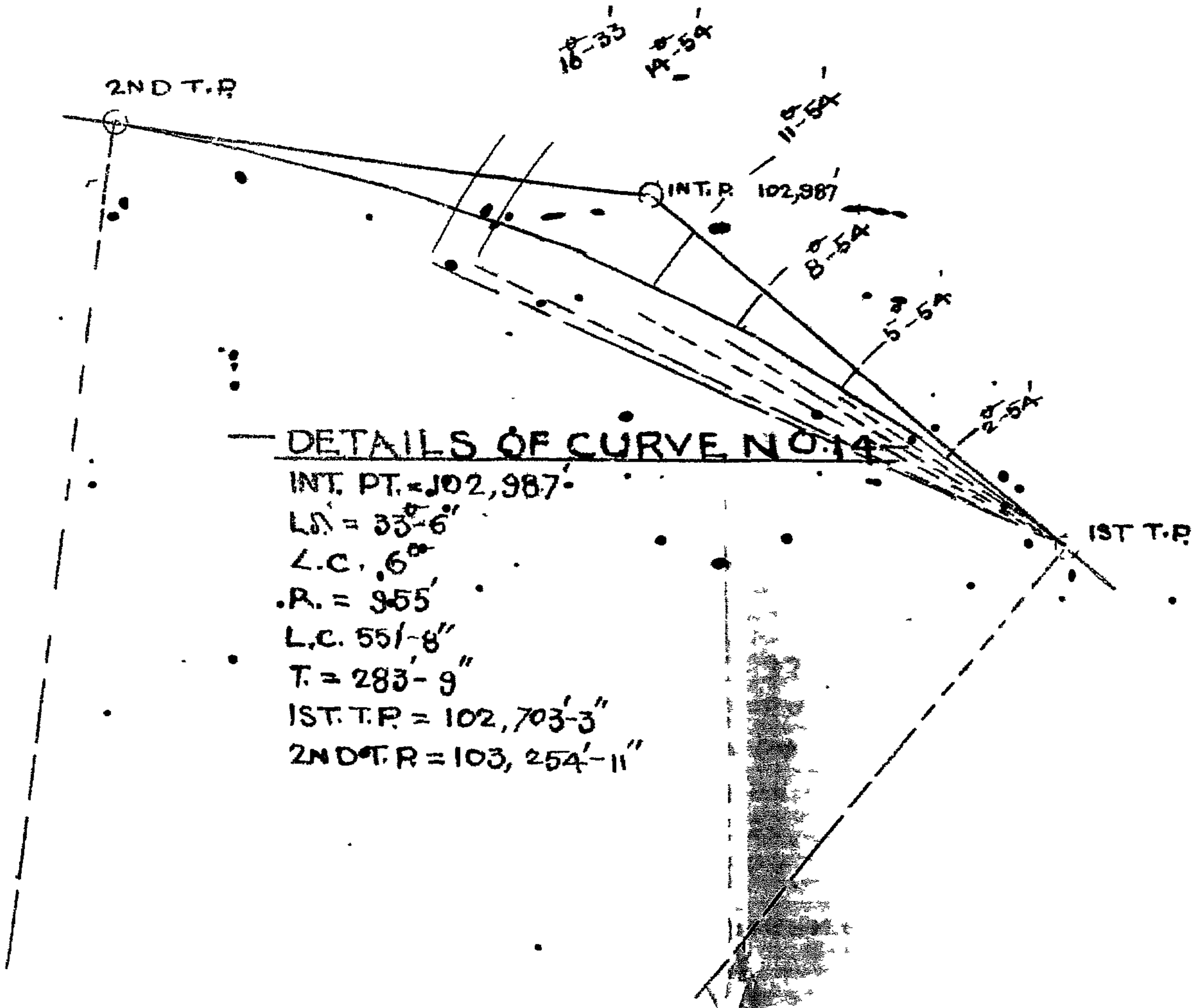


Figure 31



CHORD LENGTHS	TANGENTIAL ANGLES.
96'-9"	2°-54'
100'-0"	5°-54'
100'-0"	8°-54
100'-0"	11°-54
100'-0"	14°-54'
54'-11	16°-33
TOTAL 551'-8"	

PLAN

Figure 32.

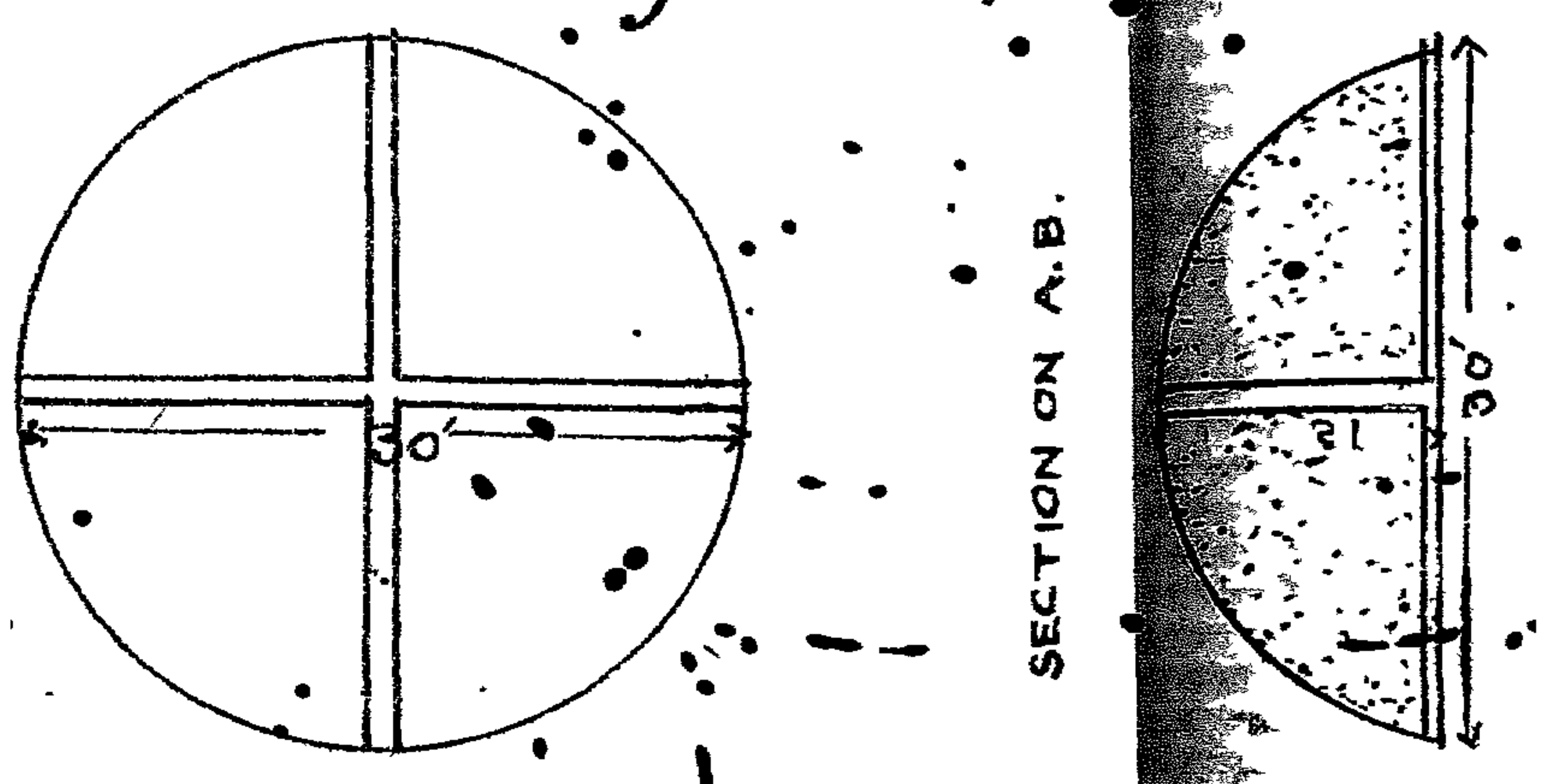


PLATE 7

Figure 33

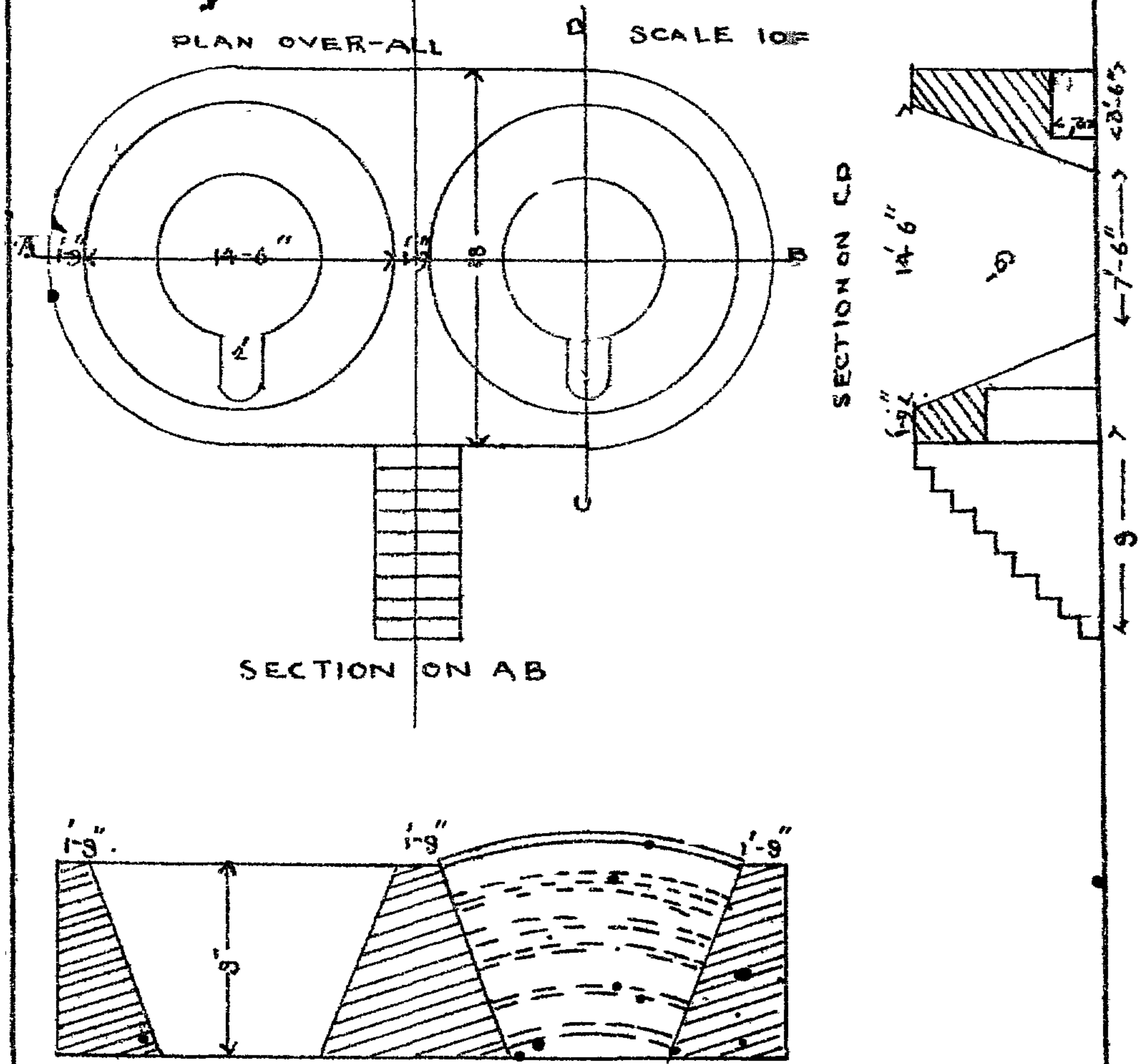


Figure 34

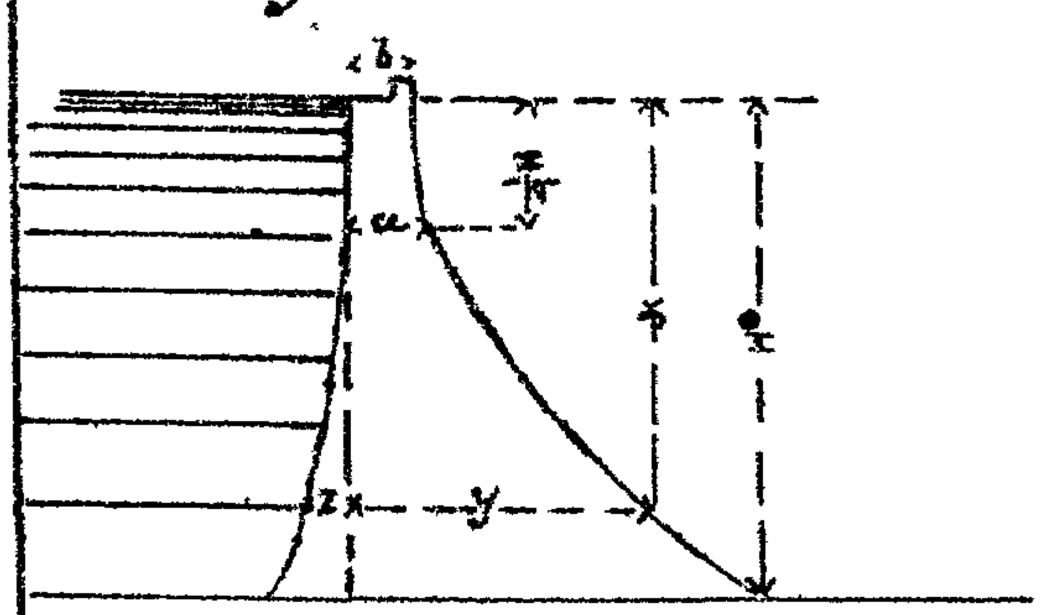


Figure 35

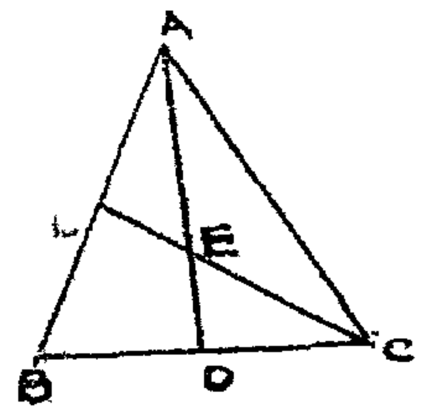


Figure 36

Figure 37

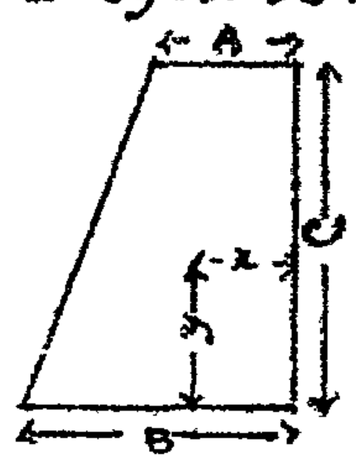


Figure 38

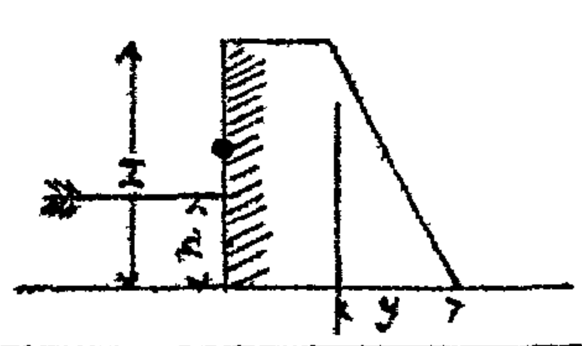


Figure 39

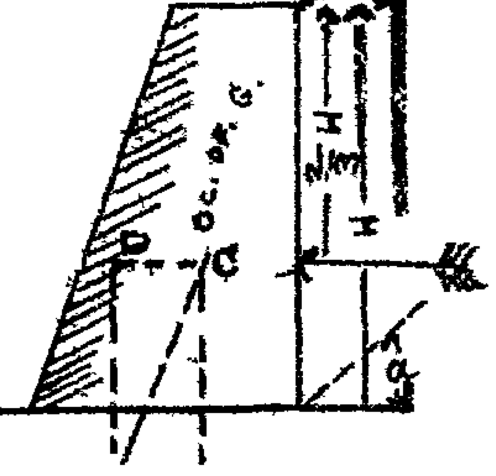


PLATE 8

Figure 41

Figure 40

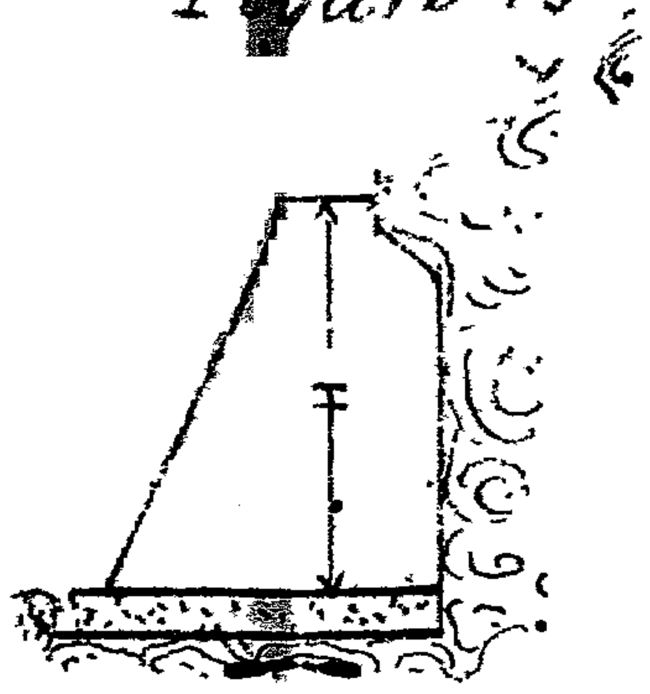
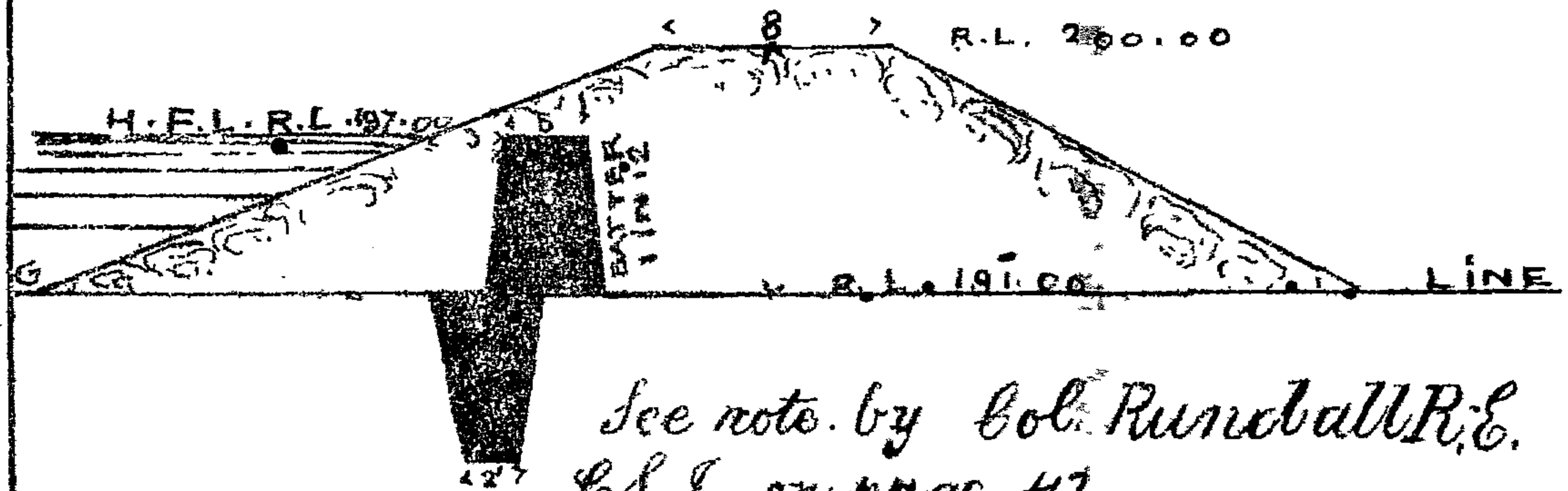


Figure 42



See note by Col. Rundall R.E. C.S.I. on page 42

Figure 43

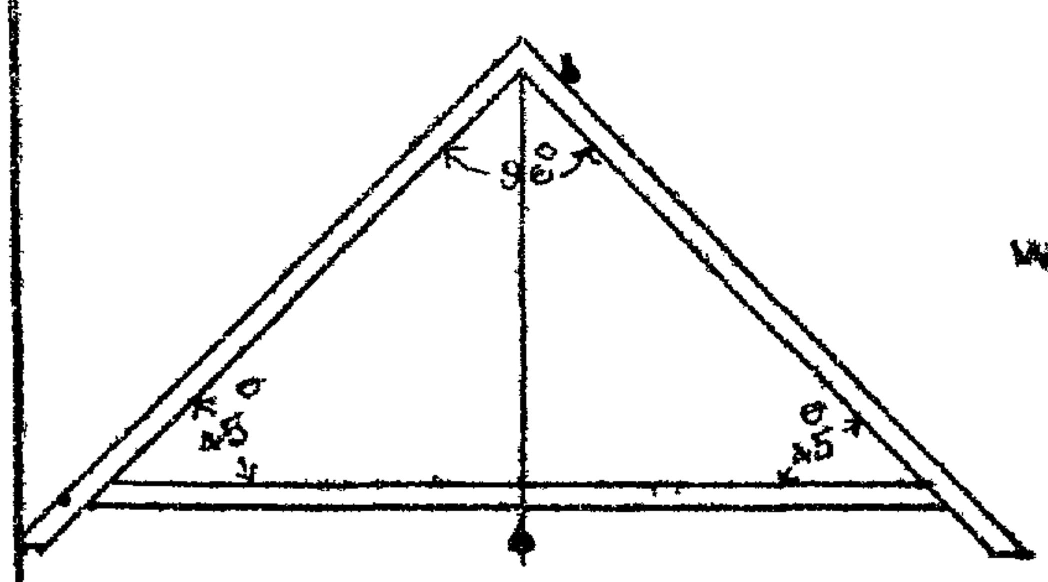


Figure 44

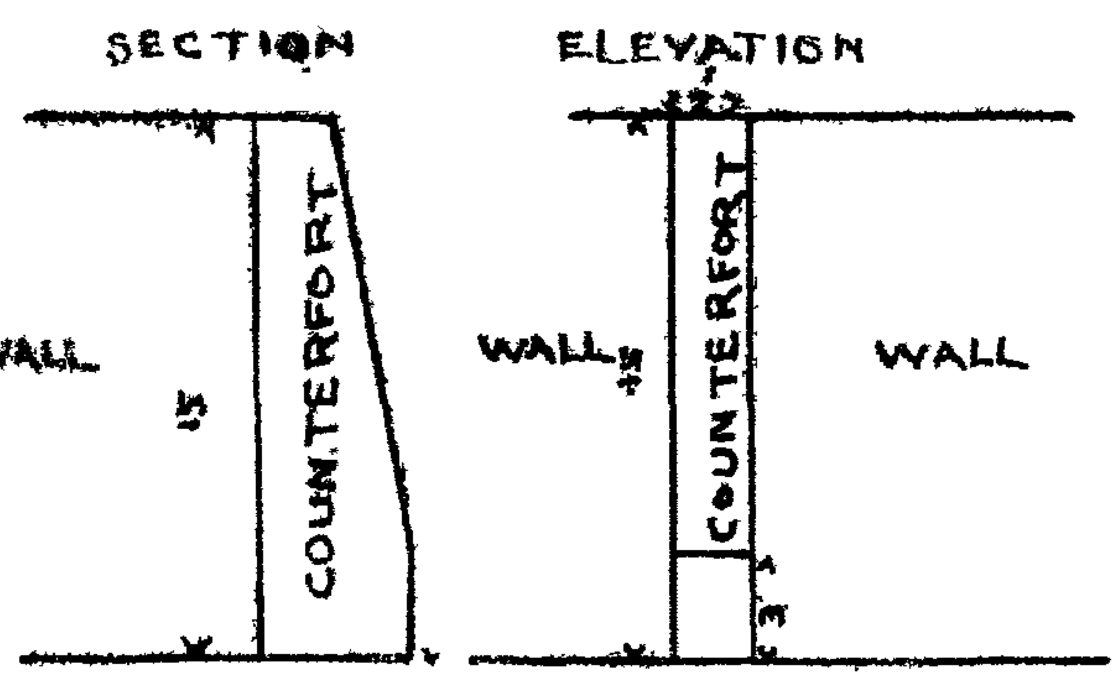


Figure 45

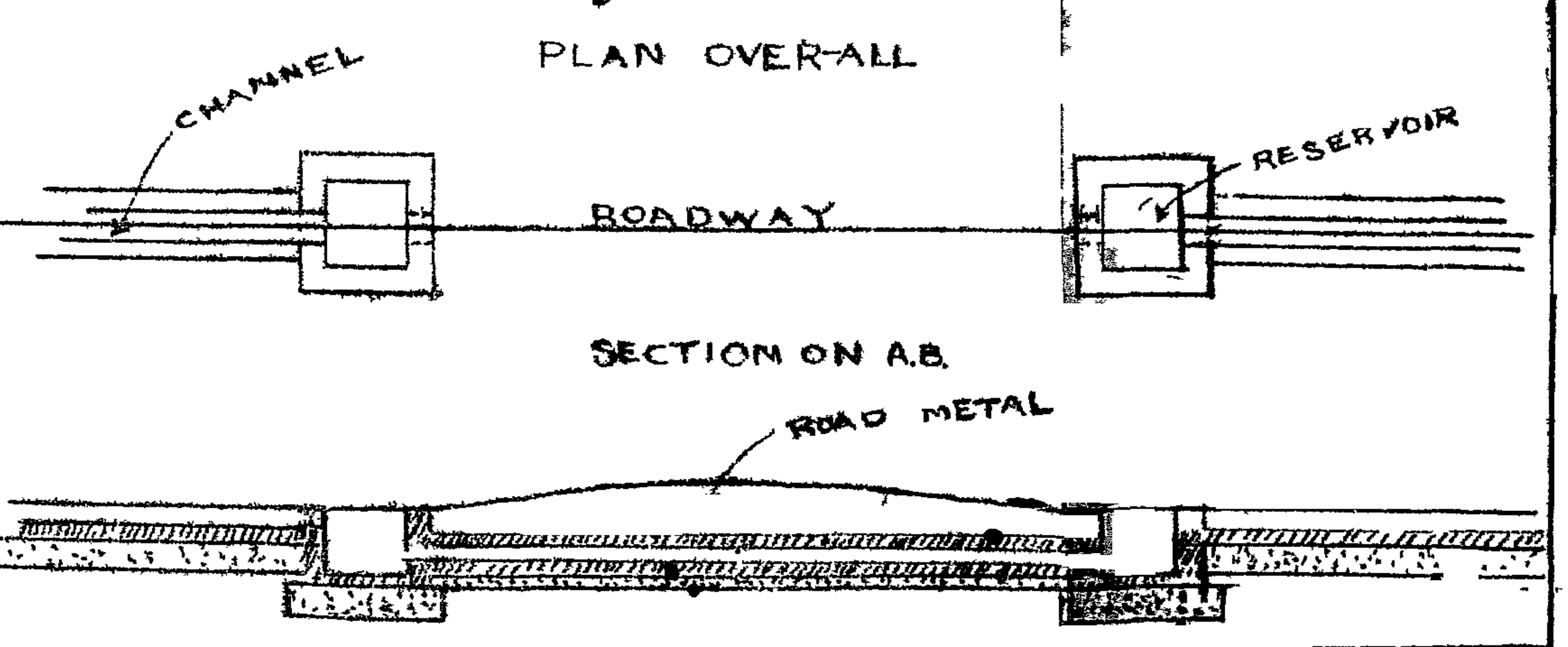


PLATE 9

Figure 9

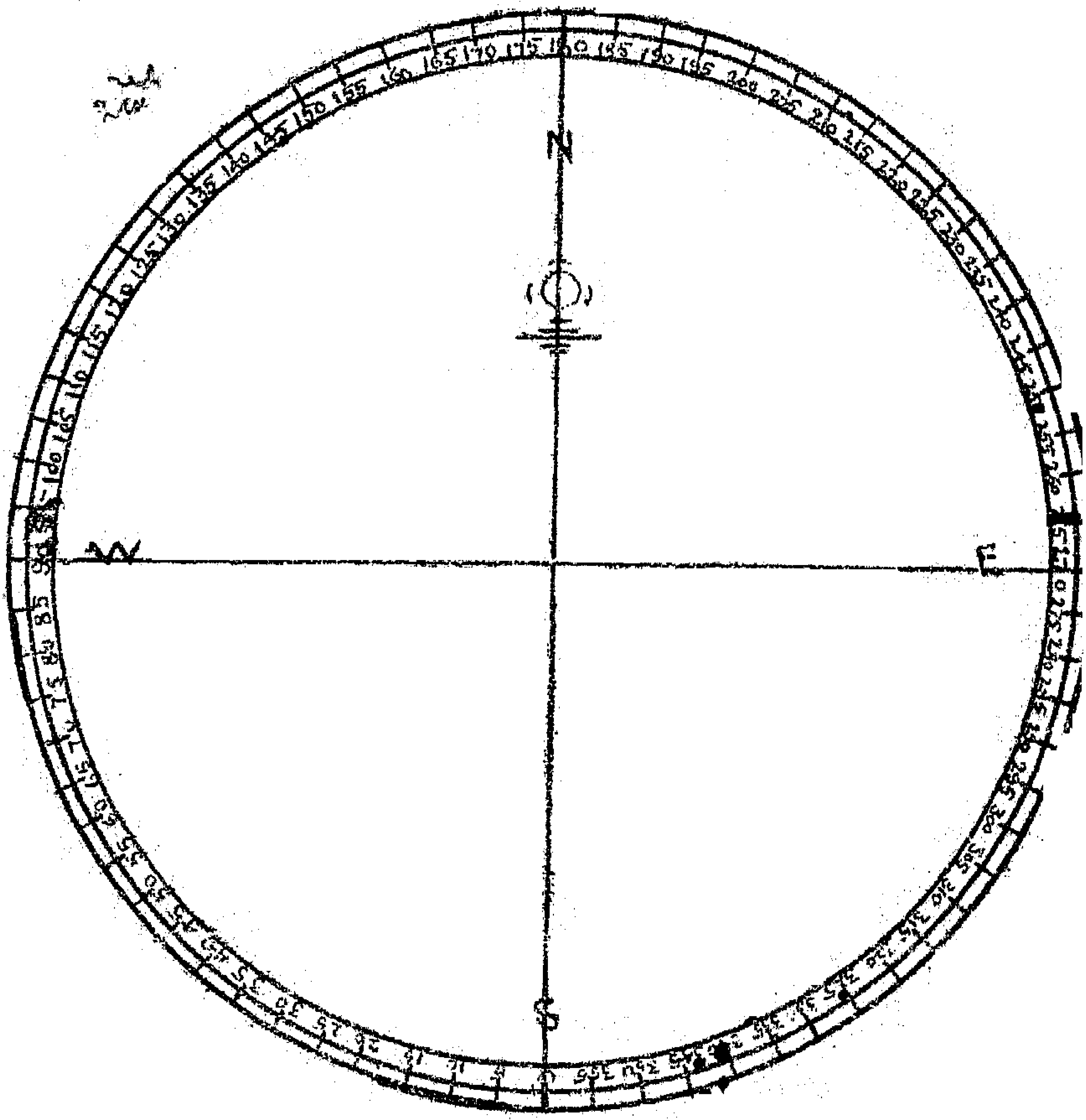
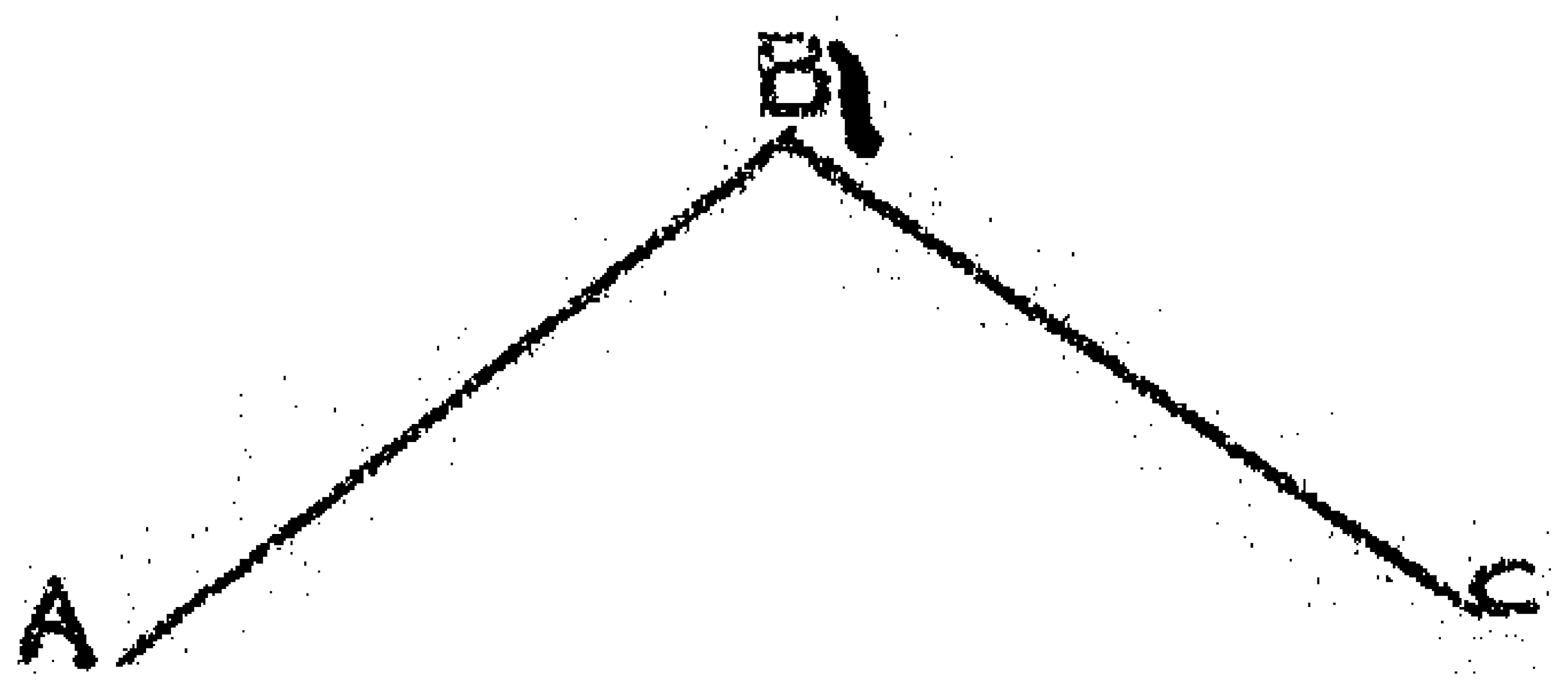


Figure 47



No. 1

Table of Discharges from given Catchment Areas,
(Calculations correct to two places of decimals)

Catchment area in sq. miles	Flat country, sandy soil, cultivated ground	Meadows, gentle declivity, absorbent ground	Wooded hill slopes, compact or stiffy ground	Mountains, rocky or un-absorbent surfaces	Naked unfissured mountains, v. steep ground or paved streets	REMARKS.
	(·25+·35)÷2=·3	(·35+·45)÷2=·4	(·45+·55)÷2=·5	(·55+·65)÷2=·6	·8	
1	387	516	645	774	1033	FORMULA BY
2	650	867	1084	1300	1734	GEO. CHAMIER. M.I.C.E.
3	879	1172	1465	1758	2344	
4	1092	1456	1820	2184	2912	$Q = A \times R \times C \times \frac{M^{\frac{3}{4}}}{M}$
5	1293	1724	2155	2586	3448	WHERE,
6	1483	1977	2471	2966	3954	Q = DISCHARGE
7	1664	2220	2775	3328	4446	IN CUSECS.
8	1838	2452	3065	3676	4904	A & M =
9	2010	2680	3349	4020	5360	CATCHMENT
10	2176	2902	3627	4352	5804	AREA IN
11	2381	3175	3969	4762	6350	SQU. MILES.
12	2494	3325	4156	4988	6650	R = AVERAGE
13	2648	3531	4414	5296	7062	RAINFALL
14	2800	3733	4666	5600	7466	IN INCHES
15	2950	3934	4917	5900	7868	PER HOUR
16	3097	4130	5162	6194	8260	C = COEFICIENT
17	3240	4321	5400	6480	8642	OF SURFACE
18	3380	4507	5633	6760	9014	DISCHARGE
19	3523	4698	5872	7046	9396	$\frac{M^{\frac{3}{4}}}{M}$ = FACTOR
20	3659	4879	6098	7318	9758	
21	3794	5060	6324	7588	10123	OF DIMINU-
22	3930	5240	6550	7860	10480	TION DUE TO
23	4066	5421	6776	8132	10842	AREA.
24	4137	5597	6995	8394	11194	
25	4328	5772	7213	8656	11544	
26	4456	5943	7427	8912	11886	
27	4584	6113	7640	9168	12226	
28	4712	6283	7853	9424	12566	
29	4836	6449	8060	9672	12898	
30	4960	6614	8266	9920	13228	

No. 2

Table of Waste Weir lengths for given Dis-charges, in Flat country, Sandy soil or cultivated ground.

Catchment Area (S.M.)	Discharge in Cusecs	Head 1 Foot	Head 2 Feet	Head 3 Feet	Head 4 Feet	Head 5 Feet	Head 6 Feet
		Lengths of W. Weirs for the following Heads					
1	387	111	39	21	14	10	8.
2	650	186	66	36	23	17	13
3	879.	251	89	48	31	22	17
4	1092	312	110	60	39	28	21
5	1293	369	130	71	46	33	25
6	1483	424	150	81	53	38	29
7	1664	475	168	91	59	42	32
8	1838	525	185	101	65	47	36
9	2010	574	203	110	72	51	39
10	2176	622	219	119	77	55	42
11	2381	680	240	131	85	61	46
12	2494	713	252	137	89	63	48
13	2648	757	267	143	94	67	51
14	2800	800	282	153	100	71	54
15	2950	843	298	162	105	75	57
16	3097	885	312	170	110	79	60
17	3240	926	327	178	115	82	63
18	3380	966	341	185	120	86	66
19	3523	1007	355	193	126	90	68
20	3659	1045	369	201	131	93	71
21	3794	1084	383	208	135	96	74
22	3930	1123	296	216	140	100	76
23	4066	1162	410	223	145	103	79
24	4157	1199	423	230	150	106	82
25	4328	1237	437	237	154	110	84
26	4456	1273	44[illegible]	244	159	113	87
27	4584	1310	462	251	163	117	89
28	4712	1346	475	258	168	120	92
29	4836	1382	488	265	173	123	94
30	4960	1417	500	272	177	126	96

FORMULA :— $L = \frac{\text{DISCHARGE}}{\sqrt{H^3} \times 3.5}$ (CLEAR OVERFALL

No: 3

Table of waste weir lengths for given discharges in meadows gentle declivity or absorbent ground.

CATCHMENT AREA IN SQ. MILES	DISCHARGE IN CUSECS	LENGTHS OF WASTE WEIRS FOR THE FOLLOWING HEADS					
		HEAD 1 FOOT	HEAD 2 FEET	HEAD 3 FEET	HEAD 4 FEET	HEAD 5 FEET	HEAD 6 FEET
1	516	147	52	28	18	13	10
2	867	248	88	48	31	23	17
3	1172	335	118	64	41	29	23
4	1456	416	146	80	52	37	28
5	1724	493	173	95	61	44	33
6	1977	565	200	108	71	51	38
7	2220	634	224	121	78	56	43
8	2452	700	247	135	87	63	48
9	2680	766	271	147	96	68	52
10	2902	829	292	158	103	73	56
11	3175	907	320	175	113	81	61
12	3325	950	336	183	118	84	64
13	3531	1009	366	193	125	[illegible]	68
14	3733	1067	376	204	133	95	72
15	3934	1124	397	216	140	100	76
16	4130	1180	416	227	147	105	80
17	4321	1234	[illegible]	237	153	109	84
18	4507	1288	453	217	160	115	[illegible]
19	4698	1342	473	251	168	120	[illegible]
20	4879	1394	492	263	175	124	96
21	5060	1445	511	277	180	128	99
22	5240	1497	528	288	187	133	101
23	5421	1549	544	297	193	137	105
24	5597	[illegible]	564	307	200	141	109
25	5772	1649	[illegible]	316	205	146	112
26	5943	1697	599	325	212	150	116
27	6113	1746	616	335	217	156	119
28	6283	1795	633	344	224	160	123
29	6449	1842	650	353	230	164	125
30	6614	1889	667	363	266	168	128

FORMULA:— $L = \frac{\text{DISCHARGE}}{\sqrt{H^3} \times 3.5}$ (CLEAR OVERFA