HOUSING IN DISASTER PRONE AREAS

Report of the Development Group

GOVERNMENT OF INDIA
NATIONAL BUILDINGS ORGANISATION
AND
U.N. REGIONAL HOUSING CENTRE ESCAP
NIRMAN BHAWAN NEW DELHI

IYSH-87 : INTERNATIONAL YEAR OF SHELTER FOR THE HOMELESS

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CHAPTER 1

INTRODUCTION

Natural disasters such as floods, cyclones, earthquakes cause large scale destruction to houses year after year in different parts of our country. Floods pose serious problems in thickly populated states like Uttar Pradesh, Assam, Bihar and West Bengal. The coastal districts of Andhra Pradesh, Tamil Nadu etc., are susceptible to cyclones and storms. More than 55 prcent of India's land area particularly in the north-eastern region falls in the seismic zone of moderate to severe intensity. The entire Himalayan Range from Kashmir to Assam, Indo-Gangetic plains and Kutch and Kathiawad regions are earthquake prone. Other forms of natural disasters which sometimes occur in northern India include avalanches in the snow bound Himalayan regions and landslides in the North-Eastern region.

The problem of disaster mitigation/relief is of stupendous magnitude and involves coordination of a large number of agencies concerned with different aspects. In a vast country like India, with its widely varying geographical features, types of population, etc., housing in disaster prone areas has to take due account of the terrain, availability of building materials, appropriate construction techniques, resources and skills available, etc.

The attention of the Planning Commission has been drawn o the problem of housing and land use in disaster prone areas. It has been observed that there is a need for evolving guidelines for ensuring proper land use in disaster prone areas to minimise the damage and destruction and for evolving designs of low cost houses which are better resistant to the effects of natural calamities. The working Group on Flood/Cylone Management set up by the Planning Commission under the aegis of the Ministry of Agriculture and Rural Development in connection with formulation of 7th Five Year Plan had suggested that suitable designs for structures built in vulnerable areas particularly the coastal regions and cyclone shelters be developed. In pursuance of this recommendation, the Ministry of Urban Development (the then Ministry of Works and Housing) set up a Development Group (Task-Force) on Housing in Disaster Prone Areas, vide their Order No. O-14016/1/64/H.II, dated 4th June, 1985 to go into various aspects of the problem and make suitable recommendations in the matter. (*See Appendix*)

The Development Group had the following composition :

CHAIRMAN

1. Director,
   National Buildings Organisation,
   New Delhi.

MEMBERS

2. Director,
   Central Building Research Institute,
   Roorkee.
3. Head of the Deptt. of Earthquake Engineering,
   University of Roorkee,
   Roorkee.
4. Director,
   Structural Engineering Research Centre,
   Roorkee.
5. Chief Planner,
   Town & Country Planning Organisation,
   New Delhi.
6. Prof. H. P. Bahri,
   Head of Department of Housing,
   School of Planning & Architecture,
   New Delhi.
7. Dr. D. K. Rakshit,
   Director,
   Department of Science & Technology
   New Delhi.
8. Chief (Projects),
   Housing & Urban Development Corporation,
   New Delhi.
9. Chief Engineer,
   U.P. Public Works Department,
   Lucknow.
10. Chief Engineer,
   Andhra Pradesh Public Works Department,
   Hyderabad.
1. Chief Engineer,
   Tamil Nadu Housing Board,
   Madras.
2. Shri A. K. Karim,
   Secretary,
   North-Eastern Council,
   Shillong, Meghalaya.

MEMBER-SECRETARY

13. K. S. Srinivasan,
   Joint Director (Designs),
   National Buildings Organisation,
   New Delhi.

The Development Group could also co-opt a maximum of 3 specialists at a time for assisting in the deliberations. The terms of reference of the Group were to :—

(i) study and analyse type of damage and destruction caused to houses and small buildings due to natural disasters and review the technical measures including construction techniques, methods and designs evolved by Research Institutes for putting up houses and small buildings that are more resistant to natural disasters and to indicate areas of further research.

(ii) identify and suggest appropriate construction techniques, designs, building codes, methods, etc., to build new houses that are more resistant to natural disasters and to strengthen existing houses and small buildings that are considered deficient in this regard.

(iii) formulate guidelines for siting and relocation of houses with a view to framing suitable building regulations in areas prone to natural disasters.

(iv) suggest specific areas for research and development work for housing in disaster prone areas.

The Development Group was required to complete its work and submit its report by 30th July, 1986. The Group held 5 meetings in Delhi and one at Roorkee. The following specialists were co-opted at the first meeting of the Group :—

1. Dr. Prem Krishna,
Professor & Head,
Department of Civil Engineering,
University of Roorkee,
Roorkee.

2. Shri B. Venkateshwarlu,
Assistant Director,
Structural Engineering Research Centre,
Madras.

At the first meeting held on 12th July, 1985 the Group reviewed the terms of reference and made a few modifications. The revised terms of reference were to :—

(i) study and analyse type of damage and destruction caused to houses and small buildings due to natural disasters and review the technical measures including cost-effective construction techniques, methods and designs evolved by Research Institutes for putting up houses and small buildings that are more resistant to natural disasters and to indicate areas of further research.

(ii) identify and suggest appropriate construction techniques, designs, building codes, methods, planning procedure etc., to build new houses that are more resistant to natural disasters and to strengthen existing houses and small buildings that are considered deficient in this regard.

(iii) formulate guidelines for siting and relocation of houses with a view to framing suitable building regulations in areas prone to natural disasters.

(iv) suggest specific areas for research and development work for housing in disaster prone areas.

(v) evolve strategy for implementation of technology for housing in disaster prone areas including transfer of technology, dissemination of technical information, training etc.

At the third meeting held in Roorkee on 19th November, 1985, Dr. Jai Krishna, former Vice-Chancellor, University of Roorkee was invited to give his expert advice in regard to earthquake disaster mitigation. The meeting was also attended by the concerned scientists of CBRI.

Other experts who attended the meetings of the Development Group were—Shri K. D. Bali, Additional Secretary, Ministry of Urban Development; Shri Mahinder Raj, Consulting Engineer and Dr. Brijesh Chandra, Professor, Department of Earthquake Engineering, University of Roorkee.

While at Roorkee, Members of the Group went round the laboratories of the CBRI to obtain first-hand information of the work being done by the Institute, specifically regarding landslides and fire. Members were shown the prototypes of instant and emergency shelters developed by CBRI for providing relief to disaser affected people.

Members of the Group also visited sites of houses and other structures damaged by landslides in Mussoorie. The study being carried out by CBRI on the stability of Mussoorie bye-pass slope around Landhour market, was explained.

No. O-14016/1/84-H.II
Government of India
Ministry of Works & Housing
(Nirman Aur Awas Mantralaya)
New Delhi, dated the 4th June 1985

OFFICE MEMORANDUM

Subject :—Setting up of a Development Group (Task Force) on Housing in Disaster Prone Areas.

In pursuance of the recommendations made by the Working Group on Flood/Cylone Management set up by the Planning Commission in connection with the formulation of 7th Five Year Plan under the aegis of Ministry of Agriculture and Rural Development for suggesting suitable designs for structures that should be built in vulnerable areas particularly the coastal regions and developing designs for construction of cyclone shelters, it has been decided to set up a Development Group (Task Force) under the Chairmanship of Shri G. C. Mathur, Director, National Buildings Organisation to go into various aspects and make suitable recommendations in the matter. The members of the Group will be as follows :—

Chairman

1. Director, NBO.

Members

2. Director, CBRI, Roorkee.
3. Head of Deptt. of Earthquake Engineering, University of Roorkee, Delhi.
4. Director, Structural Engineering Research Centre, Roorkee.
5. Shri J. L. Parasher, T.C.P.O. (Environment).
6. Prof. H. P. Bahari, Head of Deptt. of Housing, School of Planning & Architecture, New Delhi.
7. Dr. D. K. Rakshit, Director, Deptt. of Science & Technology, New Delhi.
8. Chief (Projects), HUDCO, New Delhi.
9. Chief Engineer, PWD, Lucknow, UP.
10. Chief Engineer, PWD, Andhra Pradesh.
11. Chief Engineer, Tamil Nadu Housing Board.
12. Shri A. K. Karim, Director (Housing), Govt. of Meghalaya, Shillong.
13. Joint Director (Designs), NBO.—Member-Secretary.

The Development Group would co-opt not more than three specialists at a time for assisting in the deliberations.

2. The Group will have the following broad terms of reference :—

(i) Study and analyse type of damage and destruction caused to houses and small buildings due to natural disaster and review the technical measures including construction techniques, methods and designs evolved by Research Institutes for putting up houses and small buildings that are more resistant to natural disaster and indicate areas of further research.

(ii) Identify and suggest appropriate construction techniques, designs, building codes, methods, etc., to build new houses that are more resistant to natural disasters and to strengthen existing houses and small buildings that are considered deficient in this regard.

(iii) Formulate guidelines for siting and relocation of houses with a view to framing suitable building regulations in areas prone to natural disasters.

(iv) Suggest specific areas for research and development work for housing in disaster prone areas.

3. The Development Group will be free to make such additions/modifications to these terms as may be found expedient during the course of its deliberations.

4. N.B.O. will meet all expenditure on the Development Group including TA & DA for members/Specialists and others, documentations, preparations of audio-visual materials, organising workshops etc., from the existing budget of NBO for 1985-86.

5. The Development Group will submit its report by 30th July, 1986 to the Ministry of Works & Housing. It will also keep the Ministry informed of the progress of work half-yearly.

Sd/-
(O. P. GUPTA)
Under Secretary to the Govt. of India

438 NBO/87

CHAPTER 2

TYPES OF NATURAL DISASTERS

2.1 *FLOODS*

Introduction

Floods cause large scale human suffering and loss of assets all over the world. Every year a large number of people loose their lives and property due to this type of natural disaster. The economically weaker section of society is the worst sufferer as their dwellings are easily damaged or washed away by water currents. Floods cause wide-scale damages and loss of various kinds of properties like crops, livestock, communication, irrigation works, etc.

Data available from the United Nations Disaster Relief Coordinator (UNDRC) indicates that the major impact of natural disaster is concentrated among the developing countries, mainly located in Asia, where agriculture is the main economy. It is estimated that over 90% of disaster losses in these countries are attributable to floods, indicating the importance of flood hazard assessment and mitigation planning in the background of their impact on an agricultural economy.

Magnitude of Losses in India

Flood is a perennial problem in our country. Year after year many states are suffering huge losses of their valuable assets like livestock, houses and buildings, agricultural land, grains and fodder, communication system etc. More important they cause loss of human life in large numbers. The seriousness of the flood problem can be judged from the extent of damages it causes. Available data for a period of 25 years from 1954-78 has shown that the average annual direct damage was of the order of Rs. 2,474 million. The quantified physical losses for this period are as follows :—

Total area affected—8.2 million hectares.
Cropped area affected—3.5 million hectares.
Number of houses damaged—9,25,000.
Population affected—24.6 million.
Number of human lives lost—1,240.
Number of heads of cattle lost—77,000.

Causes of Floods

'Flood' is a situation created when the river carries a flow in excess of its transporting capacity. The major causes of floods are incidence of heavy rainfall and occurrence of heavy and continuous melting of snow in the hills. Although these hydro-meteorological factors are the contributory causes—either alone or in combination for inundation of land and damage to property, disaster may also be brought upon from other sources. These sources are generally associated with the promotion of a hydraulic surcharge in water levels and include presence of natural or man made obstructions in the flood-way such as bridge piers, weirs, floating debris, tidal surge at the confluence of river and sea or wind set up in estuaries. Certain unforeseen events like sudden dam failures, avalanches, land slip or wind flow could also cause a river surge. Such sources either aggravate an already existing flood problem or create a flood problem entirely of their own manufacture.

Localised Flood

Floods are also caused by intense local rainfall. The inadequacy of the drainage system to carry away the water quickly results in flooding of the town. Excess water which does not percolate into the soil forms water-pools in low lying areas.

Tidal Flood Areas

Cyclonic winds cause high tidal waves which spill over the land flooding low lying land in the interior.

Flash Floods

Flood flow develops gradually in many large rivers. This is in sharp contrast with flash flood which is more commonly associated with small catchments. In flash flood, the time lag between the start of the flood and peak discharge is comparatively small. They are particularly dangerous because of the suddenness and speed with which they occur. They develop in a basin following isolated and localized intense rainfall originating from a thunderstorm, especially if the catchment slope is conducive to acceleration of run off. Their infrequent occurrence in a particular catchment makes efficient surveillance, warning and protection a difficult task.

A flood producing rainfall associated with other types of natural disasters like tropical cyclones and hurricanes can have a devastating effect on the human settlement as well as the natural surroundings. Such a phenomenon occurs commonly in the Eastern Coastal belt of our country when cyclonic storms are accompanied by heavy rains.

Our Rivers

The annual average rainfall in India is about 1,250 mm which amounts to about 400 Million Hectare Metre (MHM). An estimated 215 m.hm. of the total rainfall percolates into the soil and the remaining 185 m.hm. flows as surface water. The aggregated storage capacity of the reservoirs and tanks is only of the order of 16 to 20 m.hm. It is therefore apparent that even during normal times there is a large volume of water flowing in the rivers and streams during their course to the sea. The heaviest rainfall occurs for a period of 3 to 4 months during the monsoon. Even during this time most of the rain comes down in a concentrated form within a few weeks when the rivers carry 85-90% of the monsoon flow, accompanied sometimes with silt.

The river systems of India can be classified under two main groups namely rivers of the Himalayan region and rivers of Peninsular region. The Himalayan rivers are fed by the melting snow and glaciers of the Himalayan Range during the spring and summer period and by the rains during the monsoon. Peninsular rivers originate at much lower altitudes and flow through more stable area. They are characterised by heavy discharges only during monsoon months and by low discharges at other times.

A number of States including Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Assam, Gujarat, Rajasthan, Madhya Pradesh, Orissa and Andhra Pradesh are flood prone. Off and on floods also occurs in many other states due to swollen rivers, resulting from unusual rains. The flood prone area has been estimated to involve an area of 40 million hectare of land inhabited approximately by 80 million people living in several thousand of villages and hamlets. Relatively, the problem of floods causing heavy devastation is more frequent in the Brahmaputra basin in Assam, Ganga basin in Uttar Pradesh, Bihar and West Bengal and Brahmini, Baitarni, Subarnarekha and Mahanadi basins in Orissa. From ages, the flood plains of the rivers have been occupied mainly for cultivation. These settlements have been developing economically and have added population. So much so the loss in terms of lives and property is accentuated by floods. People living in these habitations, which are inevitably susceptible to floods, constitute 'high risk' population.

The problem of drainage congestion due to storm surge due to cyclone occurring simultaneously is experienced in Gangetic Plains in West Bengal and coastal peninsular states of Orissa and Andhra Pradesh and the inundation caused by the branches of the rivers in and beyond the esturies is further aggravated.

Damage to Houses by Floods

Floods constitute a hazard to houses and buildings when the flood plains which perform the natural function of carrying away excess water are used for human settlements. Inspite of some awareness of the hazard more and more people are moving to and building in flood prone areas. This is due to the pressure of population and economic compulsions.

Depending on their location, the houses can suffer damage by different kinds of floods.

The type and extent of damage to houses depends on the particular type of flood they are exposed to. Flash floods, riverine floods, local floods and coastal waves each have their own dynamic characteristics and leave distinct marks of distress on the structure after they recede. There may be a total loss of the structure or a damage of different degrees.

Severe Damage

Houses subjected to a large mass of water striking them with force collapse totally. This is typical of coastal waves followed by cyclonic winds (Tusnamis which are also in this category do not occur in our country), which may reach several metres above the sea level. In the case of coastal flood it might be possible to retrieve some of the building materials from the collapsed structures.

Flash floods also bring upon sudden pressure on the structures due to the high velocity of water and cause complete destruction. Even strong buildings constructed with RCC are badly damaged. In locations where the houses are built on loose soil severe inundation takes place leading to collapse of the structure. Most of the debris are taken away by the swift water currents. In the case of *'Katcha'* structures, built of thatch mud etc., their traces are wiped out. Very little of building materials, if any, can be retrieved in the case of structures falling directly in the path of flash floods.

Partial Damage

Riverine floods are characterised by low velocity and long duration. Prolonged inundation can be expected from riverine floods which gives rise to two types of damage to houses—

(a) The soil gets softened leading to the sinking of foundations. This will result in uneven sagging of roof with consequence damages to roof covering and supporting members, cracks in the wall and sinking of floor, scouring of foundation by a slow and steady flow of flood water can further aggravate the problem. Repairs and restoration can be done with considerable expense depending on the extent of damage.

(b) The standing water causes deterioration of finishes like painting, distempering, plastering, etc. Timber work of doors, windows, storage shelves, pelmets, etc. get soaked promoting decay.

Flooding of low lying areas by local heavy rainfall also damages houses in the manner described above.

Other Effects

Floods can also have a devastating effect on land by eroding the upper strata leaving behind a rugged surface which is unsuitable for construction. The reverse process is also a common phenomenon when the flood water brings with it large volumes of fine silt, sand or other materials and deposits on an existing settlement. This is very typical of flash floods which have the requisite momentum to carry soil and boulders which come in their way. In this case the clearing operations and restoration become a difficult task.

Vulnerability of Mud Houses

By and large the extent of damage to houses and buildings depends on the topography of the area, soil erosion characteristics, wall area exposed to the water pressure, foundation type and depth and strength of the structure. However, houses of the *'Katcha'* type, especially those constructed with mud, sundried bricks, thatch, bamboos, etc., are damaged extensively. Poor people, who are able to afford only such types of houses, are the worst sufferers.

Disaster Mitigation

Habitation in river valleys, around lakes and along coastal belts will continue due to compulsions of occupation, in spite of their being prone to flood hazard. A total evacuation of the population and their resettlement at a safer site is impracticable and leads to unfavourable economic and social consequences. The flood problem should therefore be tackled with objectivity with the two fold criteria of prevention of exposure to floods and mitigation of its effects.

The vulnerable community is generally able and willing to tolerate flooding to some extent after having come to terms with the problem after years of experience. Nevertheless, the intensification of the flood plains occupation and its growing importance to the social and economic welfare of a region have added new dimensions and there has been an increasing demand and need for flood protection. The problem is brought into sharp focus whenever a major disaster occurs.

Flood Forecasting and Control Measures

Identification and evaluation of flood hazard is a first step in planning control of land use and flood plain occupation. It is a very important step as it gives the planners and administrators necessary information for basing the decisions with regard to the degree of control required and the likely consequences that will occur if such a control is not effective.

It is possible to develop flood frequency curves from the data on frequency distribution and intensity of rainfall and knowledge of the water shed. Considerable knowledge and experience exists in this area. In developing countries like India a good amount of fundamental work in this area of hydrology has been done. Details of some complete models of rainfall/run off process have also been published.

The Ministry of Agriculture and Rural Development, Government of India is monitoring the variations in hydrologic and sediment responses of the water sheds for river valley projects and flood prone rivers. For this purpose data of rainfall, run off and sediment yield alongwith other water shed characteristics are being collected and compiled from a network of stream gauging stations and sediment observation posts. The data is used for assessing the effects of soil and water conservation, measures implemented in accordance with the integrated water shed management plans in moderating flood, silt load and run off from the water shed. The data obtained over a period of time is also used for developing prediction models for estimating run off and sediment yield of ungauged water sheds.

The Soil and Water Conservation Division of the Ministry of Agriculture and Rural Development has documented the above data for river valley projects and flood prone rivers in respect of Damodar-Barakar, Chambal (Rajasthan) Mayurkshi (Bihar), etc.

Flood Control

The need for flood protection to the community has led to development of engineering measures to control the movement of flood waters and the following engineering techniques have been well established for combating river floods.

Storage Methods

(a) Construction of a dam or dams to attenuate peak discharges by flood storage.

(b) Development of controlled and temporary storage in an unoccupied flood plain area upstream of an occupied zone.

Conveyance Methods

(c) River bank leevee construction to prevent inundation of flood plain by water levels greater than river bank top.

(d) Cutting a by-pass channel to relieve the normal river channel of flood surcharge.

(e) River channel improvement by re-aligning, enlarging cross sectional area or increasing bed slope to increase its conveyance and hence its discharge capacity.

With the exception perhaps of major dams which are constructed for water conservation as well as flood control all the other schemes have limited capacity. Floods do occur which exceed the design capacity causing inundation of the protected area. Therefore, an exaggerated sense of security should not be created in the minds of the protected people to the extent that they disregard warnings regarding occupancy of flood plain area.

Drains

Design of a proper drainage system in the towns prone to flood is of great importance. A proper drainage system will help to drain the flood water at the habited area and prevent water logging leading to damage of structures. Education of people to keep drains clean is also essential.

LAND USE AND REGULATIONS

Three aspects, namely (a) urban and rural land use (b) flood plain occupation control and (c) building regulation have to be taken into account for a planned development to mitigate the effect of flood disasters.

Land Use

Changes in land use can have an effect on the hydrology of the area thereby increasing the flood potential of catchments. In urban areas causes attributed are (i) reduction in the surface absorption causing higher volumes of run off, (ii) reduction of time of concentration giving higher volume of run off. In development of urban areas these aspects have to be carefully considered.

In rural land, vegetation and afforestation has the effect of altering the catchment flood response. Studies in USA have demonstrated that for an increase in afforestation on a small water shed, equivalent peak discharges are reduced gradually over a period of approximately 25 years by an average value of about 60 percent. The effects of rainfall induced floods have not been clearly understood. Different types of vegetation and rural land management cause have differing effects in soil water consumption and retardance of run off.

Settlements on Flood Plain

The height of land surface gradually increases above the river bank level as one goes further away. Consequently, the flood hazard gets reduced as the distance of land from the river increases. However, for social and economic reasons the occupation of flood plains cannot be avoided. It is, therefore, advisable to exercise some control on building in such cases by confining the construction to zones involving least risk. The concept of Flood Plain Zoning incorporates this idea.

By taking into account the variability of the flood hazard in river, zones are demarcated depending on the degree of risk and potential damage. Through legislation, the type and density of occupation would be controlled. The three zones identified are :—

(a) *Prohibited Zone*

This is the essential part of the flood way, the velocity and discharge of which contributes significantly to the total flow. It would be treated as the prohibited zone in the flood plain. Development in this zone of any kind should be totally disallowed to avoid damage to the property and also to avoid backlash flood effects upstream posing hazard to other settlements. The prohibited zone can be put to uses like cattle grazing etc.

(b) *Restricted Zone*

The area in the river bed where inundation is not too frequent and contributes small volume to the total flood discharge can be used as a restricted zone. As the velocity of flow is low limited building development and planned agricultural activity are feasible. However, restriction should be stipulated not only on the density and use but also on the design criteria. Minimum ground floor level, flood proofing arrangements, etc., should be considered for buildings.

(c) *Warning Zone*

The inundation beyond the design flood level and upto the estimated maximum flood level is rare and therefore, the potential disaster is negligible. People who wish to settle in this zone should be warned and advised of the risk involved regarding the safe height of floor levels, etc. The choice of setting and developing will be their own and little or no restriction is imposed from the view point of flood disaster prevention.

BUILDING REGULATIONS

Damage to individual buildings and structures may be prevented to some extent by incorporating in their design, the ability to withstand inundation and high water velocity. It is desirable to enforce some building regulations in this regard in order to see that the welfare of the individual as well as the community is protected. If such a control is exercised at regional and national levels it would contribute substantially in aggregate to mitigate flood disaster and save life and property in a large measure.

FLOOD RESISTANT HOUSE CONSTRUCTION

As flood affects the whole of the community and the related problem can be tackled adequately and satisfactorily only at the community level. Nevertheless each aspect of flood disaster mitigation warrants its own special consideration and a solution which will at least partially meet the situation. The strengthening and protection of individual houses is one issue which should be given due priority and importance. Total flood proofing of dwellings would necessitate incorporation of strong reinforcing measures which will entail considerable costs. Such a type of construction is generally not within the means of majority of the people who are vulnerable to flood disaster. However, steps could be taken to give some measure of protection to the houses which will serve mainly to save lives.

(a) Good siting of houses should be aimed at to minimize risks of damage. The buildings should be constructed on the best bearing soil on the highest ground available.

(b) Ground drainage and escape lanes should be incorporated in the settlement layout.

(c) The houses may be raised on individual mounds which are prepared by spreading and thoroughly compacting soil. The mound should be constructed with suitable locally available soil. The roof level which is a critical factor during raising of flood water is raised adding a good measure of protection.

(d) The building may be designed in such a way that their roof spaces are above the designed flood levels. The choice of roof type and area should be such that it gives protection for a period of at least 24 hours to the people who take shelter.

(e) It is a common practice to raise houses on silts. But such a type of construction increases considerably, the risk of damage/over turn in the event of a flood. Such buildings should therefore have a rigid frame construction for strength or should be adequately braced.

(f) Houses constructed with mud are highly vulnerable. They must be given water proofing treatment.

RECOMMENDATIONS

1. Storage facilities in unoccupied flood plain areas for storing peak discharges of floods should be developed.

2. Construction of river banks or raising of levels of existing river banks to prevent inundation of flood plains should be done.

3. Bye-pass channels may be cut to relieve the pressure of flood from the normal river channel.

4. Improvement of normal river channels by realigning or enlarging cross-sectional area or increasing bed slope to increase the conveyance of flood waters.

5. Proper drainage systems should be designed in towns prone to floods.

6. People should be educated about the importance of keeping the drains clean in order to avoid choking.

7. Growing of plants and afforestation in catchment area and on banks of river should be promoted.

8. Concept of flood plain zoning should be developed and implemented.

9. Some building regulations should be enforced to incorporate in the designs of buildings and structures the ability to withstand inundation and high water velocity.

10. Buildings should be constructed on the soils with best bearing capacity on the highest available ground.

11. Proper drainage and escape lanes should be incorporated in the layouts of the settlements.

12. The houses should be made on raised mounds thoroughly compacted and made of locally available soil.

13. The roof level should be sufficiently high above the designed flood level in order to provide emergency protection.

14. Water proofing treatment should be done on walls constructed in mud.

15. Plantation should be grown around the house.

R & D WORK

1. Work of flood plain zoning and demarcation of zones- prohibited zone, restricted zone and warning zone—along the river is required to be taken up.

2. Preparation of Indian Standards and Codes of Practice for construction in flood prone areas should be taken up.

3. Work of preparation of flood frequency curves based on data on frequency distribution, intensity of rainfall and knowledge of the water shed should be taken up.

4. Data on rainfall, run off and sediment yield and other water shed characteristics should be collected over a period of time on all major rivers in order to obtain prediction models for estimating run off and sediment yield of ungauged water sheds.

2.2 *CYCLONES*

Cyclones are large vertices in the atmosphere extending from 150 km to 1200 km in a lateral direction with fierce winds spiralling around a central low pressure area. A cyclone covers roughly 300 to 500 km. per day. The maximum wind speeds associated with a mature cyclone could be as high as 150 to 250 km. per hour. The highest wind speeds in cyclones which have hit the Indian coast in the past hundred years have been about 120-130 knots, i.e. 220-240 km per hour. The intensity of a cyclonic disturbance is measured by the strength of the associated winds. The international classification, which is also used in India, is given in Table 1.

TABLE 1

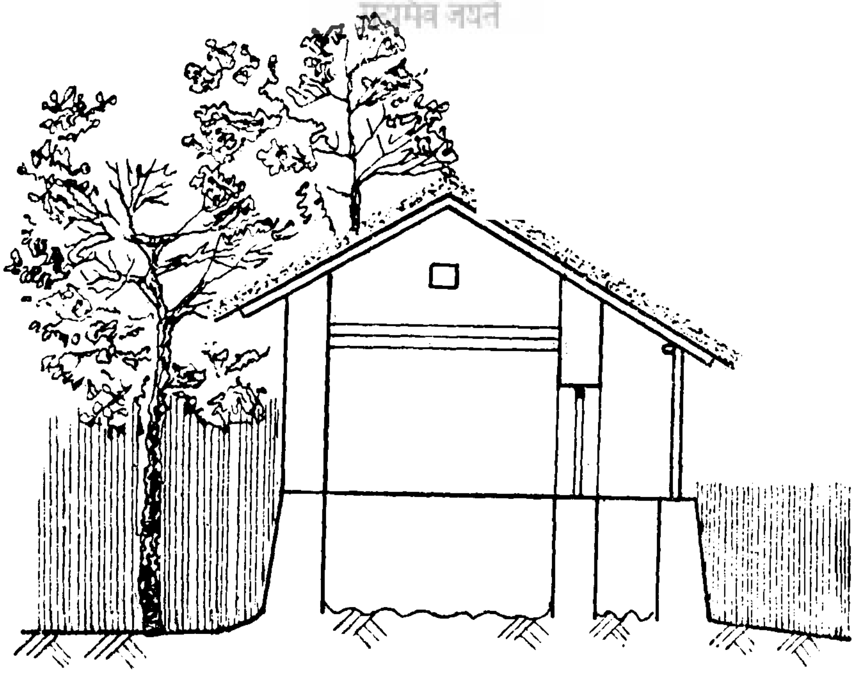
CLASSIFICATION

Disturbance	Wind speed, knots	(km/hr.)
1. Depression	17—27	(32—50)
2. Deep Depression	28—33	(51—60)
3. Cyclonic Storm	34—47	(61—89)
4. Severe Cyclonic Storm	48—63	(90—119)
5. Severe Cyclonic Storm with a core of hurricane winds	Exceeding 64	(120)

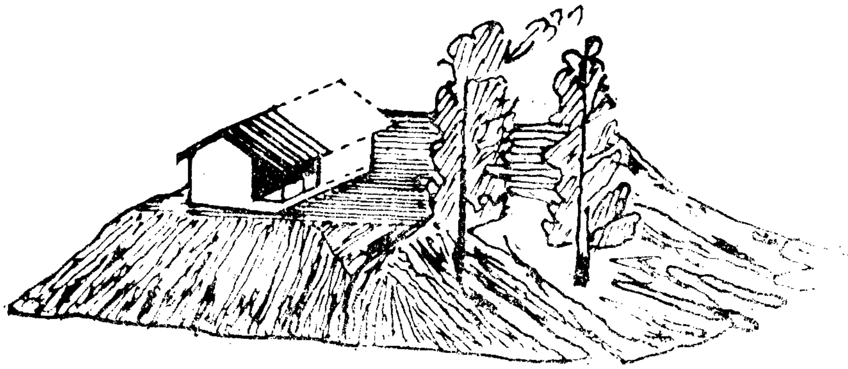
Structure of a Cyclone

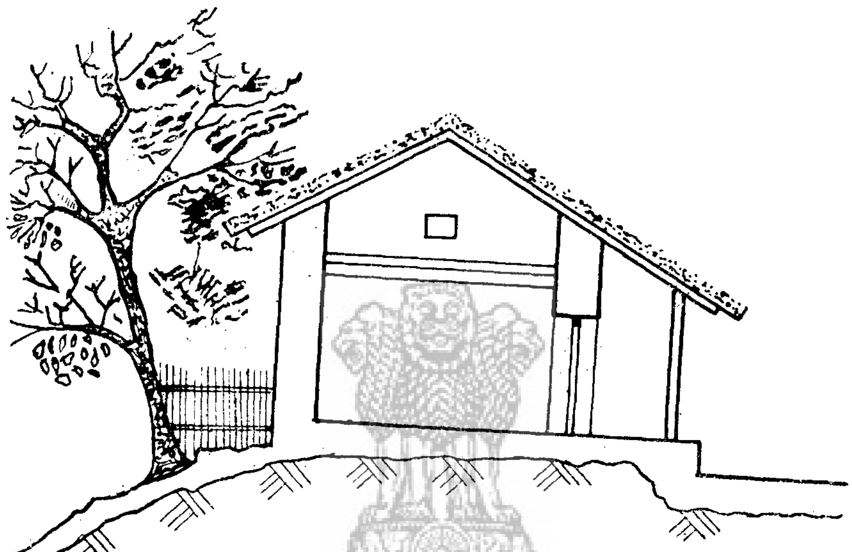
A mature tropical cyclone consists of a central region of light winds known as its 'eye' and has an average diameter of about 20 to 30 km, but it can be 40 to 50 km in large mature storms. The pressure is lowest in this region with either clear or partly clouded skies. The 'eye' is surrounded by a ring of very strong winds extending on an average upto 30 to 50 km beyond the centre. This area is called "wall cloud" region. It is the most dangerous part of the cyclone, because the strongest winds and torrential rains occur in this zone. Surrounding this region, winds spiralling in a counter-clockwise manner in the northern hemisphere, extend outwards to large distances, with speeds gradually decreasing as we move further away from the centre. The rate of decrease of winds may be rapid or gradual. In the latter, speeds of 35/40 knots (65 to 75 km/hr) may be encountered even upto 600 km from the centre. There is a certain amount of asymmetry in the wind distribution around the centre of a cyclone. The strongest winds are often observed on the right of the cyclone's track.

The total dimensions of a mature cyclone varies from a 50—100 km diameter in very narrow ones, to a diameter as large as 2000 km in large ones. Over the Indian region, the size is usually between 600 and 1,200 km (for nearly 70% of cyclones) in the post-monsoon season (October to December). It is slightly less in the pre-monsoon period (April—May), the diameter being about 400 to 800 km for 70% of the cyclones.



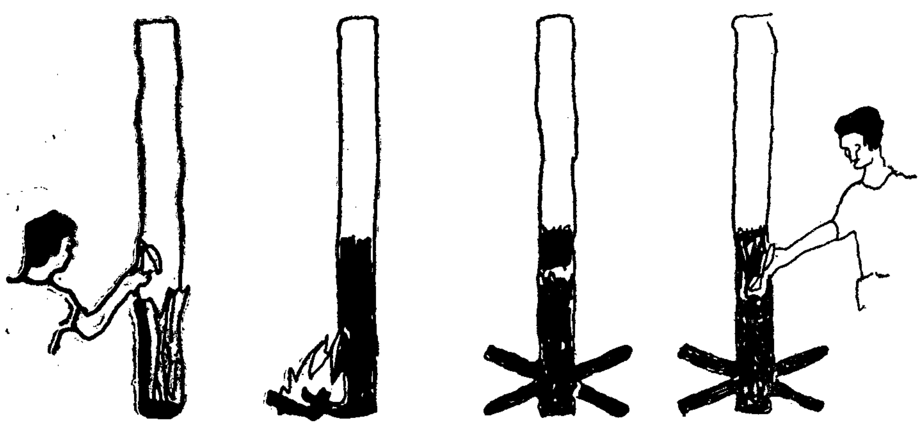
USE OF RAISED FLOOR





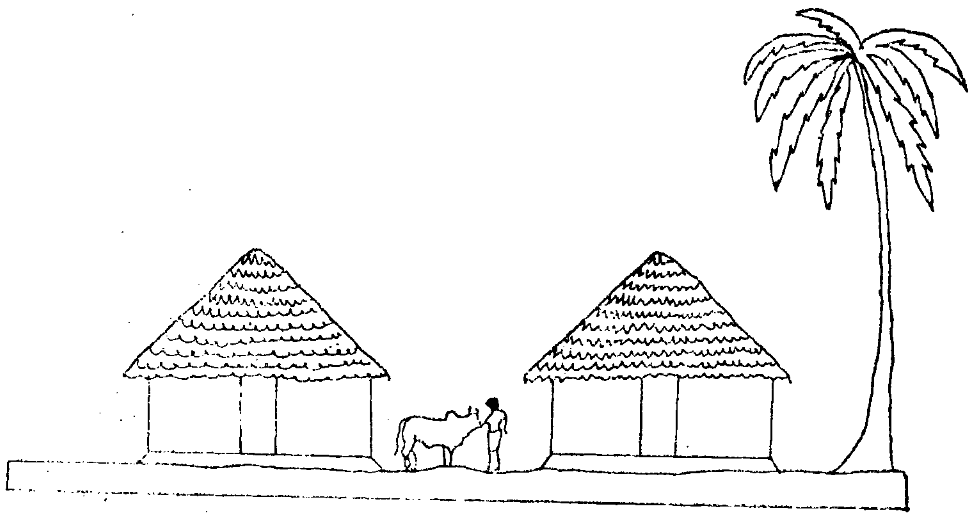
USE OF EARTH MOUND

PREPARATION OF POSTS

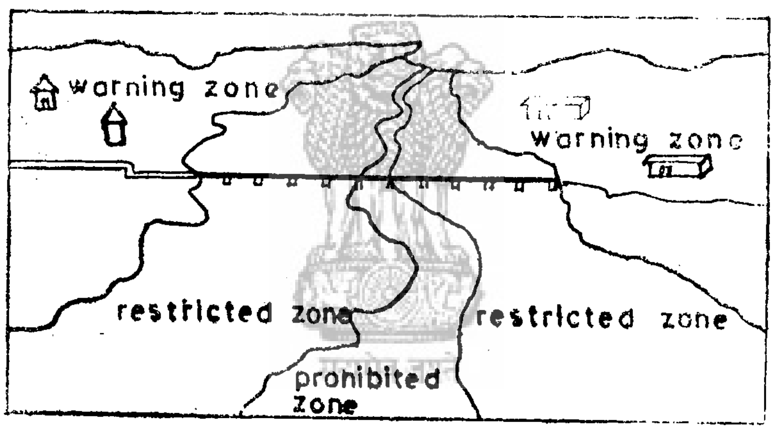


1. Remove all bark from the posts
2. Burn Bottom of posts to form a layer of charcoal
3. Fix 2 feet long cross pieces to bottom of posts
4. Apply tar to bottom of posts and to cross pieces

TREATMENT OF TIMBER POSTS



MUD HOUSE-RAISED FLOOR THICK WALLS



LAND USE PLANNING

Frequency of Occurrence of Cyclones

Cyclonic storms are a world wide phenomenon occuring in certain preferred zones. Even over Indian seas, there are only some months in which they develop. On an average, there are about 5-6 tropical cyclones in the Bay of Bengal and the Arabian Sea every year, out of which 2 to 3 may be severe. More cyclones occur in the Bay of Bengal rather than in the Arabian Sea; the ratio of their frequencies is about 4 : 1. The months of May, June, October and November are the stormiest of the year. In the post-monsoon period, the peak storm activity is reached in the second half of October and in the first half of November. Compared to the pre-monsoon sason, particularly the months of October and November are known for severe storms.

The frequency of cyclones and severe cyclones in the Bay of Bengal and the Arabian Sea during the 80 year period from 1891 to 1970, is shown in *Table II*.

Although cyclonic storms have occurred in the monsoon, the really severe ones are rare. Storms during the monsoon are more marked by rainfall, which often leads to floods in different parts of the country.

TABLE 2

FREQUENCY OF TROPICAL CYCLONES IN INDIA

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Cyclonic	4	0	2	11	13	31	31	25	22	36	35	20	230
storms with	1	1	2	3	26	4	7	1	10	26	33	14	133
in creasing intensity	2	0	0	1	3	5	3	2	4	13	6	4	43
	0	0	0	4	13	12	0	0	1	7	19	1	55

(October to December). It is slightly less in the pre-monsoon season.

Regions of Formation

Tropical cyclones form over oceans, where the temperature of sea surface is high. Over Indian seas (Arabian Sea and Bay of Bengal) cyclones generally form between 5°N and 15°N. They usually form out of weak low pressure systems and gather strength—sometimes very rapidly—as they travel over the warm seas; large quantity of moisture picked up from the ocean is the chief source of energy for the storm. On this account tropical cyclones never form over land; they also weaken off rapidly after crossing the cost and moving inland. Depressions which intensify into cyclonic storms, do so in most cases within 48 hours. Within the next 36 hours they may become severe, when conditions are favourable for further intensification of the system.

Direction and Movement

Cyclones in the Bay of Bengal which move west, northwest or even north, strike the east coast of India, some of the Arabian Sea cyclones strike the west coast of India—mainly Gujarat and the north Maharashtra coastal zones. Out of the storms that develop in the Bay, over 50% approach or cross the east coast in October and November, but only 25% of the storms that develop over the Arabian Sea approach the west coast. In the pre-monsoon season, the corresponding figures are 30% for the Bay of Bnegal and 25% for the Arabian Sea. An important feature is that along a vast stretch of the Indian Coast, there are a few preferred strips which are more vulnerable (both on the east and the west coast) to tropical cyclones.

Destructive Effects

Severe tropical cyclones are responsible for large casualties and considerable damage to property and agriculture. The destruction is confined to the coastal districts, the maximum destruction being within 100 km from the centres of the cyclones, and to the right of the storm track. The principal dangers from a cyclone are :

(i) Gales and strong winds

(ii) Torrential rain and

(iii) High tidal waves (also known as 'storm surges').

Most casualties are caused by coastal inundation by tidal waves and storm surges. The maximum penetration of severe storm surges varies from 10 to 20 km inland from the coast. Heavy rainfall and floods come next in order of devastation. They are often responsible for much loss of life and damage to property. Death and destruction purely due to winds is relatively small. The collapse of buildings, falling trees, flying debris, electrocution, rail and aircraft accidents and disease from contaminated food and water during the post-cyclone period also contribute to loss of life and destruction of property.

In as far as loss to life, property and production due to failures of installations and buildings is concerned, one important fact needs to be emphasised. Wind velocities/pressures and coefficients are assigned in the code for design purposes. The velocities are expected to cover those expected in cyclonic and other storms. If therefore the knowledge of wind forces on the concerned structures is available, a properly engineered structure should withstand the storm. On the strength of the present knowledge there does not appear to be any need for a special consideration for a cyclone, except the aspect of flooding. How good are our estimates of wind velocities and force coefficients cannot be fully rectified upon.

Storm Surges and Coastal Inundation

The most destructive element associated with intense tropical cyclones is what is called "storm surge". In fact storm surge is the greatest of all killers due to atmospheric disturbances. A storm surge as high as 6 m associated with a single cyclone is capable of causing enormous devastation.

Storm surge is abnormal rise of sea level caused by a cyclone moving over a continental shelf. Surge is generated due to interaction of air, sea and land. The cyclone provides the driving forces in the form of very high horizontal atmospheric pressure gradient and very strong surface winds. As a result, the sea level rises and continues to rise as the cyclone moves over shallower water, and reaches a maximum on the coast near the point of landfall. Sea water inundates vast stretches of coastal area and washes away all that comes in its way. The frictional stress due to the bottom of the sea provides the dissipating mechanism to the energy generated by the driving forces.

There is another kind of rise of sea level, *viz*, astronomical tide, which is well known. The rise due to tide may be as high as 4.5 m above the mean sea level at some part of Indian coasts. It is no over-emphasis to state that the worst devastation takes place when and where peak surge occurs at the time of high tide.

STRUCTURAL DAMAGE DURING CYCLONES

Damage caused by cyclones could be considered under three categories of structures :

(1) Fully engineered,

(2) Marginally engineered and

(3) Non-engineered

Fully engineered structures are those that have been very carefully designed and built. Such structures include tall steel towers, industrial buildings, chimneys and skyscrapers. Non-engineered structures are those that have been built without any guidance from a qualified engineer and generally consist of one/two storey residential buildings, cattle sheds, etc. Marginally engineered structures consist of schools, small hospital buildings and small industrial buildings where only nominal engineering attention is providing during their construction.

Fully Engineered Structures

The types of damage to such structures can be summarised as follows :—

(i) Overturning of bridges.

(ii) Damage by water waves to bridges resulting in the slab being washed away and anchor bolts getting sheared.

(iii) Collapse of tall steel towers chimneys.

(iv) Blowing off of door and window shutters. In the design of building having many windows in exterior walls, it is essential that breakage of window glasses is taken into account which results in an increase in interior pressure and may cause severe damage.

(v) Blowing off of zinc sheets and covering materials from the walls and roofs of industrial buildings. Buckling of purlins leading to failure of masonry walls to which they are anchored.

(vi) Total collapse of tall industrial buildings with pitched and trussed roof. The failure occurs due to excessive lateral horizontal deflections at the truss supports.

(vii) Partial damage to break waters.

Marginally Engineered Buildings

Damages to such buildings are of the following types :—

(i) Inadequate connection between roof members, between roof and walls and inadequate strength of frame joints particularly at the foundation level causes severe damage to such buildings.

(ii) Inadequate vertical bracing results in complete collapse of industrial buildings.

(iii) Infilled walls between the columns fail due to inappropriate connections with columns.

(iv) Railings and parapets of buildings are blown off.

(v) In elevated situations, foundations fail due to improper consolidation.

(vi) Transmission towers, electric and telephone poles get twisted due to broken wire condition as well as strong winds.

Non-Engineered Buildings

Single and multi-family houses, single/double storey apartment houses and small shopping centres receive practically no engineering attention in their construction. The damage in such buildings can be summarised as in the following :

(i) The most vulnerable points in such buildings are; connection at the inter-section of two walls, between walls and foundations, between walls and roofs, and attachment of cladding or sheathing to walls or frames.

(ii) Rafters fail due to failure of anchorage in uplift or at the connection details with wall.

(iii) Roof covering consisting of asbestos cement, clay tiles, asphalt shingles and mangalore tiles suffer great damage.

(iv) Walls fail due to their incapability to resist normal as well as lateral loads.

(v) Openings in walls create stress concentrations which may be critical particularly at the corners of the opening.

(vi) The projections at eaves level are especially vulnerable to excessive upward pressure.

(vii) Buildings with flat roofs suffer maximum damage except those constructed with reinforced cement concrete.

(viii) Single and double storey buildings with flat RC slab roof walls in mud mortar brick work collapse due to tidal waves. Buildings with brick walls in cement sand mortar or lime mortar and flat RC roof slab escape damage.

(ix) R.C. cantilever and sun shades collapse.

(x) Improperly detailed lintels over opening and these with inadequate bearing trigger off failure.

(xi) Almirahs and cupboard walls forming an integral part of partition walls add to the effective stiffness. However, where these are provided in exterior walls, local failures occur to the extent of their length due to reduction in wall thickness.

(xii) Water damage occurs where buildings are constructed on spread footings without accounting for scour underneath the footing. Buildings properly founded on piles suffer no damage. The suction due to the receding wave is very severe and carries away people, cattle and building components.

RECOMMENDATIONS FOR BUILDINGS IN CYCLONE AREAS

A study of damaging effects of wind on different categories of structures gives rise to the following recommendations :—

(i) The geometry and orientation of a structure are important parameters determining its overall wind resistance.

(ii) Structures fail mainly because of the forces (pressures and suctions) induced by wind when acting on their critical components or by wind induced resonant vibrations.

(iii) Non-engineered and marginally engineered buildings are specially susceptible to failure under cyclonic winds due to several inherent weaknesses in them which result from none or little attention paid to the details of design and construction.

(iv) Certain types of structures are very weak against lateral and uplift forces of wind and fail easily.

(v) A small increase in the attention towards wind engineering principles applied to such constructions should give large returns in terms of substantial wind resistance and safety from collapses.

(vi) Large losses of lives have resulted in the past due to water flooding by high tidal waves associated with cyclonic winds.

Recommendations regarding planning, design, and strengthening of buildings are given below :—

Planning Aspects

The site coniderations involved are as follows :—

(i) The building site should be chosen at a ground level above the probable maximum tide level or the ground should be raised to that level.

(ii) The foundation should be taken to a firm natural soil level so that the resistance under the footing may not be lost due to flooding. Piles should be used if site conditions so require from bearing capacity or scouring considerations.

(iii) The water retreating to the sea applies substantial scouring action and pitching of slopes will be desirable.

(iv) Sites which lead to wind concentrations should be avoided. Protruding ledges on hill slopes will be such locations.

(v) Sites which offer shielding from high winds such as valleys are preferable.

Orientation of Buildings

In the case of normal prevailing strong winds, the logical orientation of buildings is that which presents minimum exposure to the wind. The building should be shaped in such a way as to reduce the wind pressure on it. Although this is not so easy in cyclone-prone areas, since the cyclone, while following a general path which may be relatively straight and predictable, may blow in virtually any direction, yet it will be desirable to place the smallest face of the building across the prevailing high wind direction.

In the same manner, although a site may be good or bad from the point of prevailing winds, breeze, sun and other factors, a cyclone will render the careful layout in relation to those considerations largely irrelevant. One cannot provide shelter against wind from all directions without discarding the important benefits of cool breeze in normal periods. Nevertheless, it may be possible for strong winds to be mitigated by proper orientation and permeable obstructions that cause less interference with gentle winds.

Wind Breaks

A rudimentary wind-break occurs when a building is erected on the windward side of an existing building. Depending on the height of the wind-break, there is considerable blocking of wind from buildings on their leeward side. Angling the blocks in plan, or staggering them causes only minor differences in the amount and direction of wind penetrating beyond the wind breaks. If the successive rows of buildings are spaced apart at less than seven times their height, the wind movement will reduce. Wind-tunnel tests on wind-breaks show that solid wind-breaks, such as, walls cause eddies over the top which reduce their utility. Permeable barriers such as belts of trees are more effective in some ways because, while not reducing wind velocities as markedly as solid barriers, there is a greater depth of protection.

The permeability of different kinds of trees and other barriers can be varied. The optimum porosity of the barriers is in the range 30 to 50 percent. A lower figure will cause a greater reduction in wind speeds, but an open barrier will be more effective for a greater distance. The performance of different types of permeable barriers, such as, boarded fences, dense belts of trees, thinner belts of lighter texture trees will produce significant difference for the first five to ten times or so of their height in horizontal distance from the barrier. At about 30 height units there is no appreciable effect of the wind barrier.

It is important to note that besides affording protection wind-breaks may divert wind to other places. This can have both beneficial or an adverse effect. Similar effects may result by using trees to reduce wind speeds in a particular area.

Design Aspects

Roofs : The considerations in respect of roof are :

(i) Flat roof arrangement should be avoided since it results in much higher negative wind pressures (suctions) compared to those on inclined roofs. Reinforced concrete slab roofs are, however, suitable in view of their weight and rigidity.

(ii) The span of the sheeting, connections of the sheeting to purlins and purlins to trusses, roof overhangs at eaves level and the roof anchors with walls should be designed for appropriate pressures. Bolts for sheeting connection should invariably be used with washers so as to avoid punching through under wind sections.

(iii) Roofs and their anchors with the walls should be properly designed.

(iv) The purlins should be adequately anchored to the gable ends and diagonal bracing installed in the plane of the roof using purlins as the struts so as to provide stiffness against the failure of gables.

Projections : The projecting elements like antennas and tall chimneys above the roof should be avoided as far as possible. When necessary, they should be kept low and adequately anchored to the structure.

Horizontal projections such as eave projections, 'chhajjas', sunshades, etc. are subjected to very large uplift forces during cyclones. The projecting length should be kept minimum and designed for pressures as recommended in the Codes. Adequate anchoring into the structure of the building should be provided.

Walls and Supporting Frames : Design considerations are summarised below :

(i) To avoid collapse of walls inwards on windward side or outward on the other faces, they should be adequately designed for appropriate design wind pressures.

(ii) Where necessary the walls should be reinforced with vertical steel reinforcement or buttressed.

(iii) Providing a reinforced concrete band (ring beam on all external and internal load bearing walls) will greatly improve their individual stability as well as integral box like action and increase the stability of the buildings to make them cyclone resistant to a great extent. Joint reinforcement should alternatively be provided at wall junctions, say, in every fourth layer.

(iv) Adequate diagonal bracing must be provided in frame type constructions both in the vertical and horizontal planes and along both the principal axis of the building.

(v) In-fill walls, particularly on external faces, should be properly secured to the columns.

(vi) Reinforced masonry (brick walls, hollow concrete block masonry, sandwich walls etc.,) should be encouraged in cyclone prone areas.

(vii) Foundation details in the frames should be carefully designed.

Timber Construction : The related design considerations are :

(i) The building should be designed to act as a single unit by connecting all components together anchoring the whole structure to the foundation by suitable anchor bolts.

(ii) Connectors must be corrosion resistant and should not be exposed to rain.

(iii) Where nails are used with connectors, they should be designed such that the nails are loaded laterally rather than in direct tension.

Door and Window Openings in Walls : The following important considerations need to be noted :

(i) One of the most dangerous effects of strong winds, ranking perhaps equally with flying roof sheetings, is the amount of broken glass. Large sheets of glass in windows or doors commonly shatter because they are too thin to withstand the local wind pressure. Quite common is also their breakage when struck by wind born missiles. Ways to combat this danger are (a) to reduce large areas of glass by glazing bars or mullions, and (b) to use wired and/or thicker glass. Use of smaller glass panes will be economical initially and easy to replace later when broken.

Additional advantage of avoiding breakage of glass by reducing size or strengthening large window areas is that this reduces the chances of sudden entry of violent wind into the building which is a major cause of the lift-off of roofs.

(ii) Wooden shutters can also be provided to protect glass areas. There would indeed be some locations where wooden shutters could be adequate alternative to glass windows as, for example, in high-ventilating windows under eaves. These windows generally remain permanently open. Shutters are sometimes lowered. However, they themselves may fail through deterioration caused by weathering and intermittent use, and this should be taken care of by proper maintenance.

(iii) Door and window frames should be anchored to the walls or columns adequately through hold-fasts.

(iv) The bolting or locking device of the door and window shutters should be simple and strong so that they could be used quickly and resist the cyclonic wind load adequately and keep the shutters shut.

Cranes : The stability of gantry and other mobile cranes should be checked against uplift and everturning by cyclonic winds and adequate safety built-in by making wider base and/or incorporating holding down devices.

Emergency Protection Against Strong Wind

(i) Large areas of glass should be taped in small square pattern either with medical adhesive tape or insulating tape.

(ii) All loose articles such as bicycles, garden furniture, etc. should be removed from outside the buildings or held down to the ground by rope or chains. Otherwise these could be lifted by high winds and act as projectiles.

(iii) All loose materials should be heaped and netted by rope nets and anchored to the ground through spikes or held to buildings or trees.

(iv) As far as possible all windows and doors should be kept tightly shut throughout the cyclone period.

(v) Weak or doubtful roofs, weak framed structures should be covered with coconut rope netting or tide down with guy ropes at 45° to ground and anchored to hooks or rocks.

STRENGTHENING EXISTING BUILDINGS

The following strengthening measures will improve the cyclone wind resistant quality of existing buildings a good deal.

(i) Introducing locking devices in door and window shutters.

(ii) Adding pisters or buttresses to masonry walls from the outside.

(iii) In rectangular plan buildings, introducing an all-round bandaging using angle irons or channels interconnected at corners and connected to walls at intermediate points through bolts.

(iv) Improving anchoring of sheeting to trusses and that of trusses to walls.

(v) Introducing diagonal braces in both vertical planes of a building and also in the plan.

(vi) Introducing well connected infill panels within the frame members.

(vii) Improving connections between frame members by additional bolting, welding, nailing or tying with ropes.

(viii) Anchoring the whole wooden buildings to the ground.

CODAL PROVISIONS

The National Building Code provides guidance for design of structures against wind loads. The detailed provisions for this aspect of design are given in Section 1 'Loads' in Part-VI 'Structural Design'. Buildings and other types of structures particularly in the coastal areas are subjected to high lateral forces from cyclonic winds and the incorporation of special design features stipulated in the Code will ensure structural safety.

The Building Code has pointed out that strong winds of velocity greater than 80 kms/hour are generally associated with cyclonic storms, thunder storms, dust storms or vigorous monsoon. A feature of the cyclonic storms occurring in India is that they weaken rapidly after crossing the coast and move as depression inland. The influence of a severe storm after crossing the coast and a severe storm after striking the coasts does not generally exeed 60—70 Kilometers though sometimes it may extend even upto 120 Kilometres.

The liability of the building to high wind pressure depends not only on geographical locations and proximity of other obstructions to air flow but also on the characteristics of the structure itself.

Wind pressure is expressed in terms of a basic pressure which is equivalent to the static pressure in the direction of flow of wind. The basic wind pressure is decided by the appropriate authority having regard to local meteorological data and local conditions such as characteristics and location of structure and duration of wind flow. The Building Code gives two maps of India showing the basic maximum wind pressure including winds of short duration and excluding such winds for reference purposes, which are to be adopted in the absence of meteorological data.

For calculation of wind pressure on structures of various plan shapes other than rectangular plan shape, the Code has indicated modification factors. A table included in this section gives modification factors for circular, octagonal and square shaped structures taking into account different ratios of height to base width.

The internal air pressure in a building depends upon the degree of permeability of the cladding to the flow of air. Four cases have been considered in the Code, giving criteria for structural design. They are (1) buildings having a small degree of permeability, (2) buildings of normal permeability, (3) buildings with large opening and (4) buildings of open types.

This chapter of the Code provides detailed guidance for calculation of wind pressure on walls and roofs. For calculation of design wind pressures on roof, two categories have been considered namely; (a) flat and pitched roof; and (b) special types for roofs in which are included singly curved structures, doubly curved surfaces, butter-fly type structures and independently standing lean-to roofs.

PROPOSED WORK

The first prime need is that for precise, prediction of the formation, intensity and movement of the tropical storms in the Indian sub-continent, detailed observational studies such as those done for other oceans in the globe be conducted. This naturally needs very good observational facilities like aircraft reconnaisance, special ship and satellite observations. Besides these observational studies rigorous work is required to evolve objective and numerical methods to forecast the movement and intensity of the cyclones.

As a long term measure, it is also necessary to develop numerical models to predict the movement and simulate the behaviour of tropical cyclones of Indian Seas. The above study about the cyclones can be best undertaken by an organisation such as the India Meteorological Department.

In respect of housing in particular the following aspects need to be studied :

1. Study of damage during severe cyclones to

   (a) Engineered construction.

   (b) Marginally engineered construction

   (c) Non-engineered construction.

Surveys carried out already indicate that damage due to cyclones is mostly caused in the last two categories of construction or to structures which are engineered but not adequately.

2. Survey of local materials, and, design and construction practices along the east and the west coasts.

3. Wind tunnel studies on models of

   (a) single houses

   (b) groups of houses

to determine the force coefficients, interference/shielding effects etc.

Steps 1 and 2 can be best undertaken by organisations like the SERC or the CBRI and step 3 will be best undertaken by research and teaching institutions having the facilities for wind tunnel work. It may be relevant to mention that a large size wind tunnel facility will shortly be built as a national facility at the new campus of the SERC at Ghaziabad. The design parameters of the proposed facility is expected to meet the requirements of designing of disaster-prone structures. The work under steps 1 to 3 give a very good idea of the modes and causes of failures, the shortcomings in present practice and the improvements needed.

4. Based on information obtained from the above steps there is a need to prepare brochures in simple language (perhaps even in regional languages) giving the necessary guidance for constructing houses which will resist cyclones. Such effort has been made by the UNESCO with particular reference to school building. Various other countries affected by cyclones, such as Australia, Srilanka are making similar efforts for housing in general.

There is also a need to take other measures such as to specify Do's and Don'ts during and after a cyclone, to construct shelters and hospitals in the cyclone areas to allay the suffering of people during the storms and other rehabilitation measures.

Thrust Areas for R & D

Research may be undertaken on the following :

(a) Improving the durability and performance of low cost buildings and houses particularly in rural areas to withstand the effects of cyclone to a great extent.

(b) Model studies may be undertaken to consider aspects related to configuration of buildings and their relationship with wind effects.

(c) Proper planning of human settlements taking into consideration the total effect of wind on human settlements particularly the infrastructure should be studied.

(d) Wide publicity should be organised to promote designing of building and houses to withstand the wind effects adequately.

(e) From the point of view of disaster mitigation an estimate of the extent to which inundation of coastal areas due to storm surge would occur is necessary. Appropriate models that would achieve this need to be developed.

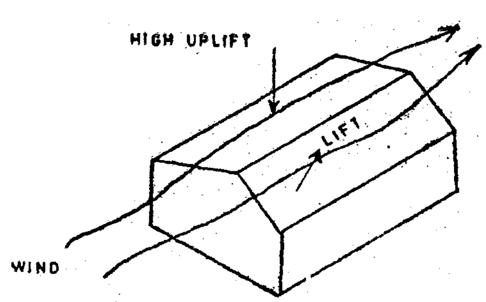
(f) On lines similar to the Standard Project Hurricane and Probable Maximum Hurricane Concepts used in U.S.A., a study leading to probable maximum surge estimate along eastern and western coasts of India would form a rational basis for design of coastal structures.

(g) Construction technology based largely on the use of local building materials for putting up houses instantaneously (i.e. instant houses) with a view to providing immediate relief to the victims in cyclone prone areas should be undertaken on priority basis.

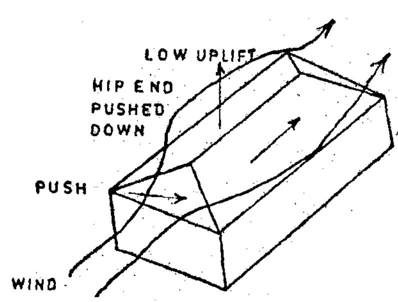
(h) Material and technology for putting up houses having short life at the lowest possible cost on project sites and developing reasonable types of structures.

(i) Appropriate materials and techniques for quick repair and rehabilitation of existing dilapidated houses and buildings.

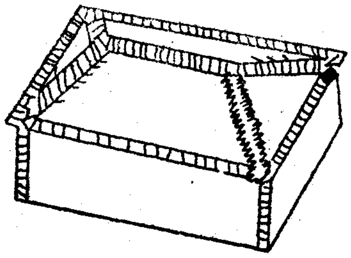
MEASURES TO WITHSTAND CYCLONES



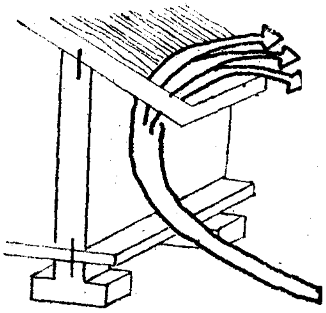
STEEP GABLE-ENDED ROOF
(NOT RECOMMENDED)



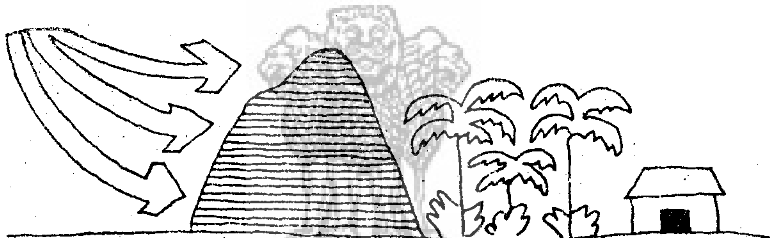
STEEP HIP ROOF
(RECOMMENDED)



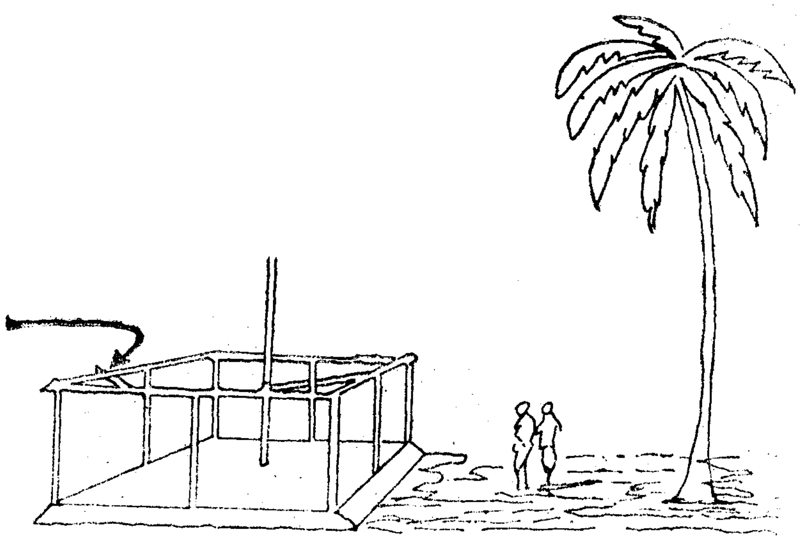
REGIONS OF ROOF EXPERIENCING HIGHER LOCAL UPLIFT FORCES (HENCE REINFORCING BAND TO BE PROVIDED)



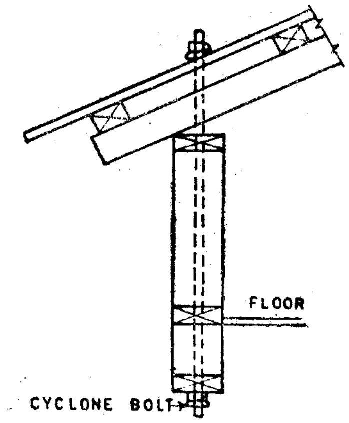
FIRMLY CONNECT ALL PARTS OF YOUR BUILDING FROM ROOF TO GROUND KEEP ANY OVERHANG SMALL OR ALLOW WIND TO BLOW THROUGH IT



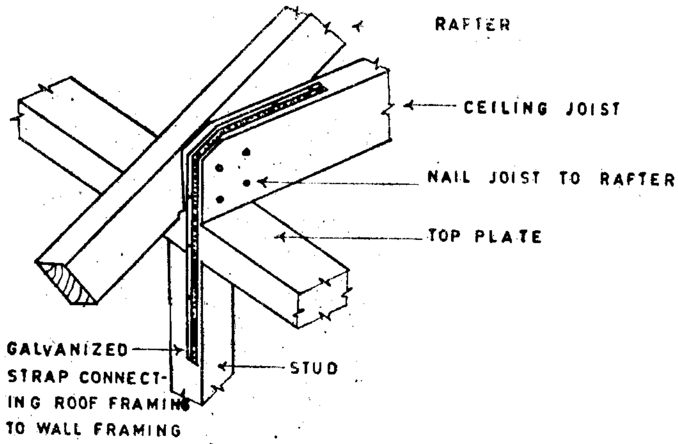
PROTECTION OF HOUSE BY HILLOCK/TREES



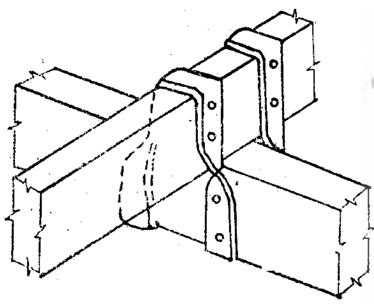
DIAGONAL CROSS PIECES AT ALL CORNERS



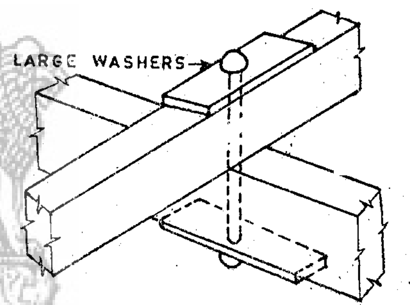
Cyclone bolting



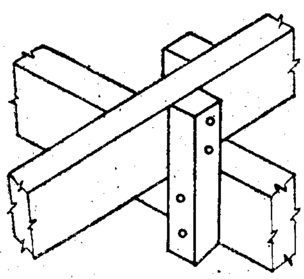
Connection of roof frame to wall frame



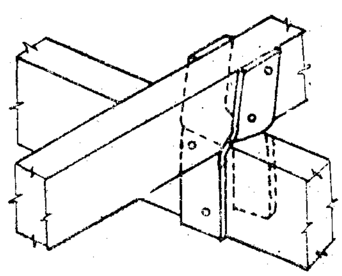
Steel strap fixing



Steel bolt fixing



Wooden cleats nailed to purlin and rafter



Metal bracket fixing

CYCLONE RESISTANT JOINTS AND CONNECTIONS

438NBO/87

2.3 *EARTHQUAKES*

INTRODUCTION

Of all the man-made structures, the collapse of buildings during an earthquake is the main contributor to the loss of lives and injuries to the people. The buildings could broadly be classified as engineered and non-engineered. Engineered buildings are those which are structurally designed and constructed by qualified architects and engineers taking into consideration the specified loads including earthquake and wind forces and permissible stresses according to Indian Standards. It is usually presumed that the building structure so designed and built will have the necessary features of strength, ductility and quality of construction which would make the building earthquake resistant. Practical experience, however, shows that the situation even with the engineered buildings may not be so optimistic and there remain indeed a number of deficiencies which get exposed during severe earthquakes when such buildings also collapse as happened in the Mexico earthquake of 1985. Reinforced concrete frame and shear wall buildings, steel buildings with rigid joints or bracings will fall under the category of engineered buildings.

The non-engineered buildings are those which are traditionally and spontaneously constructed by the people through masons, carpenters and petty contractors with little or no intervention of professional designers. The modern looking load bearing brick buildings with reinforced concrete or brick slab roofs or floors will also fall under this category in spite of the facts that the house plan may have been developed by a practising architect and reinforcement in slabs may have been specified by him, since the structure of the building, that is, the wall and piers, remain essentially undesigned and inadequate for the lateral forces of earthquakes. All rural and most semi-urban and urban houses fall under the category of non-engineered constructions which are weak from the seismic viewpoint particularly in Seismic Zones III, IV and V of India which cover about 56 per cent of the Indian territory. The unfortunate situation is that the new housing stock being added even under Government sponsorship by and large does not cater for any earthquake resisting features on the argument of added cost, although the minimum seismic features may not cost more than 2 per cent of the cost of the buildings.

In view of the prevalence of the non-engineered buildings and the least attention they are receiving, this chapter is aimed at the seismic problem of such buildings.

EARTHQUAKE FORCE

Earthquake 'force' is a misnomer in the sense of an 'external' load acting on a structure. Earthquake by itself consists of a set of compressional and shear waves passing through the earth's crest shaking the structure up and down as well as sideways in a random manner. Forces are caused 'internally' in the structure due to inertia of its masses at any instant of time. The important points to note are that :—

(i) During an earthquake the whole structure including its contents whether resting on floors or attached to the walls are shaken from their position of rest.

(ii) The movements are alternating in directions, both horizontally and vertically. The number of reversals would be few to many in each second depending on the characteristics of the earthquake accelerogram and those of the structures.

(iii) Horizontal and vertical forces, which vary at different instants of time, are caused on the masses of the structure. Anything not possessing mass will not give rise to earthquake force.

(iv) The maximum forces generated in the structure strongly depend on the mass and stiffness distribution in the structure, the manner in which it is supported on the foundations, the damping and energy dissipation characteristics of the materials and structure of the system.

(v) The type and extent of damage to the structure during an earthquake depends on the strength of materials of construction, the structural systems, joint details, quality of construction, foundation stability and strength, *etc.*, besides the intensity of earthquake shocks.

The earthquake-structure interaction is best represented by acceleration response spectra shown in *Fig. 1.* Here it will be relevant to state a few important points.

(i) For most small buildings, the time periods will lie in the short period range, less than 0.5 sec., and the maximum elastic response accelerations will be several times the peak ground value.

(ii) In most earthquake codes of the world, the design seismic coefficients are a small fraction of the values indicated by elastic response spectra, which may usually be four or more times the former.

(iii) The gap between the maximum and design acceleration value is explained by several factors, *viz.*, occasional nature of the earthquakes, energy dissipation through plastic deformations, damage of non-structural elements causing absorption of earthquake energy, *etc.* To avoid collapse, therefore, ductility or plastic deformation capacity is a vital requirement of the structural systems.

(iv) The effective time period of the structure can be elongated and elastic response reduced by base-isolation techniques. For small buildings, the 'sliding concept' in which sliding of super-structure at plinth level is permitted, has been found quite effective in controlling the inertia forces in the building super-structure.

Taking various considerations into account, for small buildings the seismic coefficients given in *Table 1* may be considered representative.

TABLE 1

SEISMIC COEFFICIENTS FOR SMALL BUILDINGS

Design Condition	Seismic Intensity Zone Indicated by Maximum MM Intensity VII	VIII	IX
(a) For working stress design of buildings of wood steel or reinforced concrete*	0·04	0·05	0·08
(b) for determining reinforcing requirements of masonry buildings	0·16	0·20	0·32

*It is assumed that the resulting structural system will have appropriate design details to make it ductile with a ductility ratio of about 4. Also, for important buildings like community buildings, the coefficients may be increased by 50%.

BEHAVIOUR OF BUILDINGS AND TYPE OF DAMAGES

The supporting members, walls piers and columns, which would carry basically vertical loads without earthquake or wind, are subjected to horizontal bonding and overturning effects as well, under these forces. The stress condition in a typical pier will change from uniform compression to that of compression bending and shearing combined as shown in *Fig 2*. An important point to note here is that whereas the compressive stress before earthquake remains fixed in value, the bending and shearing stresses due to earthquake or wind increase proportionately to their magnitude. The resulting stress distribution may be as at (d), (e) or (f) depending on the value of lateral force. Hence the net tensile stress increase is out of proportion to the lateral force, the increase being much faster. Thus checking of brittle structures at low values of design seismic coefficients gives little guidance about their safety in a real earthquake. It is for this reason that higher seismic coefficients are recommended in *Table 1* for checking the reinforcing requirements of brittle structures.

MATERIAL PROPERTIES

From the seismic view point, the following material properties and characteristics are most important :

(i) Unit Weight; lighter the material consistent with strength, the better it is.

(ii) Strength; compression, tension and shear including dynamic effects, if any, for strain rates as induced during earthquake motions.

(iii) Modulus of elasticity including strain-rate effects.

(iv) Damping value at various strain levels, higher the better.

(v) Lateral load-displacement characteristics of elements and components under reversed loading including plastic deformation.

(vi) Durability, that is resistance against weathering action, corrosion, insect attack, *etc*.

(vii) Fire Resistance.

The status of determination of some of the above properties for certain common building is presented in *Table 2*. It will be seen that whereas most of the properties are determined by tests for the materials used in engineering constructions, such as timber, concrete, and steel many properties for the commonest of the materials used in dwellings have not yet been properly determined. Therefore for applying proper engineering principles to their designs, extensive research has to be undertaken up in this regard.

TABLE 2

PROPERTIES OF CERTAIN COMMON BUILDING MATERIALS*

Sl. No.	Material	Mass Density	Comp. Strength	Tensile and Shear Strength	Elastic Modulus	Damping	Hysterosis Shape	High Strain Rate Effect
1.	Adobe	B	C	X	X	X	X	X
2.	Burnt Brick in Mud Mortar	B	C	C	C	C	X	X
3.	Burnt Brick in 1:6 Cement Mortar	A	A	B	B	C	X	X
4.	Burnt Brick in 1:2 Lime-Surkhi (Powered Brick) Mortar	B	B	C	C	C	X	X
5.	Random Rubble, Half Dressed (Field Stone) Masonry in Mud Cement or Lime Mortar	B	X	X	X	X	X	X
6.	Dressed Stone	A	B	X	X	X	X	X
7.	Timber	A	A	A	A	C	X	X
8.	Cement Concrete (1:2:4)	A	A	A	A	B	C	B
9.	Mild Steel	A	A	A	A	B	A	A

*Determined very well—A
Fairly well —B
Little —C
No information —X

STRUCTURE SYSTEMS

There are three main components of the structure of dwellings; foundations, walls and roof. Whereas the roof structure is practically independent, the type of foundation is closely related with the wall types. Those commonly used for dwellings along with some variations in their details are described below.

(i) *Earthery Houses*

Construction Types : The basic material for their construction is clayey earth either in mud lump form, or rammed earth in wood forms or rectangular shaped bricks and blocks, called adobe. Usually the naturally available soil is used without treatment except mixing of some fibrous material like straw, hay, human hair and horse's hair, etc.. For one storeyed houses the walls are kept 30-35 cm thick for adobe and 40-50 cm thick for other types. The thickness is increased in the lower storeys of 2 or 3 storeyed houses. Sometimes the thickness of the walls is tapered upwards. In some variations, wooden elements in the form of sawn lumber or original tree-branch form are inserted between courses particularly at the corner and T-junctions of walls.

The room enclosures in earthen houses are usually of small dimensions 3m×4m or so in plan particularly when pitched roofs are used. But in case of flat roofs consisting of wooden log beams or sawn lumber, the length of the room may even be 10m long keeping the clear span as 3m.

In two or three storeyed houses, which are used mostly in dry climates, the intermediate floors consist of wooden beam and planks in some cases while in some others they are heavy, consisting of wooden beams, reels or tree branch decking and earth cover.

In 'Dhajji Diwari' construction prevalent in Kashmir, pillars of adobe 60 cm × 60 cm in size are constructed at every 1.5 m to 2 m centres, the intervening space being filled with bricks or stones. The floors are of wooden joists and planks. The joists rest on wooden wall plates and also, sometimes, have wall plates on top of them. These wooden wall plates form runners all round the houses. The roofs are usually pitched.

Another variation of earthen houses is where the pitched roof of thatched or tiles is supported independently on wooden posts just on the outside of the clay enclosures.

A better quality construction than pure adobe construction is composite wall construction in which the outer face of the wall is built-in burnt bricks laid in mud mortar, the inner is built from unburnt bricks and the two are bonded together by header bricks. The outer layer protects the wall from erosion during rains and helps in carrying the vertical loads of floors and roof in a better way.

Earthquake Behaviour of Earthen Buildings : The performance of earthen houses during earthquackes of MM VII or more has been generally very poor consisting of wide cracks in the walls and separation of walls at corners. Complete collapse of walls, roofs and floors leading to death and injury to the residents are also common. Due to heavy mass of debris, rescue work of buried people also has been found to be difficult and time-consuming. Even more so if the streets get blocked by fallen debris. Single storeyed adobe and rammed earth houses with flat heavy roofs have shown fair behaviour during the Dhamar Yemen earthquake of Dec. 1982 even in MM VIII area, in that they did not collapse and cracking damage was minimum, but most of the two and three storeyed houses collapsed completely.

(ii) *Burnt Brick Buildings*

Construction Types : The basic materials for these constructions are fired bricks, prepared in different sizes in various countries, by hand moulding or machine moulding and fired in different types of clamps and kilns. The standard nominal size including mortar joints in India is 23.8 cm × 11.4 × 7.6 cm (9″ × 4½″×3″). Modular bricks having nominal size 20 cm × 10 cm × 10 cm have also been suggested and to a limited extent adopted in practice. The following wall thickness are commonly adopted.

Partition walls, non-load bearing . .	11·4 cm (4½″ or 1/2 brick)
Load bearing walls, one storey in mud . .	23·8 cm (9″ or one brick)
Load bearing walls, two storeyes in cement or lime mortar . .	23·8 cm (9″ or one brick)
Load bearing walls, First of 3 storeyes in cement or lime mortar .	35·2 cm (53½″ or 1½ brick)

The room sizes depend on the types of roof. Where flat roofs are used consisting of wooden joists, the room width is restricted to 3 to 3.4 m and length be any thing from 4 m to 8 m or even more. Sometimes wider rooms are obtained by using an intermediate girder of steel or timber. Constructions in town and cities are making increasing use of reinforced concrete or reinforced brick slab. Room widths may be upto 3.5 m for slabs and still wider if T-beams are used.

In India, mostly English Bond is used for the construction of wall, that is 'stretchers' and 'headers' in permits breaking of vertical joints. With standard bricks, the overlap is 5.7 cm (2¼"). Normally 'toothed' joint is made between the walls meeting at right angles, although the joints in practical constructions are rarely fully filled up.

Foundations normally consist of stepped types syrip footings over rammed earth and brick bats. Second class bricks, slightly under as overburnt, are mostly used in foundations. The plinth masonry is kept half a brick thicker than the walls at ground floor. In first class construction, the base may be made using lime concrete with brick aggregate or lean cement concrete of 1 : 4 : 8 mix.

A variation in this form of construction is the use of brick piers having sides of 1½ brick thickness spaced at about 3 m having unburnt brick infill panels. The piers have independent footings projecting by about half brick in each direction beyond the pier. It is not unusual in on these cases to use wooden ring beams on top of walls to receive the hipped roof.

Brick masonry is not only used for small dwellings but also for schools, dispensaries and other community buildings. In these cases, larger enclosures are used of size such as 5 m × 7 m and roofs consist of RC T-beams and slabs. In such buildings, thicker walls, better mortar and qualified engineering supervision is used. Although the National Building Code of India gives the procedures for 'calculated' masonry, wall thickness is rarely calculaed. For earthquacke safety, these buildings need special design and cannot rationally be covered by general rules as applied to houses due to longer spans of walls and larger heights.

Earthquake Behaviour of Brick Buildings : The performance of brick buildings during earthquakes has been much related with the type of roof, the mortar used and the quality of construction. Performance has been poor with piched roofs having no binding effect on walls, poorer wih mud or weak mortars and still poorer with poor constructions. Ironically, the quality of construction is seen to improve automatically with the quality of mortar since supervision becomes stricter.

Behaviour of brick buildings having arched roofs without ties has been catastrophic; so also those having wood-joists-clay type flat roofs over long rooms.

Buildings with rigid slab roofs have generally behaved much better than others due to their binding effects on walls as walls-diaphragm action by which lateral load is transferred to shear walls is available in the direction of earthquake motion.

Cracking is frequently observed in diagonal or cross form in the masonry piers between the openings, vertical cracks near the corners leading to separation of perpendicular walls through the toothed joints, and horizontal bending cracks in the walls which are at right angles to the predominant direction of the earthquake.

(iii) *Stone Masonry Buildings*

Construction Types : The basic unit of stone masonry is natural stone which is used in masonry work in random rubble, half-dressed or fully dressed state, the mortars being mud, cement, or lime. Dry masonry without any mortar is also adopted. Random rubble in mud being the cheapest construction where stone is locally available, is the commonest of the three types. Fully dressed stone construction is very costly in terms of labour and is therefore sparingly used. In half dressed stone masonry, the outer facia is constructed with stones with outer face dressed to rectangular slope but the inside wythe consists of field stones. It thus forms two, more or less independent wythes with mortars and chips filling in-between them. The wall thickness varies from 45 cm to 75 cm and could even be 90 cm in 3 to 4 storeyed buildings. When used with wood-beam-clay floors and roof, the building becomes extremely heavy having loads of say 5 t/m² of covered area. Foundations are also constructed in stone but where exposed rock is available on surface, the construction is started from the rock itself. A few of the variations are stated below :

— Single storey with pitched roof sloping both ways. Walls about 2 m high with gables in stone masonry; rooms 3 m × 4 m.

— Single storey with flat roof consisting of wooden logs used as beams, with tree branches and bushes making the deck with clay topping; rooms 3 m × 4.5 m, but sometimes long room upto 8 m are also made.

— Single storey laterite stone unit walls 25 to 30 cm thick with hipped roof. Rooms may be wide and long, 6 m × 9 m having an inner row of wooden posts.

— Single storey stone house with RC slab roof, 3.5 m × 4 m or so; typical height being 2.4 m.

— Two storey with attic floor extra, intermediate floors of wooden joists and boards with clay-cowdung, topping. Rooms upto 3 m × 7 m, stone gables.

— Three to four storeyed, 10 m × 12 m in plan with heavy clay door and roof having some rooms 3 m wide and 10 to 12 m long.

Performance During Earthquakes : The performance of stone masonry buildings during an earthquake has been most disastrous except where fully dressed stone with cement mortar is used. There are inumerable instances of complete collapse of such building in all seismic affected countries of the world, leading to death or serious injury to the inmates.

(iv) *Wooden Buildings*

Construction Types : Wooden buildings include those in which the main load bearing structure consists of wooden columns and frames, although the cladding may be of brick or stone. The wood used in construction includes logs, sawn lumber of various wood species as well as bamboo. The systems of construction can broadly be classified into two main forms viz. stud wall and brick nogged timber frame.

Stud wall construction consists of wooden sill plates laid at plinth level into which are framed vertical wooden posts at short distances of about 80 to 120 cm. The studs carry wooden plates at their top to which they are framed and the connections between these plates at corners and junctions of walls stabilize the framing. The sill plates are fixed to the masonry plinth by means of iron bolts of wire. Horizontal members of lighter cross-section are inserted between the studs at regular intervals. These are also either notched into the studs or spiked to them. The roof is pitched or nipped type having wooden rafters and purlins to which the sheeting is nailed or bolted. The wall cladding consists of sheets, boards, *etc*. Sometimes, the panels are also diagonally braced.

The brick nogged timber frame consists of heavy corner columns, sills, intermediate verticals at about 1 m centres, wall plates, horizontal nogging members, and diagonal braces in typically alternate panels, framed into each other. The space between framing members is filled with tight fitting burnt or unburnt brick masonry in stretcher bond, called brick nogging. Flat stone (slate, laterite) filling is sometimes used. The roof is invariably hipped or pitched with sheating or tile covering. Thatch is also sometimes used. Most houses of this type are two storeyed having an intermediate and an attic floor. Sometimes more than two storeys are also made.

The foundation of both types of wooden houses is usually random stone masonry in mud mortar. Cement or lime mortar is used for official buildings.

There are other types also which have extremely low cost, like log houses, wattle and daub, bamboo and thatch type huts used by very poor people. The pattern varies very widely from place to place. These are usually safe during earthquakes. They would be critical if constructed in cyclone affected areas where the people keep heavy things like stones so that they are not blown off.

Performance during earthquakes and wind storms: The earthquake performance of wooden buildings has generally been good, particularly that of the wooden frame, and also where the cladding consists of sheeting, boarding, Ikra walling, bamboo matting, etc. The brick or stone infills have frequently shown movement out of the plane of frames. The most dangerous aspect of wooden buildings has been their poor fire resistance and the danger during earthquakes, due to kitchen fires as well as due to short circuiting of electrical wiring. The sheeted roofts as well as the light framework are vulnerable to cyclonic winds and tornadoes. Unreinforced masonry chimneys frequently fall down.

Building Standards and codes or construction practices

Section 1 'Loads' of Part VI—'Structural Design' of the National Building Code contains provisions pertaining to design of structures against seismic loads. Some of the important provisions stipulated in the Code for design of structures against seismic forces are given below ;

The movement of ground from earthquake shocks causes vibration of the structures. The structure should be designed to take care of the stresses generated from the vibration which can be resolved in any 3 perpendicular directions. The predominant direction of vibration is horizontal.

The vibration intensity of ground depends on the magnitude of earthquake, depth of focus, the distance from epicentre and strata on which the structure stands. The Code specifies that important structures should be designed for maximum vibration intensity expected at the place.

The response of the structure to the ground vibration is a function of the nature of the foundation soil, materials, form, size and mode of construction of the structure and the duration and intensity of ground motion. This section of the code specifies design/acceleration for structures standing on soils which will not settle considerably or slide appreciably due to vibrations lasting for a few seconds.

The Code specifies that (a) in the case of structures designed for horizontal seismic forces only, it should be considered to act in any one direction at a time. Where both horizontal and vertical seismic forces are taken into account, horizontal force in any one direction, at a time may be considered simultaneously with the vertical forces; (b) The vertical seismic coefficient should be considered only in the case of structures where stability is criterion of design or for overall stability.

The Code further clarifies that though the basis for design of different types of structures is covered, it is not implied that structural analysis should be made in every case. There might be cases of less importance and relatively small structures for which no analysis need be made, provided certain simple precautions are taken in the construction. For example, suitably proportioned diagonal bracings in the vertical panels of steel and concrete structures add to the resistance of frames to withstand earthquake forces. Similarly, in highly seismic areas, construction of a type which entails heavy debris and consequent loss of life and property, such as masonry, particularly mud masonry and rubble masonry, should be avoided in preference to construction of a type which is known to withstand seismic effects better, such as construction in light weight materials and well braced timber-framed structures. For the specified features of design and construction of earthquake resistance of buildings of conventional types reference may be made to good practice.

The Code provides for the following assumptions in the earthquake resistant design of structures :—

(a) Earthquake causes impulsive ground motion which is complex and irregular in character, changing in period an amplitude each lasting far small duration. Therefore, resonance of the type as visualized under steady state sinusoidal excitations will not occur as it would need time to build up such amplitude; and

(b) Earthquake is not likely to occur simultaneously with wind or maximum flood or maximum sea waves.

Seismic Zones

For the purpose of determining the seismic forces, the country has been classified into 5 zones which are indicated on a Map of India. (Page 64)

The basic horizontal seismic coefficient for 87 cities and towns lying in different seismic zones have been tabulated in the Code. The design seismic forces are computed on the basis of importance of the structure and its soil foundation system for which guidance have been given. The values of basic seismic coefficients and seismic zone factors in different zones have been tabulated.

The Code also gives detailed guidance regarding calculation of horizontal earthquake forces and specific design criteria for multi-storeyed buildings.

Masonry Structure

Masonry structure are highly vulnerable to the destructive forces of earthquake and require special strengthening arrangements. The National Building Code deals with the special aspects of design of masonry structure in Part VI, Section 4.

The special features of design and construction for earthquake resistant masonry buildings applicable to buildings in seismic-zones III, IV and V, are given in the Code with a mention that no special provisions are necessary for buildings constructed in zone I & II. This Part of the Code provides guidance regarding types of bricks and mortars used and the reinforcement required in masonry walls to counter the stresses generated during earthquake. Special construction features required to be incorporated in masonry structures, like lintel-bands, roof bands etc. have been stipulated and detailed guidance has been given as to the quality of reinforcement etc.

RECOMMENDATIONS FOR STRENGTHENING BUILDING AGAINST EARTHQUAKES :

Earthen Houses

The main weakness and defects in earthern houses are,

(i) Poor strength of material in tension and shear and not high enough compressive strength, for two or three storey constructions, against earthquake stresses.

(ii) Poor bond between walls meeting at right angles.

(iii) Large openings being too close to the corners.

(iv) Small bearing length of lintels across openings.

(v) Eroded/deteriorated or unrepaired state at the time of earthquake.

(vi) Height being more than one storey and large storey heights.

(vii) Heavy roofs and floo...

(viii) Poor erosion resistance against rain and flooding.

The following may be considered as good features of such houses and some of the variations used in their construction.

— Cheap initial cost, particularly if constructed through self-help community voluntary activity.

— Good thermal insulation against heat and cold.

— Resistant to fire.

— Fibrous admixtures like straw and cowdung make the adobe and rammed earth strong.

— Tapering walls providing better stability against lateral forces.

— Large savings of energy costs in construction.

— Use of burnt brick outer facia is a good feature against water and wind erosion.

— Application of mud-cowdung mix plaster on outside faces and its yearly repair are good for maintenance of the house.

— Wooden wall plates in continuous runner form provide integrity to the enclosures as a box against lateral forces.

Precautionary and Strengthening Measures : Water is a most detrimental to clay/mud houses and the following precautions have to be taken.

— Construct foundation with burnt brick or stone in lime or cement mortar upto plinth level.

— Provide plinth level above the storm water flow level.

— Keep the roof with good projection, say half a meter beyond the walls to drain the rain water away from the walls.

— Make the roof waterproof by embedding a layer of black-polythlene sheet in the roof clay cover.

— Use a water proof plaster on the outside of the house.

From the earthquake view point, the following may be done :

— Restrict length of rooms to about 4 m. maximum and storey height to about 2.8 m.

— Use symmetrical rectangular house plan, arrange openings symmetrically.

— Restrict height to one storey only.

— Restrict openings width to one-third of the wall length and place these away from the corners by about three times the wall thickness.

— Use clayey soil with about 20% clay and adequate fibrous admixtures, both for adobe units as well as for mortar.

Use adequate bond beams on all outer and inner walls with full continuity at junctions. Bond beam could be of reinforced concrete, wood or bamboo.

— Select roof of minimum weight as far as possible.

In the above recommendations, bond beam is the only component requiring additional cost. If more investment can be made, it will be desirable to,

- Use water proofing admixture, like cement, lime or asphalt in making adobe and mortar.
- Use compacted adobe pressed with machines.

In case of seismic intensity of MM IX or more, vertical reinforcing of adobe walls by bamboo or cane, pretreated against white ants, will also be desirable for greater safety against collapse.

Burnt Brick Buildings :

The following may be considered as defects and weaknesses in burnt brick buildings :

- Poor strength of material in tension and shear, particularly where mud mortar or lime-sand mortar weaker than 1 : 3 or cement mortar weaker than 1 : 6 is used.
- Toothed joint causing a vertical plane of weakness between perpendicular walls.
- Large openings and their placement too close to the corners.
- Eroded mud mortar due to lack of protection or maintenance.
- Very long rooms having long walls unsupported by cross-walls.
- Unsymmetrical plan of building, or with too many projections.
- Poor quality of construction.
- Use of heavy roofs having flexibility in plan.
- Use of light roofs with little binding effects on walls.

The following are good features burnt brick buildings :

- Durable construction lasting hundreds of years with minor maintenance.
- Traditionally constructed through local artisans.
- Comfortable interior, reasonable insulation against heat and cold when one brick thick walls are used.
- Resistant to rain and flooding if erosion from the surface of mud mortar is prevented with cement or lime pointing or plaster or if these mortars are used in construction.
- Resistant to fire.
- Burnt brick buildings are considered of status in the society.
- Well constructed and integrated brick wall enclosures provide good stability against vertical as well as lateral loads, permitting use of even thinner wall than one-bricks for load bearing constructions.
- Use of rigid slab floors and roof is a good feature for improving stability of brick wall enclosures.

Earthquake Protection Measures : For earthquake resistance the following measures have been found effective not only in preventing collapse but controlling the propagation and widening of cracks :

- Symmetry and rectangularity of building in plan.
- Symmetry in the location of openings.
- Simplicity in elevation that is avoidance of ornamentations, large cornices, etc.
- Intersecting internal walls in good number so as to divide the total plan in square enclosures of not more than 6 m side.
- Total width of openings in a wall not more than 50% of wall length in one and two storeyed houses and not more than 40% in three storeyed buildings.
- Width of piers between openings or from opening to wall corner not less than half the height of opening.
- Use of steel or wooden dowels going into walls meeting at corners or T-junctions to provide effective bonding between them, say every fourth course.
- Use of bond beam or band of reinforced concrete at lintel levels of openings and serving as lintel too. This is one single feature which is most effective in ensuring the integrity of enclosures like a rigid box.

Sections of the building, viz, corners and junctions of walls and jambs of opening, going from foundation into the floors and roof slab, so as to provide strength and ductility to the shear walls.

Seismic analysis of 3 to 5 storeyed residential flat type buildings constructed in brickwork, in cement or lime mortar, situated in MM VIII zone indicates that tensile and shear stresses increase rapidly in the shear wall piers as the building height increases. It will therefore be advisable to restrict the building height to three storeys in MM IX zone and to four storeys in MM VIII zone.

Stone Masonry Buildings

The following are the defects and weaknesses in stone masonry buildings of random rubble or half dressed types :

- Weak in tension and shear and unstable configuration of stones when shaken from initially constructed position making the wall collapse due to heavy vertical loads.
- Very weak bond between walls at right angles to each other leads to very easy separation.
- Delamination of wall into separate outer and inner wythes due to absence of 'bond' stones.
- Easy shattering and collapse of stone gables.
- Poor quality of construction.
- Poor state of maintenance.
- Very heavy mass.
- Flexible floors and roof, little binding effect on walls, no diphragm action.

The following are the good features of stone masonry buildings :

- Durable construction in non-seismic areas.
- Traditionally constructed through local labour and local materials.
- Good insulation from heat and cold due to large wall thicknesses.
- Resistant to fire.
- Stone buildings with half-dressed stone facia and pointing considered of status in the society.

Earthquake Protection Measures : For stone masonry buildings, all the protective measures as for brick buildings are found useful. For random rubble and half dressed stone masonry, the following additional measures are absolutely necessary :

- Provision of 'through' stones or 'bonding' elements along the wall thickness at regular intervals of about one element per sq. m. of wall.
- Restriction of the thickness to not more than 45 cm since larger thickness encourages undesirable filling material inside, adding to mass but reducing strength.

Wooden Buildings

The following can be listed as the poor features or defects in wood houses of common construction :

- Short life of untreated wood due to rot and white ant attack.
- Loss of strength of wood due to weathering action, particularly when it is exposed to the action of sun and rain.
- Loosening of joints due to drying with age and weathering action etc.
- Prone to fire hazard.
- Falling of brick nogging during earthquake shaking.
- Tearing apart of roof and frame during high winds.
- Use of brick or stone chimney flues.

The following are the good properties and features of wood construction, for seismic forces :

- Light weight.
- Good tensile and excellent impact or shock resistance.
- Braced as well as nogged frames have high lateral load resistance.
- Joints with steel straps stay tight for long and maintain the frame in excellent stiff condition.

Precautionary and Strengthening Measures : To make wood houses durable and weather resistant, the following actions are found effective :

- Use of anti-termite treatment of the house site particularly inside the foundation masonry and over a metre or so outside.
- Use of rodent shield just above plinth.
- Use of seasoned and chemically treated wood.
- Use of steel straps at the splices and joints with screwed or bolted connections, or nails clenched across the grain on the opposite face.
- Use of water proof paint on all exposed surfaces.
- Use of fire-resistant paint on inside surfaces.
- Adequate, say 50 cm, projection of roof beyond wall frame for protection against rain.

For achieving resistance against lateral loads of wind and earthquake, the following are necessary :

- Installation of diagonal braces in all vertical planes of the wood frames or stud walls.
- Bolting down of the sill plates to the plinth masonry.
- Continuous top plate all around acting as 'Band', connecting all wall frames.

— Installation of horizontal diagonal braces at the corners and junctions of walls for providing resistance against torsional effects.

— Holding down of sheeting to purlins to rafters and so on, with adequate resistance against wind uplift.

— Use of asbestos pipe chimney for the flue gases or reinforced brickwork.

— Fixing of brick nogging to wooden members through shear connectors or holdfasts.

R & D Work

On the basis of the work reported herein, the status of studies in regard to earthquake disaster mitigation as well as the areas for further work in this direction are briefly summarized in this section.

India in fact has been the pioneer in regard to earthquake safety of such buildings, particularly the brick buildings. The research work had started in 1960 on strength of piers and walls with and without openings, under static and lateral loads. The work was further developed towards dynamic testing using a railway wagon shock table on which 1/3 and 1/2 scale specimens of one room enclosures have been tested and very significant new concepts have been developed. The work has however, suffered setback due to non-availability of modern earthquake-simulating shake table on account of which the results can not be fully proved under real earthquake situations. The testing facilities have also to be updated.

Further detailed research work is required on the following specific areas :

(i) Determination of material properties to remove the deficiencies indicated in *Table 2.*

(ii) Detailed survey of house construction types in India for identification of critical points of weakness against seismic effect; and further research for removal of the same through minimal modification.

(iii) Simulated earthquake withstand tests on various house types.

(iv) Preparation of appropriate literature and models for effective dissemination of already available knowledge regarding earthquake safety for each region in the language of the region, based on seismicity level, and prevalent construction.

(v) Preparation of model municipal byelaws suitable for the different regions.

(vi) Research in repair and strengthening techniques of existing important buildings, such as schools, hospitals and other various techniques for determining their effectiveness.

Most of this research work can be conducted in collaboration between Department of Earthquake Engineering, Department of Civil Engineering both at the University of Roorkee and the Central Building Research Institute, Roorkee, Structural Engineering Research Centre, Roorkee/ Ghaziabad. Visible results can be achieved within a period of five years through a mission oriented coordinated project involving laboratory research on materials, field surveys, large scale shake table tests, information, dissemination and implementation programme taken together.

RECOMMENDATIONS

The following recommendations can be made based on the above study of the materials and construction aspects of small buildings in relation to earthquake risk mitigation.

1. The materials normally used in small building construction have received little attention for determining their properties which are relevant to rational design against the natural hazards. This requires long range programme of testing. This could be done at an institution such as the Central Building Research Institute and the Civil Engineering Department, Roorkee University.

2. The structural systems are broadly well understood which would make the houses hazard resistant. They can qualitatively be ranked as very good, good and poor by using the results of crude analyses and performance observed during earthquakes. But the precise quantitative ratings cannot be made for want of controlled test data on earthquake simulating shake-tables. This would require a well thought out shake table testing programme. This testing programme, could be carried at Department of Earthquake Engineering, University of Roorkee.

3. Dwellings constructed according to tradition generally require only minor and low cost modifications and strengthening measures for raising their hazard resistance levels sufficiently so as to prevent their complete collapse. Appropriate guidelines are already available in IS : 4326-1976 and IAEE Monograph on Non-Engineered Construction reprinted as Manual of Indian Society of Earthquake Technology. Implementation effort must now be made through the mass media, the construction and funding agencies such as HUDCO.

A large outlay is envisaged for construction of housing during the Seventh Plan. This opportunity should not be lost and it must be ensured that all new houses are built with already known earthquake resisting factures.

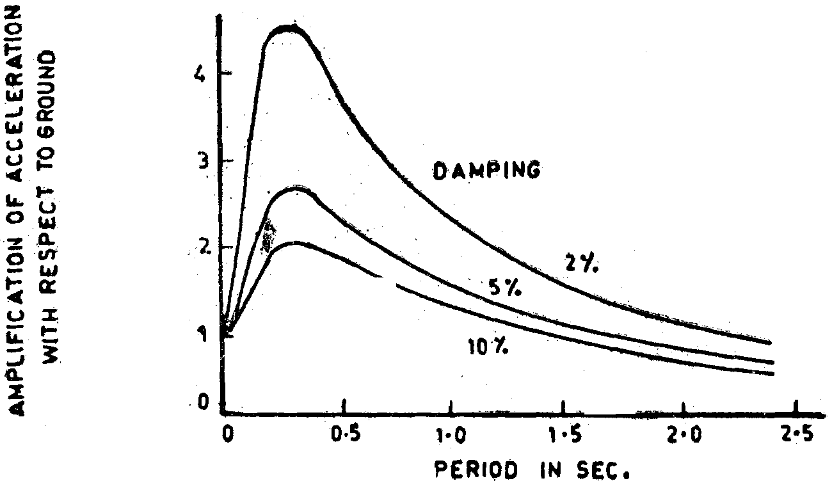


FIG. 1 ACCELERATION SPECTRA OF EARTHQUAKE

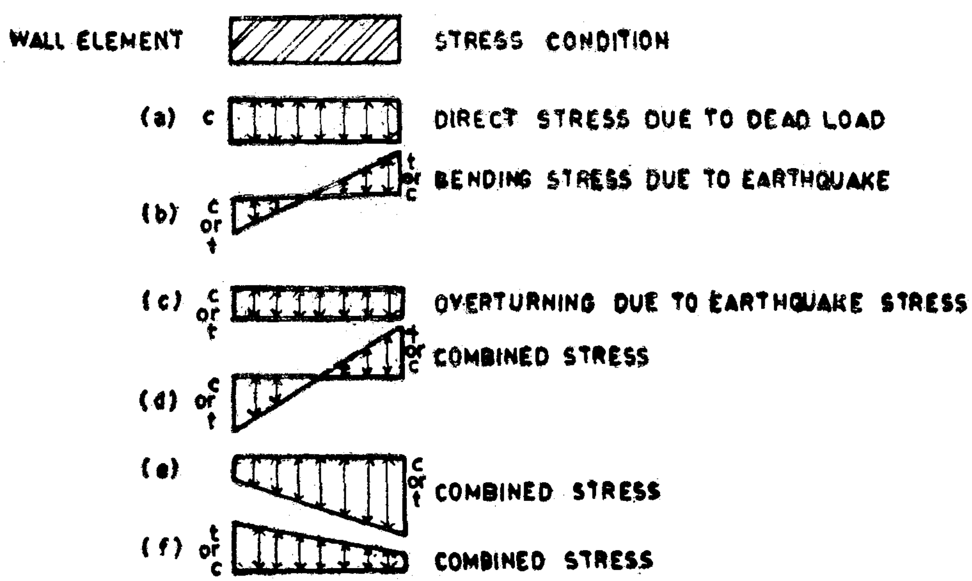


FIG. 2 STRESS CONDITION IN WALL ELEMENT

2.4 *FIRE*

INTRODUCTION

Fires are unwelcome but frequent hazards in most countries and seem to go hand in hand with industrial and urban development. Industrial development introduces operations and processes in which energy is extensively applied and organic materials are handled in large quantities. Any misuse or mishap can lead to a fire, resulting in costly damage. Urban development leads to congested lay out of buildings and high occupancies, where fires can have tragic consequences. The Fire Research Station, U.K. using statistical approach in analysing building fires has concluded that :—

(i) Numerically large fires constitute only about 1% of all fires, but they account for about 60% of total fire damage.

(ii) The chance of all fires spreading beyond the room of origin (Ps) and the chance of fires becoming large (P L) are approximately related as $P_L = Ps^3$

(iii) The chance of a fire becoming large is about 4 times as great at night than during the day.

(iv) The critical area of a fire is about 40 sq. m. and that the critical control time, which is related to the size of fire on arrival of the fire brigade is about 20 minutes after which the fire may be uncontrollable.

(v) The time to detection i.e. time from ignition to detection of fire is very important. Since the fire brigade attendance time is large it is therefore essential that detection time is reduced to minimum so that losses due to large fires specially at night may be considerably reduced.

Direct damage by fire can occur not only to buildings but to equipment, work in progress, stores, records and other contents. Incidental damage also arises from heat, smoke and the water used in fire-fighting. The fire loss statistics are not available either in an upto date or complete form. Nevertheless, the total annual fire losses are believed to run into Rs. 1000 crore per annum. Destruction by fire is estimated as much as a fourth of 1% of the Gross National Product, every year. Fire casualties are 5–6 lakhs per annum of which 1 lakh are fatal, 8 out of every 10 of these are women and children. It therefore necessitates an urgent need for introducing adequate fire prevention and fire safety measures in our country.

Buildings of all types-residential, industrial, community and office buildings account for a sizeable portion of capital investment and national wealth and represent potential fire hazards. A number of building regulations in our country relate to fire prevention. Some are based on sound appraisal of what can and does happen in fire, while others are based on grounds which are merely speculative. In the past it has sometimes been possible to meet the fire requirements in the course of satisfying other criteria such as those relating to the strength of structures. But the use of new building materials make this more difficult.

STAGES IN THE DEVELOPMENT OF A FIRE

The development of a fire in a building can be regarded as following the three stages of growth, steady burning and decay shown in Figure 3. In practical circumstances the stages may be considered as outbreak, spread and extinguishment. Structural fire precautions are concerned principally with the spread of fire (covering the growth and steady burning stages) since outbreak is in most cases accidental and frequently not associated with the building structure, and extinguishment normally accelerated by fire-fighting measures, most of which will be independent of the structure.

Prior to flashover the ignitability, flammability, fire spread, heat release and the production of smoke and toxic products of the contents and linings are relevant. Thereafter the behaviour of structural elements in preventing collapse of the building and minimising the spread of fire becomes important.

Outbreak

The initial cause of many fires is a small source of heat. It is difficult to legislate against the insidious risk of small local heating such as a discarded match stick, smouldering cigarette end or an electrical short circuit setting fire to readily ignitable materials. Bedding, upholstery and curtains are examples of contents susceptible to ignition. Fires originating in contents are much more frequent than those originating in the structure of a building and can only be prevented by care on the part of the occupants of buildings.

Most combustible materials used in the construction of buildings cannot be readily ignited by a small source of heat. The most vulnerable parts of a building in this respect are the materials comprising the surfaces of walls and ceilings. Whilst only a few of these that are commonly available can be readily ignited by a small source of heat, many will ignite and continue to burn if subjected to flame from the burning contents of a building. Some contribution towards reducing the number of serious outbreaks of fire in buildings can therefore be made by ensuring that surfaces consist of materials that are difficult to ignite. This can be done by using materials that have low surface spread of flame characteristics, since this is also (to some extent) a measure of their resistance to ignition.

Ignition

This requires a source of heat, combustible materials, and air. Materials vary in their case of ignition, and both their physical form and chemical properties are important. Thus sheets of materials, foams or bulk fibres are more easily ignited than thick solid blocks. *Materials* can be treated to reduce their case of ignition from small sources but such treatments do not necessarily affect their rate of burning in a fire. The principles of protection are primarily to segregate all possible known ignition sources from combustible materials. Where this cannot be done, for example cigarettes and matches from furnishings, fire protection ensures that the materials are not readily ignitable from such sources and are of such a type that, even if ignition occurs, the ensuing fire will not develop rapidly.

Spread of Fire Within the Room of Origin

Once a fire has started it is likely to spread by radiation and convection (direct contact with flames and hot gases) among combustible contents and over combustible surfaces in the room of origin. Initially the fire spreads more readily upwards than sideways, and more rapidly over low density combustible materials such as plastics foams and other insulating materials rather than over combustible materials of higher density, such as wood.

When flames reach the ceiling they 'mushroom' beneath it and even if the ceiling is non-combustible, the horizontally extended flames radiate heat downwards, increasing the rate of fire spread among the contents. This effect can be much greater when a combustible ceiling is involved. Materials that delaminate, disintegrate or melt, such that burning pieces fall towards the ground, can greatly accelerate fire spread.

At some stage the air in the room may become sufficiently lacking in oxygen to reduce fire spread, but an extreme hazard to life exists before this situation arises.

A phase of very rapid fire growth occurs (flashover) and all the combustible materials in the room eventually contribute to the fire. Before this stage is reached all life is extinct in the room of origin and there is grave danger to occupants of adjoining rooms.

Fire spread can be slowed down by correct wall and ceiling linings and by using only suitable furnishings, curtains etc.

Spread of Fire Outside the Room of Origin

The routes of fire spread are firstly through any existing gaps or openings in the construction (including doors), secondly by burning through or opening up gaps, and thirdly by heat conducted through the construction. It is therefore important to ensure that elements of building construction (walls, floors, etc.) have the required fire resistance and that gaps or other openings in or between elements are properly 'fire stopped'. Pines and other services passing through walls and floors must conform to the required standards. Ducts must be fitted with fire dampers at appropriate locations.

Spread in Cavities

A particular hazard is caused by extensive cavities in horizontal or vertical constructions. If fire penetrates them, they act as chimneys or flues conveying flames and hot gases over considerable distances. The situation is aggravated when they are lined with combustible materials. Thus all cavities must be sub-divided by cavity barriers at approprate intervals.

Smoke

A fire produces vast quantities of smoke and hot gases which penetrate far ahead of the flames, and although they eventually cool they still constitute a hazard. A very high degree of dilution with fresh air is required to reduce the smoke from the average fire to a concentration which would be acceptable on an escape route.

Spread of Fire from Building to Building

Fire spread from one building to another may occur by conduction of heat or passage of flame through a wall separating adjoining rooms by radiation, or by flying brands or fllame projected across a space separating buildings. In this latter instance the construction and behaviour of external walls and of roof coverings is important.

Building legislation requires that every building shall be so designed and constructed as to

(a) reduce sufficiently the risk of the ignition of any part of the building and the spread of fire within the building, into the building and out of the building; and

(b) withstand the effects of fire for a sufficient period to avoid such collapse of the building as would increase the risk of the spread of fire.

It also requires that—

(c) Every building shall be so designed and constructed that in the event of an outbreak of fire in the building and its precincts. The occupants may come out safely.

(d) All heat-producing appliances, together with the necessary accessories, shall be so constructed and installed as to prevent the ignition of any combustible material forming part of the building, or any combustible material that may be placed against the surface of any wall or other part of the building, enclosing or adjacent to the appliance.

Fire Tests

Regulations normally make use of standard fire tests to specify acceptable performance standards which materials or elements of construction would need to meet in defined circumstances. Developed countries and our own country have their own national test standards and work is continuing at the Central Building Research Institute, Roorkee to extend its range of standard fire tests. However it should be noted that fire tests are essentially attempts to assess at laboratory scale, the burning behaviour of a material, product, structure or system under standardised and reproducible test conditions which approximates to one or more stages of a real fire. Many tests use a specimen which is to small to reflect the structural performance of a material or component in fire, or an ignition source which, being static and often of low intensity, cannot reproduce the exposure conditions typical of actual fires and thus cannot provide a full assessment of the fire hazard. The tests (only useful) compare the behaviour of materials under the specific conditions of test and some may only be appropriate for checking quality control during the manufacturing process. Great caution is necessary therefore in using the results of fire tests to assess potential fire hazard in use. No fire test, or combination of tests, can guarantee safety in any particular situation. Tests can, however, provide data for a systematic approach towards establishing fire hazard or determining the level of fire safety.

Room Linings

Internal linings form large areas of continuous surface which may be heated by the burning contents of a compartment. When hot, these linings will heat-principally by radiation-materials not yet involved in the fire, and if the linings burn the flames will heat in involved materials. The contribution to fire growth from combustible linings is particularly important if heat is evolved at an early stage in the fire before the heat released by the burning contents has reached a significant level. Some indications of the fire hazard of combustible lining materials are given by tests which measure the ease of ignition, the rate of spread of flames over the surface under fire conditions, and the rate at which the materials will contribute heat to a fire. The results obtained in such tests are heavily dependent on the exposure conditions and many other factors, and cannot be interpreted as describing fundamental properties of the materials.

Although, non-combustible materials do not contribute directly to fire growth and spread their thermal insulation properties and heat capacity can affect the development of a fire. Thus materials with good thermal insulation allow a more rapid rise in temperature in the fire compartment, and this may lead to the earlier ignition of other combustible materials present. Conversely walls, floors or ceilings of high heat capacity soak up heat from fire and tend to slow its rate of growth. Building regulations for India according to National Building Code prescribe minimum acceptable test ratings for room lining in different occupancies and situations. The general requirement is class I as per BS 476 : Part 7 (*Fig 4*) but this is relaxed under carefully defined conditions to allow a limited use of class 3 surfaces. Where the highest degree of protection is required for example in circulation spaces which often constitute escape routes, regulations do not deviate from class I.

Untreated timber and its derivatives can generally achieve a class 3 rating; however, the use of flame retardant treatments will enable these materials to achieve class I. Treatments cannot make combustible materials non-combustible nor do they usually affect the rate of charring away of timber in a fire. The types of treatment involve either surface application or impregnation and their action varies; for example, the treatment may provide an impervious barrier over the surface of the material or when heated it may cause a reaction which inhibits combustion or insulates that surface of the material.

The choice of a suitable treatment may depend upon practical considerations such as the type of surface to be treated, over-painting, weathering and smoke emission. The durability of surface treatments should always be questioned, many being degraded by regular wetting, e.g. by rain or condensation.

The choice of lining material will frequently involve consideration of layered or laminated systems. It is, therefore, important that the methods of fixing or bonding use on site will not permit premature delamination in the event of fire, resulting possibly in a markedly different response by an otherwise 'satisfactory' finish or veneer. One of the problems associated with delamination is the exposure of the combustible substracts to the fire sooner than designed for.

Certain plastic materials, because of their softening characteristics, cannot be assessed in the tests for fire performance of building materials. Thermoplastic materials soften and melt in a fire. Those which do so before they ignite do not contribute significantly to fire spread if they fall away from the flames, although falling of hot material may be a hazard to people beneath. Materials which ignite and burn while falling may result in rapid fire spread. The performance depends on the types of plastics material, thickness of sheets and the way they are held in position.

Elements of Building Construction

Regulations require such fire resistance for elements of building construction as will provide reasonable assurance that (a) the elements of structure will not collapse in a fire, (b) fire will not spread from one compartment to another in the same building, and (c) fire will not spread from one building to another.

The fire resistance of a specimen (for example a wall floor, column, beam or door) is determined under IS : 3809-1979 by subjecting it to heat from a furnace which is controlled to follow the time-temperature curve shown in *Figure 5*. The performance of the specimen is expressed as the time in minutes for which the appropriate criteria of stability, integrity and insulation are satisfied. Although the stability criterion is applied to both load-bearing and non load bearing constructions the interpretation is not the same for each case.

Failure is deemed to have occurred in the case of,

Stability—when collapse or excessive deflection takes place.

Integrity—When cracks or other openings develop through which flame or hot gases can pass which can cause flaming of a cotton wool pad. Where the level of radiation is such that the cotton wool test cannot be used, failure shall be deemed to have occurred if a crack or fissure exists or develops exceeding 6 mm × 150 mm.

Insulation—When the mean temperature of the unexposed surface of the specimen increases by more than 140°C above the initial temperature, or the temperature at any point increases by more than 180°C.

Specimens to be tested should be full size or, where this is not possible, should have specified minimum dimensions. Elements are normally heated in such a way as to simulate their exposure in a fire, e.g., walls from one side, floors from beneath and columns from all sides.

Columns and beams have to satisfy only the stability criterion; glazing is required to satisfy only stability and integrity (regulations usually permit doors to be similarly judged since it is unlikely that combustible materials would be stored adjacent to them) and floors and walls have to satisfy all the three criteria.

Walls

Depending upon its situation and function within a building, a wall may be expected to fulfil different requirements in the event of fire. Most fire resisting walls used to separate buildings, enclose compartments and contain fire, will be required to provide a barrier to the passage of fire from one side or the other. They must therefore be able to satisfy each of the three criteria from either side for a prescribed period. Other situations may arise where fire resistance is not required from both sides and where the construction may have to satisfy the criteria to different extents.

Glazed Screens

Because of the transmission of radient heat by annealed glass, construction incorporating wired glazing cannot satisfy the heat insulation requirement for more than a few minutes, although they can achieve results in terms of stability. The function and location of a screen will dictate whether it may be fully glazed, partly glazed, glazed above a minimum height, or not glazed at all. There may be a risk to people escaping past the screen or a risk of ignition of combustible materials stacked in close proximity on the side remote from the fire. However, it should be noted that some unwired glazing products have recently been introduced in Europe, two of which are able to restrict heat transfer, and therefore could be used without the foregoing restrictions.

Doors

Different parts of a building may be separated from each other into compartments by a fire-resisting construction in which openings are closed by doors which have precise functions to fulfil in case of a fire. First, the door assembly should prevent the passage of excessive amounts of combustion products which could interfee with the safe use of escape routes. Second, it should maintain the effectiveness as a fire-barrier of the wall in which it is located. Every fire door is therefore required to act as a barrier to the passage of fire and smoke to varying degrees. These depend upon its location in the building and the fire hazard associated with the building or room, which in turn depends on the nature of its contents, occupants and use.

Most fires start from small sources and develop quantities of smoke in the early stages. There will generally be pressure differences across a doorway caused either by the wind or by the fire itself. These pressures can act either to force smoke through gaps or craks between the door and its frame, or sometimes to oppose its flow. In the absence of effects due to wind or changes in temperature in the fire compartment, the flow into the fire compartment takes the form shown in *Figure 6*.

A door in the walls enclosing the fire compartment will be subjected to these pressures and smoke will be forced through gaps. As the fire progresses, the door may become deformed and allow greater quantities of smoke to pass through. If the fire becomes large the door will be required to withstand exposure to the high temperature conditions without losing its integrity as a barrier to the fire.

Floors

Horizontal elements are heated from underside in the standard test, so the measured fire resistance of floors frequently depends on the protection given by the ceiling on the underside. This is particularly true with the floors of steel or timber joisted construction. Once the ceiling below has been penetrated the joists and underside of the floor boarding become exposed to fire. Although the fire resistance of an element of construction applies to the complete assembly, the stability of any individual member supporting a fire-resisting membrane must be considered.

NATIONAL BUILDING CODE

Chapter IV of the National Building Code is devoted to 'Fire Protection'. It deals with safety from fire and explosion. It specifies the demarcation of fire zones, restrictions on construction of buildings in each fire zone, classification of buildings based on occupancy, types of building construction according to fire resistance of the structural components and other restrictions and requirements necessary to minimise danger to life from fire, smoke, fumes or panic before the buildings can be evacuated. The Code recognizes that safety of life is more than a matter of exits and accordingly deals with various matters which are considered essential to the safety of life.

Buildings have been classified into 10 Groups according to use and characteristic of the occupancy. Residential buildings come under Group 'A'.

Residential buildings (Group 'A') include any building in which sleeping accommodation is provided for normal residential purposes, with or without cooking or dining or both facilities except the buildings classified 'Institutional' (under Group C).

Buildings and structures under Group A are further sub-divided as follows :—

Sub-division A-1 Lodging or rooming houses

Sub-division A-2 One or two-family private dwellings

Sub-division A-3 Dormitories

Sub-division A-4 Apartment houses (flats)

Sub-division A-5 Hotels

Detailed description of the above types of residential buildings is given in *Appendix Page* 37.

This chapter of NBC also gives the estimated fire resistance ratings for different structural elements of buildings.

The fire protection requirements for buildings of more than 15 mtrs. height have also been given therein.

FIRE DETECTION AND ALARM SYSTEM

Early detection and warning system in case of a fire is not only important for the safety of occupants but also for taking first aid fire-fighting measures and for early call of fire brigade before fire engulfs large areas. A study of the circumstances surrounding 342 dwelling fire deaths in Ontario, Canada indicated that the use of smoke detectors could have saved 41 per-cent lives. Further, most large fire losses occur in such buildings when they are not in operation after working hours or during holidays and weekends. Incipient conditions are locked up at closing time, giving plenty of time for fire growth and making headway. Even during business hours, fires in unoccupied or concealed areas are often not detected until it is too late. A detection system by detecting fire in the earlier possible stage allows time :

— for the safe evacuation of buildings;

— for trained firemen to arrive and attack the fire when it is still small;

— to extinguish a fire before enough heat can be generated to trigger a thermal detector for first aid fire-fighting, thus preventing needless destruction of large quantities of materials by fire and water.

Although ionization, photo-electric, infra-red and heat detectors are used depending on the type of occupancy and nature of contents, heat detectors are quite common. Heat detectors should be fitted so that heat sensitive element is not less than 25 mm and not more than 150 mm below the ceiling or roof. Maximum allowable spacing between detectors is 10 m in halls and 15 m in corridors. Closing spacing may be needed in some cases mostly depending on the type of ceiling or roof construction.

However, if economy does not permit automatic detectors, manually operated fire alarm should be provided.

Extinguishing System

No fire can develop into a big fire until it is allowed to grow. After detection of fire, very precious time is lost till the fire brigade arrives. If the extinguishing system is provided in the building, much property loss can be avoided. The system includes :

— Manually operated portable fire extinguishing equipment;

— Fire hydrants at ground level outside the building;

— Wet-dry riser with hydrants on each floor;

— First aid fire-fighting hose reels;

— Automatic fixed fire extinguishing systems.

The systems are usually a combination of automatic fire alarm and fire extinguishing devices. When fire occurs, an audible alarm is sounded and fire extinguishment is immediately started. The extinguishing media may be water, carbon dioxide, halogenated hydrocarbons or dry powder depending upon type of occupancy and material, machinery units etc.

Automatic sprinkler system is very important for certain type of occupancies. Consideration of design and installation of automatic sprinkler system has shown that the cost of sprinkler installation comes to around Rs. 50/- per sq.m. of floor area. Although it adds to the cost of building, it is virtually an assurance for the safety of life and property. Besides, General Insurance Corporation and Tariff Advisory Committee provide rebate of the insurance premium as an incentive.

Escape Routes

Provision should be made for everyone inside a building to escape safely and surely by his own unaided efforts if fire breaks out. Following considerations should be made while designing proper escape routes :

— Two escape routes leading in opposite directions should be available so that (a) no one needs to go towards the fire, (b) all are familiarised with normal stairways.

— More instructions and training is required in case of emergency escape routes.

— In case of long horizontal routes corridors should be provided by fire resisting walls, fire check doors fitted at access points and at intervals in the corridor. The corridor enclosure should have the same fire resistance as the staircase enclosure.

Vertical parts of escape routes should be enclosed such that fire and if possible smoke cannot spread into them and (a) the fire resistance of the enclosing walls and access doors should at least be 30 minutes (b) in case of higher fire resistance of floors, stair case shaft should also have the equivalent fire resistance to preserve integrity of compartment (c) as all staircases require ventilation to remove any smoke which may enter, they are normally best suited against the external walls of the buildings. This also allows advantage to be taken of natural daylight. The interior finish of staircases should be also of non-combustible materials.

— Suitable measures should be provided so that escape routes are not smoke logged.

RECOMMENDATIONS

1. Openings in walls and floors should be properly 'fire stopped'.

2. Cavities in the buildings should be subdivided by cavity barriers at appropriate intervals.

3. A detection system for detecting fire in the earliest possible stage should be installed.

4. Extinguishing system should be provided in the buildings.

5. Proper escape routes should be provided in the building for safe escape of building inmates.

6. Strict implementation of provisions in National Building Code while planning and designing of buildings and houses.

7. While selecting the appropriate techniques of construction, fire safety requirements should be given due consideration.

8. A 'system-approach' has to be followed for meeting the fire-hazard specially with respect to present day trends of high-rise buildings.

9. Materials used for walls and floors finishes should be such selected which are difficult to ignite.

R & D

Although most important aspects of the design of buildings for fire safety are governed by national building codes or codes adopted by different corporations and metropolitan cities even then a competent design team can increase levels of safety beyond regulations provided in the code without any additional expenditure. It should be clear to everyone that fire safety is not something that can be added on after completion of the building. In fact, the problem of fire safety must be taken into account from the first step to architectural design. It is therefore very essential that fire problem should be fully understood.

The Fire Research Laboratory at the Central Building Research Institute, Roorkee has investigated the problems of fire covering aspects of prevention, protection, detection, limitation and extinguishment.

Achievements of the Institute include development of (a) method for fire retardant treatment of thatch (b) fire retardant treatment of curtains (c) fire retardant treatment of 'shamyanas' (d) an automatic sprinkler of the soldered link type (e) a particulate extinguishing agent for liquid fires (f) an extinguishment for metal fires. Besides these our country has distinction of being the only country next to Japan in Asia to have facilities for (a) evaluation of burning behaviour properties of different types of building materials (b) determination of fire resistance of wall, floor, door, bulkhead, deck, glazed window (c) evaluation of sprinklers, detectors, fire-fighting appliances (d) leakage characteristics of doors and windows (e) explosion property of dust, liquid and vapours.

There is need for more research work on new building materials which are being developed in various research laboratories to test fire effects on these.

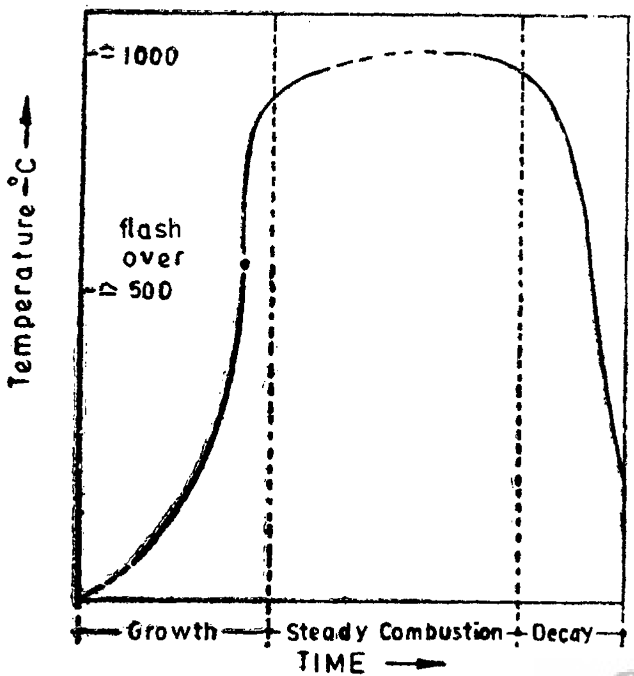


FIG. 3. DIFFERENT STAGES OF A TYPICAL FIRE IN A BUILDING

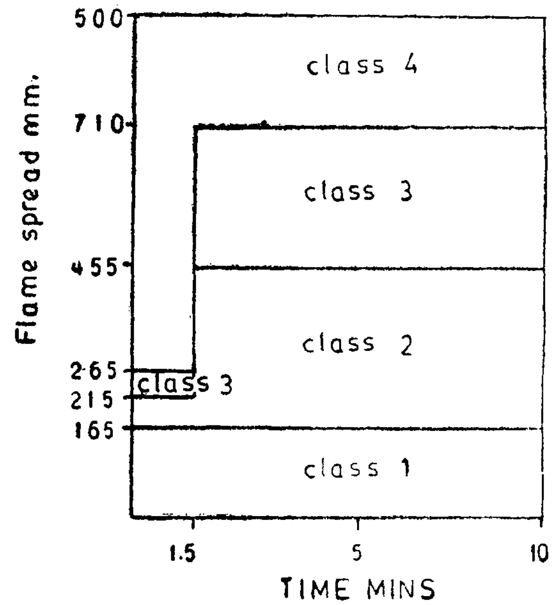


FIG. 4 AN INDICATION OF CLASSIFICATION LIMITS FOR THE SPREAD OF FLAME TEST

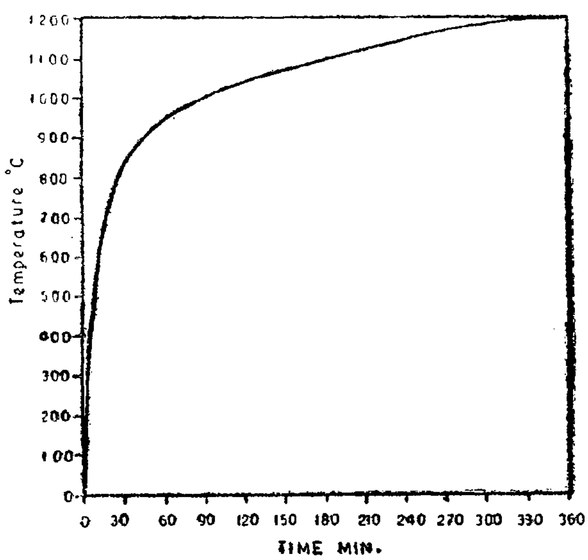


FIG 5. STANDARD TIME-TEMPERATURE CURVE (IS : 3809-1979)

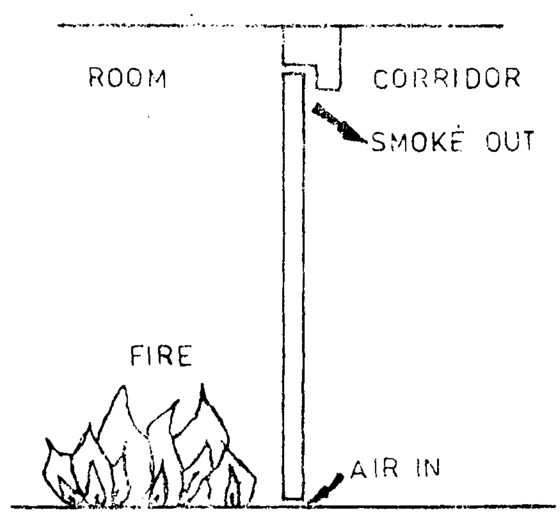


FIG. 6. TYPICAL MOVEMENT OF AIR AND COMBUSTION GASES AROUND THE EDGES OF A CLOSED DOOR TO A ROOM (WIND AND EXPANSION EFFECTS IGNORED)

APPENDIX IX

Details of Sub-divisions of Residential Buildings

(a) *Sub-division A-1 Lodging or Rooming Houses*

These shall include any building or group of buildings under the same management, in which separate sleeping accommodation for a total of not more than 15 persons, on transient or permanent basis, with or without dining facilities, but without cooking facilities for individuals, is provided.

A lodging or rooming house shall be classified as a dwelling in Sub-division *A-2* if no room in any of its private dwelling units is rented to more than three persons.

(b) *Sub-division A-2 One or Two-Family Private Dwelling*

These shall include any private dwelling which is occupied by members of a single family and has a total sleeping accommodation for not more than 20 persons.

If rooms in a private dwelling are rented to outsiders, these shall be for accommodating not more than three persons per room.

If sleeping accommodation for more than 20 persons is provided in any one residential building, it shall be classified as a building in Sub-division *A-3* or *A-4* as the case may be.

(c) *Sub-division A-3 Dormitories*

These shall include any building in which group sleeping accommodation is provided, with or without dining facilities, for persons who are not members of the same family, in one room or a series of closely associated rooms under joint occupancy and single management, for example, school and college dormitories, students and other hostels and military barracks.

(d) *Sub-division A-4 Apartment Houses (Flats)*

These shall include any building or structure in which living quarters are provided for three or more families, living independently of each other and with independent cooking facilities, for example, apartment houses, mansions and chawls.

(e) *Sub-division A-5 Hotels*

These shall include any building or group of buildings under single management, in which sleeping accommodation, with or without dining facilities, is provided for hire to more than 15 persons who are primarily transient, for example, hotels, inns, clubs and motels.

2.5 *LANDSLIDES*

The Himalayas constitutes the youngest system in the world shadowing the subcontinent of India. It is not one long continuous landmass but comprises of a series of curvilinear parallel folds running along a grand arc, convex to the south, generally NW-ENE direction between 27° and 36°N latitude for a total length of 2400 km. The width of the mountain belt is more or less uniformly 320 km throughout its course. Because of very wide variations in geology, geomorphology, climate, altitude and rock types, the Himalayas present a 'treasure house' of landslides having no parallel in the world. History is witness that before Man's intervention in the ecological system large scale displacements of rock masses did block Himalayan rivers, and snow avalanches did hurtle down the slopes in the higher regions as they do now. In the recent years unprecedented and unwise exploitation of Himalayas by men do combine with its immature geology, heavy rainfall, river action and seismicity to produce a variety and class of landslides and other mass movements without any parallel in the world (*Fig. 7*). Implementation of a number of hydro-electric schemes for harnessing of enormous water potential, exploitation of forest produces and establishment of related industries, boosting up of agricultural growth, tourism *etc.*, have further intensified road construction activity right from foothills to altitudes upto 5000 m.

The differing geological settings and formations when exposed to varying climates, hydrological conditions, rainfall, seismicity, flash floods *etc.*, do trigger different kinds of landslides. When left uncontrolled, landslides enlarge themselves generating more furrows, more gullies and more landslides blocking natural drainage, uprooting trees and carrying down all that would have otherwise turned green and gay by the turn of the season. Reports from Kashmir valley suggest that snow avalanches often play havoc with slopes not only robbing them of beautiful pine forests but also leaving them barren and therefore more vulnerable to the onslaught of bigger mass-movement to follow.

Economic losses due to Indian landslides are staggering. For example, in Sikkim alone, restoration works were estimated to cost Rs. 140 million in 1968 and Rs. 80 million in 1973. Soil conservation work had cost Rs. 2.3 million in 1975 and even then only a small fraction of the demand could be met. Added to this, the extra expenditure on consumption of motor fuel and on wear and tear of vehicles for a six month period is estimated to be at least Rs. 1.18 million. Besides, the indirect losses in the shape of risks and hardships to the travelling public, delays, time and costs involved in detouring to avoid slide prone and slide inflicted areas are also quite alarming. In fact it is difficult to calculate the loss when strategic lines of communication are cut at a time when they are needed the most. What is more, about half a dozen people are killed in Sikkim every year and there is no count of those injured. Heavy annual losses of life and property are also reported from elsewhere because of avalanche accidents every year, particularly in Kashmir valley. The losses in a great majority of cases, could be minimised and even avoided through delineation of hazardous areas and regulating construction and developmental activities in tune with the dictates of the ecology of the region. The scars on Himalaya inflicted by landslides and their mass movements and the related treatments are the scope of this chapter.

GEOLOGY OF HIMALAYA

The complexity of the Geology of Himalayas continues to throw a challenge, sometimes of such a magnitude that all known systems of identifications and classifications and all tools and techniques of analysis and control in the armoury of landslide specialist pale into insignificance.

Geologically the Himalayas can be grouped into four roughly parallel belts of varying width introduced in *Table 1*. The generalised geological map of the Himalayas is presented in *Fig. 8*.

The geological section across the Garhwal-Kumaon Himalayas indicating the presence of faults, thrusts and folding structures is shown in *Fig 9*. The detailed geology of the Himalaya of Western sector as well as eastern sector are shown in *Fig. 10 & 11*. These maps show the structural variations in these two sectors.

COMMON CAUSES & CURES

The road system traverses through Sub-Himalaya, Lower Himalaya and Higher Himalayas over a labyrinth of narrow valleys and ridges. The occurrences of landslides on this network have been attributed chiefly to faulty alignment in a terrain of immature geology, heavy rainfall and cloud burst, deforestation and slope erosion, slope toe undercutting due to fast flowing and meandering rivers and flash floods, intensive construction activities without 'preventives' and to the seismicity of the region. The commonly employed cures include grading of slopes and checking of slope erosion, provision of subsurface and surface drainage, addition of restraining structures, soil reinforcement including prestress rock anchoring, rockfall control netting, fences, traps *etc*.

In Sikkim Himalayas the annual rainfall ranges between 3500 and 5000 mm of which as high as 80 per cent is concentrated in the period of four monsoon months (*Fig 12*). Most of the problems are encountered within this period or immediately after leaving an extremely tight working season of not more than 3-4 months. The rainfall shows a progressive decreasing trend from the Eastern to Western Himalayas.

A directory of exceptionally heavy rainfall event and devastating landslides in recent times is presented in *Table 2*. Devastating earthquakes triggering major landslides in the Himalayan region are listed in *Table 3*.

CLOUD BURSTS

Rainfall is often punctuated by flashes of cloud bursts. A cloud burst comes with the speed of thunder, lasts for a few minutes to as long as 3 hours at a

TABLE 1

CLASSIFICATION OF THE HIMALAYAS

Group	Relief	Description
Greater or Higher Himalaya	High relief zone of glaciation	It is characterised by serrate nature of mountains with abundant sharp edged features and discordant drainage system. Comprise granite and other crystalline rocks. Slopes are mostly bare with debricones and moraine walls at their base.
Lesser or lower Himalaya	Medium to High relief zone	The northern slopes are gentler, densely forested, colder and not much inhabitated. The southern slopes are steep, bare and gullied, comprise essentially the sedimentary strata and are subject to mechanical and chemical weathering. Deforestation, overgrazing, impact of monsoon *etc.* are primarily responsible for denudation and mass wasting.
Outer or sub Himalaya and Shiwaliks	Zone of intense mass-washing	Comprise soft tertiary sediments, sand stones, silt stones, shales and clays prone to disintegration. It experiences full force of monsoon season. Shiwalik range is still thickly wooded.

time and leaves behind a trail of devastation worse than inflicted by the combined effect of rainfall for the rest of the season. The record of cloud burst in Teesta valley for the period 1891-1965 speak of rainfall intensity more than 250 mm in 24 hours. *Table 4* puts the range at 310—1800 mm in 24 hours, rising to as high as 4032 mm in an isolated case. Taking the mean annual precipitation as 5000 mm for Teesta Valley, the figures of precipitation for the event (*Table 4*) are seen to vary between 6.2 and 36 per cent of the mean annual precipitation. Thus event coefficients (Ce), according to Guidicini and Iwasa (1977), would range between 0.06 and 0.36 which are remarkably high values from any standards, and are usually associated with landslides on the lower side of the scale and 'catastrophes' on the higher. Admittedly, conclusions derived from study of 'event coefficient' alone that 'cloud bursts' of intensities exceeding 1000 mm in 24 hours trigger mass movement practically under any circumstances.

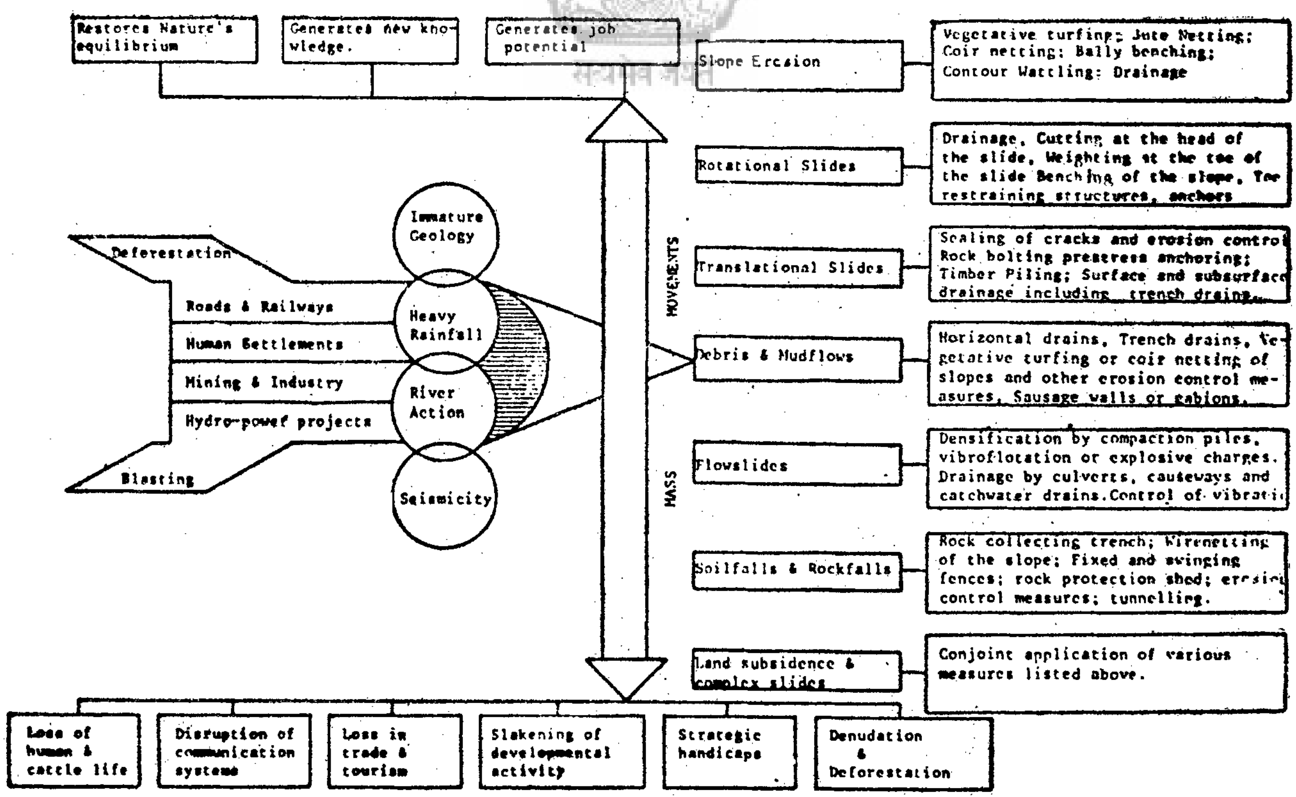
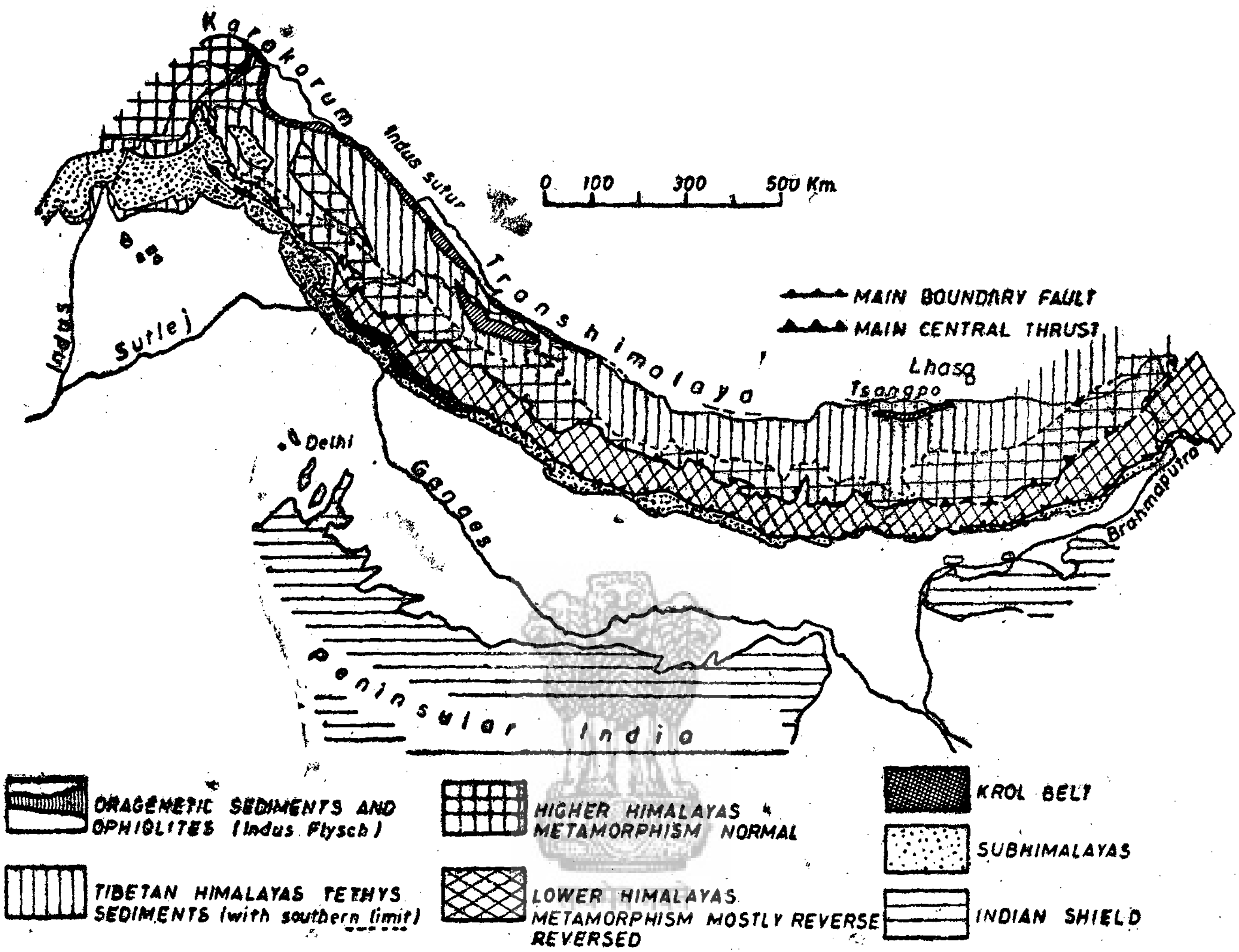


Fig. 7



Karakorum
Indus sutur
0 100 300 500 Km.
Transhimalaya
MAIN BOUNDARY FAULT
MAIN CENTRAL THRUST
Lhasa
Tsangpo
Indus
Sutlej
Delhi
Ganges
Brahmaputra
Peninsular India
ORAGENETIC SEDIMENTS AND OPHIOLITES (Indus Flysch)
HIGHER HIMALAYAS METAMORPHISM NORMAL
KROL BELT
SUBHIMALAYAS
TIBETAN HIMALAYAS TETHYS SEDIMENTS (with southern limit)
LOWER HIMALAYAS METAMORPHISM MOSTLY REVERSE REVERSED
INDIAN SHIELD

FIG. 8

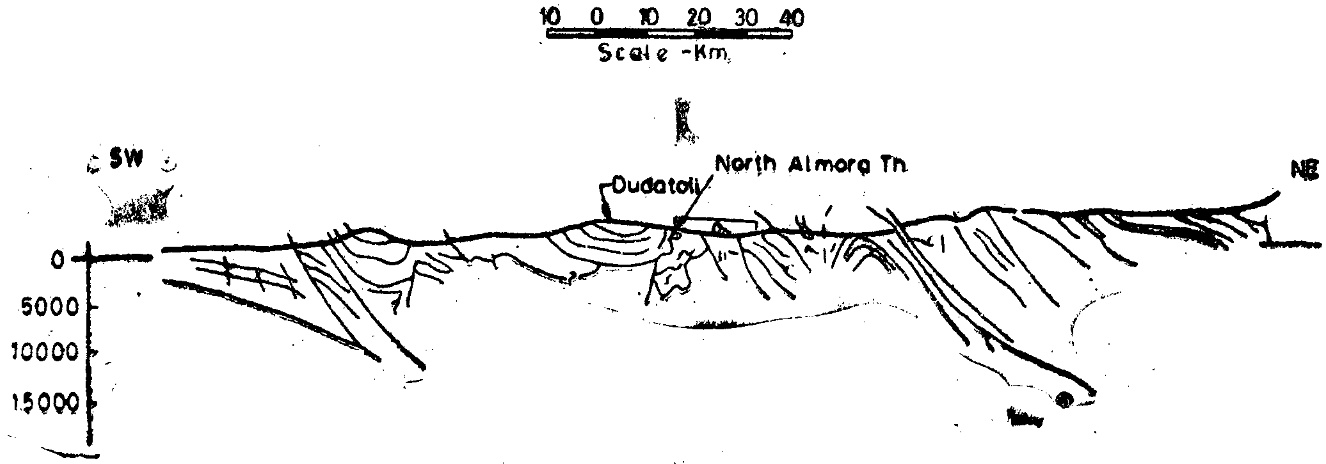
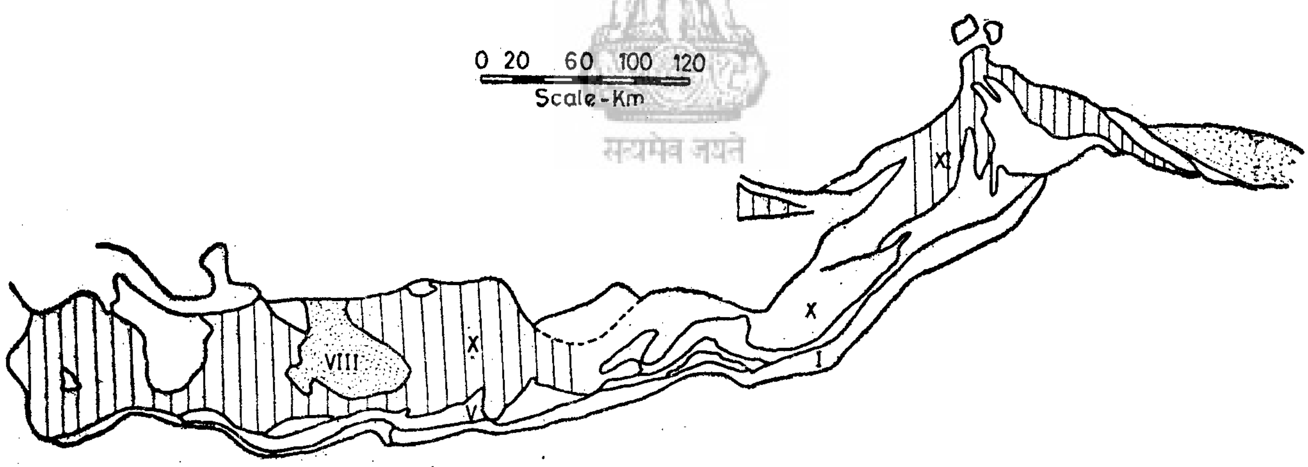


FIG. 9 SECTION ACROSS GARHWAL-KUMAON HIMALAYAS



I - Shiwalik Belt Boundary
V - Jaunsar Buxa Group Boundary
VIII - Metamorphic Nappes
X - Fossiliferous Sequence Over Metamorphic Nappe
XI - Central Crystallines

FIG. 10. STRUCTURAL BELTS OF THE HIMALAYAN EASTERN SECTOR

STRUCTURAL BELTS OF THE HIMALAYAN WESTERN SECTOR

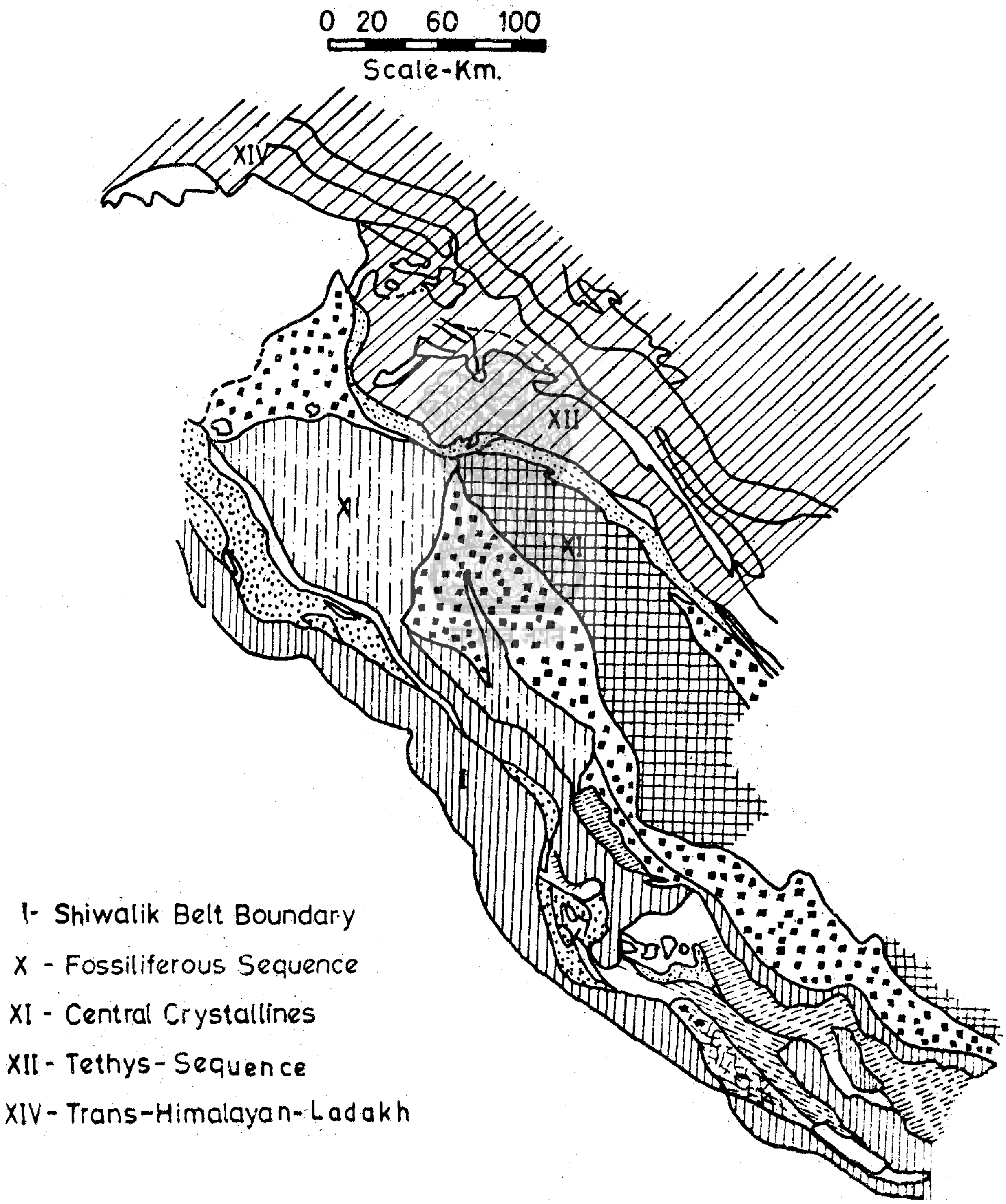
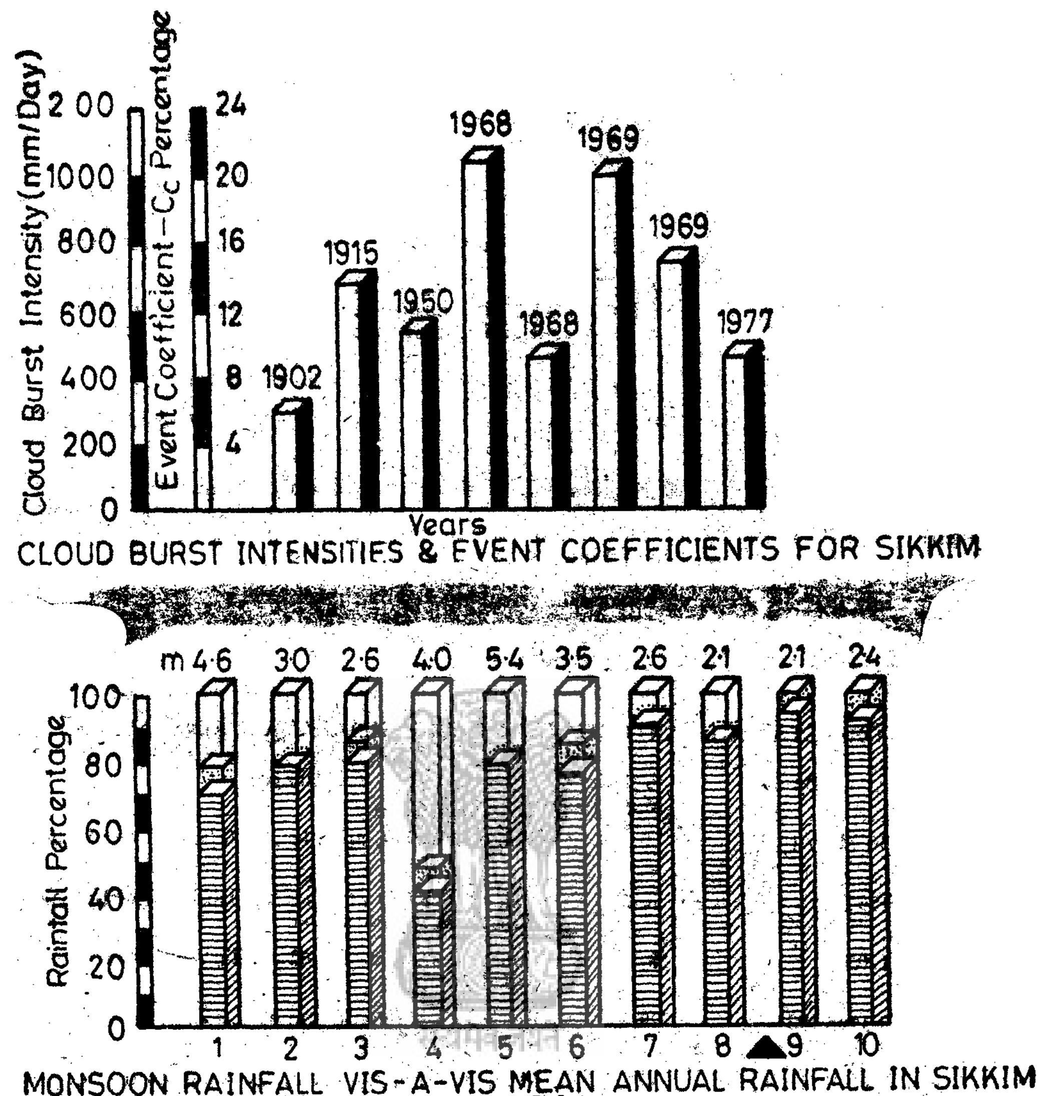
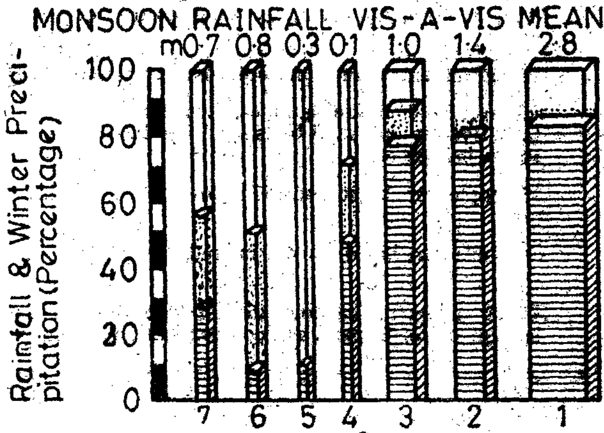


Fig. 11





SN	M	SD	V
1	42	37·6	0·89
2	43	21·2	0·49
3	26	22·6	0·87
4	37	25·2	0·68
5	61	43·3	0·71
6	35	27·6	0·79
7	33	31·5	0·95
8	35	16·5	0·47
9	35	25·0	0·71
10	40	24·0	0·60

M=Mean, SD=Standard Deviation
V=Variation

1 - Bhutan
2 - Nepal
3 - Mukteshwar
4 - Leh
5 - Kargil
6 - Dras
7 - Srinagar

Winter Precipitation
Monsoon Rainfall

FIG. 12. PATTERNS OF MONSOON RAINFALL & WINTER PRECIPITATION FROM THE EASTERN TO THE WESTERN HIMALAYAN

TABLE 2

EXCEPTIONALLY HEAVY RAINFALL & DEVASTATING LANDSLIDES

Place	Date	Consequence of heavy rainfall
Darjeeling & Jalpaiguri (North Bengal)	3-5 Oct, 1968	Wide spread landslides and other mass movements causing death and devastation all over.
Uttar Pradesh	July 1970	Alaknanda River caused considerable loss of life amount pilgrims. Many bridges houses and an entire village were washed away.
Jammu & Kashmir	Sept 1970	Landslides and house collapses took a toll of 223 human lives.
Jammu & Kashmir	Feb. 1971	Widespread landslides causing disruption of traffic and communication systems.
	Aug. 1972	Widspread landslides causing damage to life and property.
"	March, 1973	Landslides cut off Kashmir valley from the rest of the country.
Shimla (Himachal Pradesh)	July 1973	Landslides cut off Simla from the rest of the country.
North Bengal	July 1975	Teesta, Jaldhaka and Diana rivers in spate. Widespread landslides and floods rendered 45,000 people homeless.
Jammu & Kashmir	Sept. 1975	Landslides killed 2 labourers and disrupted transportation system for 3 days.
Darjeeling (North Bengal)	June 1976	Teesta in floods triggering many landslides 3 people burried alive due to caving in of a hillock.
Jammu & Kashmir	July 1977	Shrinagar-Leh road blocked due to landslides.

TABLE 3

DEVASTATING EARTHQUAKES IN THE HIMALAYAN REGION

Place or Epicentre	Date	Richater's Magnitude	Damage
Kashmir (34·6°N—4.4°E)	30 May 19-5	7	Felt over 11000, sq. miles, 6000 people were killed.
Assam	1897	8·7	Pelt over 25,000 sq. miles landslides flowslides and ground subsidences were wide spread.
Kangra (32.5°N, 76·5°E)	1905	8	Felt over an area of 1.625 million square miles 20,000 people were killed.
Bashghur (Afganistan)	2 June 1931	7-8	Felt very severely. 50 houses destroyed and many damaged. Boulders fell down from mountains.
Quatta	24 Aug. 1951	7-8	Many buildings and a railway bridge destroyed.
Nepal (26·6°N-86.8°E)	1934	8-3	Extensive landslides, collapse of buildings, lateral ground spreading, ground settlement and sand boils over an area of 4,320 sq. miles.
Assam (28·7°N, 96.6°E)	15 Aug. 1950	8·5	Felt over 0·42 million sq. miles, caused extensive landslides and rock-falls, fissures and sand boils resulting into collapse of buildings, roads, bridges etc.
Tibet (30·5°N, 91·5°E)	17 Aug. 1952	7·5	55 people were killed and 157 injured. 850 buildings were destroyed
Srinagar (33·9°N, 74·7°E)	Sept. 2, 1963	5·3	79 people were killed and 400 injured.
Kinnaur	1975	6·f	Huge boulders hurting down the hill slopes resulted in widespread damage to life, property and communication system.

FLASH FLOODS

Occurrence of flash flood, particularly in a narrow river gorge, seem to be one of the much feared cause of some of the major Himalayan Landslides. Accumulation of slipped masses, shooting boulders, charge of river silt and above all massive rocks transported by the turbulence of flowing water throttle the narrow river passage building up a reservoir of water (pressure) that eventually flushes the obstacles. The resulting drawn down effect trigger slides in the region, eventually jeopardising the stablility of the hill as a whole.

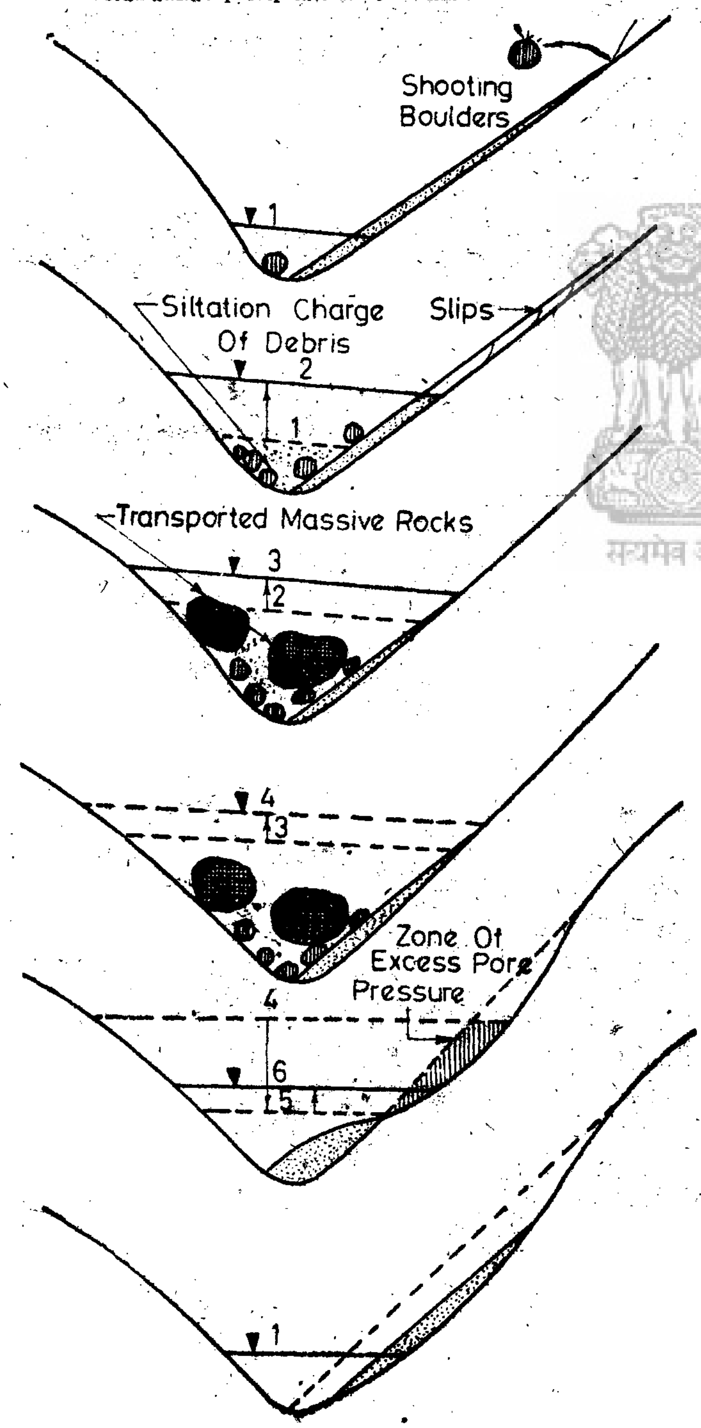
Some of the formidable landslides have often created landslide dams in the narrow river gorges (*Fig.* 13) Examples of major landslide dams in Himalaya are given in *Table 5*

TABLE 4

RECORD OF CLOUD BURST IN TEESTA VALLY

Year	Date	Recorded Rainfall	Rate mm/hr	Rate mm/day	Event coeffi-cient*
1902	26-27 Sept.	310 mm—24 hrs	12·9	310	6·2
1915	11-13 June	690 mm—24 hrs	28·8	690	13.8
1950	12 June	546 mm—24 hrs	22·8	546	10·9
1968	3-5 Oct.	1580 mm—36 hrs	43·9	1044	20·9
	5-6 Oct.	465 mm—24 hrs	19·4	465	9·3
1969	5 August	3000 mm—72 hrs (Labha phapar, kheti)	41·7	1001	20·0
		2970 mm—96 hrs (Algarh-Gorubathan)	30·9	742	14·9
1972	17 May	168 mm—1 hr	168	4032	80·6
1977	10 June	230 mm—12hrs	19·2	460	9·2
1978	20 May	225 mm—3 hrs	75	1800	36

*Event coefficient (Ce) — (precipitation record of the event/mean annual precipitation);
Mean annual precipitation—5000 mm.



(1) River Level in Lean Period

(2) River Level During Monsoon Season

(3) River Level when its Narrow Gorge is throttled by Transported Boulders

(4) Further Rise in River Levels as a result of cloud burst

(5) Level upon draw down

(6) Rise due to slide Debris

FIG. 13. EFFECT OF TRANSPORTED BOULDERS CLOUD BURST & FLASH FLOOD ON SLOPE STABILITY IN A NARROW RIVER GORGE

TABLE 5

MAJOR LANDSLIDE DAMS IN THE HIMALAYAS

Event

October 1983

Gohana slide which hurtled down from a height of a few thousand meters into Birahi Ganga, a tributory of Alaknanda, filled up the river bed to a height of 350 m. The Lake formed was 5 km x 2 km. On 24th August 1984, the dam topped raising water level by 50 m at Srinagar. Two days later, the level of river rose by 4 m in Hardwar.

1968

Floods in Rishi Ganga created 40 m high blockade near village of Reni in U.P. Lake silted up by May 1970 and eventually blockade breached in July 1970

July 1970

Narrow construction of Patal Ganga got choked and more than 60 m high reservoir was built up, the bursting of which resulted in flood pulse in Alaknanda triggering many landslides.

Floods in Birahi Ganga near its confluence with Alaknanda triggered landslides causing major blockade of river with 10-12 mm afflux. A girder bridge was by-passed and another one was destroyed.

August 1978

The Kanauldhia Ghad, a tributory joining Bhagirathi river upstream of Uttarkashi in the U.P. Himalaya spread a debris cone across the main river impounding river to a height of 30 m. Breaching caused flash floods and havoc. A 1.5 km long, 20 m deep lake was left behind by the landslide dam.

Deforestation

The nexus between 'deforestation' and 'slope instability' has been a subject of considerable research. That deforestation brings about erosion and soil movement is generally accepted (Gray, 1973) but opinions differ on its impact in so far as 'creeping" slopes are concerned. Ellison and Coaldrake (Brown and Sheu, 1975) report greater creep velocities in slopes covered by trees in the region of Queensland (Australia) than in slopes merely covered by grass, in a region of rain forests. Brown and Sheu (1975) using mathematical analyses based on experimental observations (by other authors) conclude that removal of overload of vegetation and consequent elimination of wind action on the vegetative cover improve stability. They however confess that benefits of improved stability are temporary and disappear with time. Prandini *et al* (1977) has presented an excellent state-of-the-art on this subject. The author supports the views of Croft and Adams (in Gray, 1973), Soares *et al* (1975) and Poncano *et al* (1976) that deforestation leads to loss of mechanical support imparted by rock system. Reinforcing power of roots is also demonstrated by the results of insitu block shear tests which show that shear strength increases with increase of root density (Endo and Tsuruta, 1960).

Human Activity

The stability of Himalayan slopes have large extent jeopardised by construction work of roads which invariably involves deep back cutting into hills. These cuttir tremendous relief of stress, setting in a progressive failure. Due to paucity of fu seldom possible to protect the freshly cut provide effective surface and subsurface dra landslides are therefore inevitable. Hum ments add to the gravity of the problem b minate felling of trees or by tampering with drainage of the area.

CONTROL OF LANDSLIDES

Common antislides and anti Mudflow m the Himalayas are summarised in *Table* 6. the important techniques are illustrated.

Erosion Control

Bamboo Check Dams

Bamboo check dams are found to be usefu ing further erosion of depressions, channels, on the denuded landslide slopes (*Fig.* 14). stakes or stakes of self generating branche like fienc cunea, willows and erithrina spe ragmite's, kaka, Lamea grandis, arundodonc etc. are driven across the erosion gullys. T to the flowing water charged with debris get silted up. There are a number of landsli bamboo check dams have proved successful.

Jute and Coir Netting

Coir/jute netting or asphalt mulch tec vegetative turfing are extensively used as m erosion control even in high rainfall areas coir instead of jute provides a more stable ing. Coir threads of 0.6 cm thickness w 2 cm square grid and nets are available i 30 m x 1 m. Rolls of 5 m length with 1.2 are also available. Jute nets are available in of 1.22 m and in mesh openings of 2.54 cm cm.

Bituminised Slopes

The protection of freshly exposed rc generally desirable and sometimes essential f of long term safety against erosion hazard been found that two coats of bituminous (Standard RC 3) are usually enough. Ex have indicated that spray-ability of a cut-bac state can be improved by increasing solvent 50%. The slope to be treated is scapped debris. The mixture 1 litre per sq. metre sprayed on the slope filling in all joints and

A convincing evidence of the success of th of bituminising rock slope is provided by tr performance of the landslide at 'The] Nainital (*Fig.* 15).

Contour Wattling

The method of contour wattling has also effectively been utilised, for example, in stabilising lower reaches of Nolota Nala Landslide on Dehradun-Mussoorie road in UP Himalaya. The central idea is to treat a rilled and gullied slope to make it better resistant to erosion.

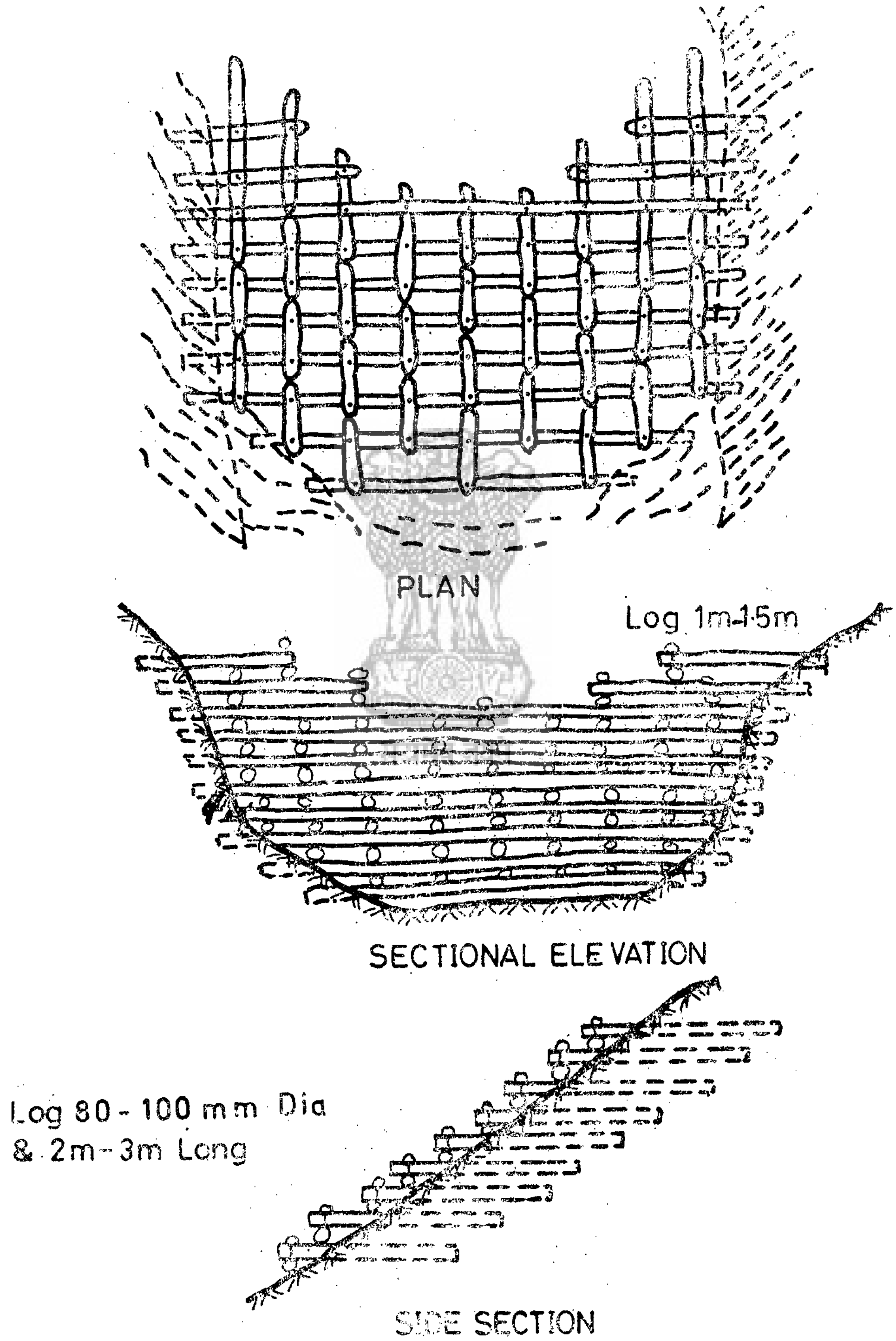


FIG. 14. LOG WOOD CHECK DAMS

TABLE 6

COMMON ANTI LANDSLIDE AND ANTI MUDFLOW MEASURES IN THE HIMALAYA

Avoidance of the problem	Erosion Control	Rockfall Hazard Mitigation & Control	Restraining Structures	Anti River Action	Surfacen Drainage
Realignment of the road Stress-Relief	Plantation, Afforestation, vegetative turfing Paving and pitching Jute, coir or wire netting	Tunnels Covered sheds Dressing benching and wire netting	Gabions, sausage walls Masonry and rainforced concrete walls	River diversion by guide spurs Clearing of narrow river passages by passages by rock blasting	Contour drains Roadside drains Causeways Trench drains
Cutting of the head of the slide, elimination of shear zones	Bamboo checkdams Contour wattling Longwood check dams	Road side rock collecting trench Fixed Swinging Fences	Reinforced earth walls. Breast, check and drop walls	Slope toe protection by tetrapods	Subsurface Drainag Horizontal dams Drainage Gallaries Bamboo Drains
Dressing, grading and benching of slopes	Bitumenous cutback spraying on freshy exposed rocks	Deflection Walls Rock anchoring bolting *etc.*	Toe walls Anchoring of walls	interconnected massive cement concrete blocks and toe walls	Culverts Trench Drains
Preventives Maintenance of slopes vegetation drainage, pitching and protection of freshy exposed cuttings	Improvement of drainage Benching of slopes and provisions of dropwalls Densification of slide masses and terracing	Grouting Deflector chutes and traps on the slope Combination of one or more of the above measures	Banded dry masonry-walls Pile supported retaining walls Cribh walls	Diversion of discharge from contour drains and drainage chutes into river at appropriate locations	Drains are designed to take care of charge of debris that come with the discharge of water

Contour Wattling (*Fig.* 16) is done by breaking up the slope to provide wattles at intervals of about 5 metre. A treach 0.3 m wide and about one metre deep is dug up and (5-6 cm diameter) brush wood bundles are placed inside the trench, horizontally, to impart mechanical strength to the wattle. On the down hill side of the trench, species (that sprout on planting) are placed at about one metre interval. The trench is then backfilled with the dug up soil about 10 cm short of the ground level.

At the stage, brushwood (after extraction of posts) and other locally available shrubs are woven around the posts upto about 20 cm above the ground level. This barrier smoothens the erosive effect of running water and promotes debris deposition. Eventually posts sprout and offer stability.

Bally Cribbing & Terracing

Bally cribbing is, in most situations, ideally suited to staple shallow landslips and mud flows in the Himalayas. Driving of ballies (timber piles) results in densification of slide mass and provide the much needed 'stitch action'. Ballies are usually stiffened in one or both directions. A classical example of successful application refers to Padamchen slide in the eastern Himalaya where nearly 60,000 ballies of 12.5-15 cm diameter, 3 m length were driven to depth ranging between 1.5 and 20 (*Fig.* 18).

Flexible Retaining Walls

To orthodox buttress walls, the second generation technique of gabions and current popular reinforced earthwall are shown in *Fig.* 19. A low cost technique of construction of retaining walls using empty bitumen drums and slope waste material has been developed. One such wall 93 m long and 2.15 m high was designed and constructed at the site of Kaliasaur landslide near Srinagar on Rishikesh-Badrinath road. The wall has stood well the rains and sliding debris so far, pointing to the high potential the technology holds in the Himalayan belt (*Fig.* 17). Other possibilities appear to be multitiar block walls, pier walls or grid walls shown in *Fig.* 20.

Training of Meandering River

The power of flowing water is highlighted in *Table* 7. Apart from haulage of landslide debris of all sizes including boulders, the river inflicts heavy toe erosion. The situation could be contained either by diverting the river onto its right back or providing the protection works at appropriate location or by a combination of the two.

SABLE 7

POWER OF FLOWING WATER

Size of transported rock fregments	Velocity of flowing water (m/s)
Fine sand	0·3
Coarse sand	0·6
Fine gravel	1·0
Egg-sized gravel	1·2
Gravel 10 cm	2·0
Gravel 20 cm	2·4
Boulders	7·3

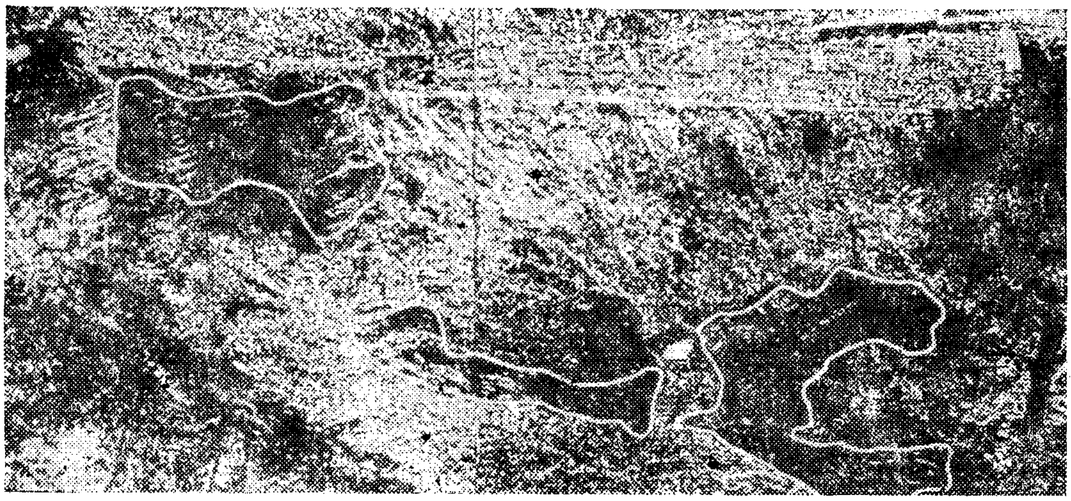


FIG. 15 THE LANDSLIDE AT 'THE PINES' AFTER SLOPE TREATMENT WITH BITUMINOUS CUTBACK

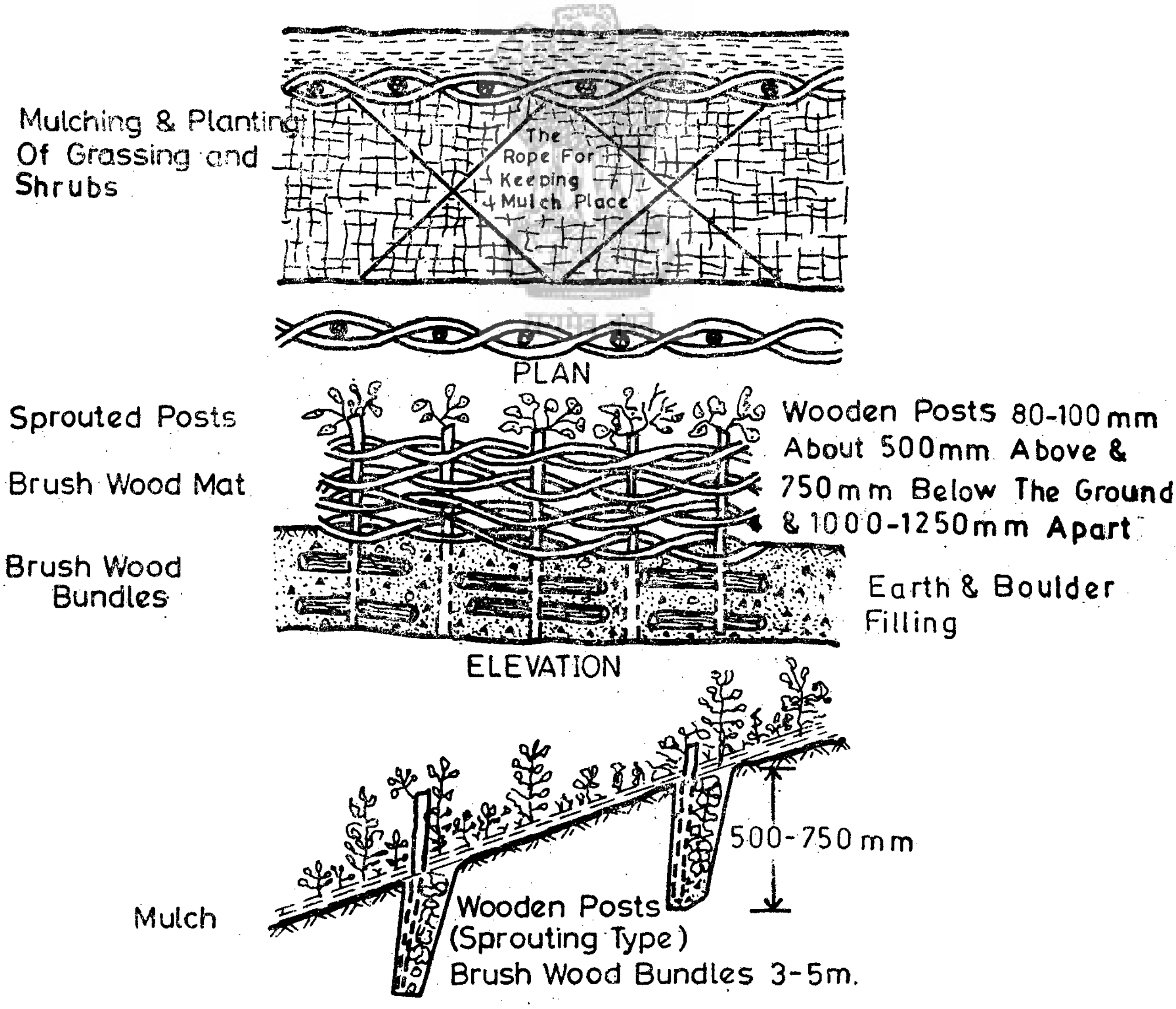


FIG. 16 WAITING AS A MEASURE OF EROSION CONTROL

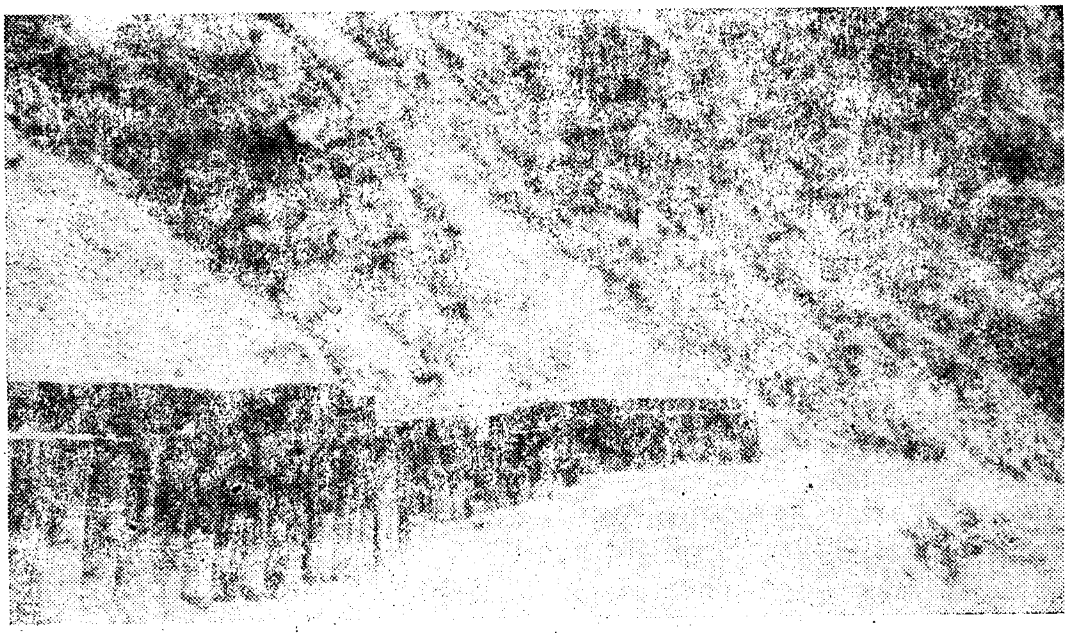


FIG. 17 RETAINING WALLS WITH EMPTY BITUMEN DRUMS.

FIG. 18 BALLY CRIBBING AND TERRACING AT PADAMCHEN

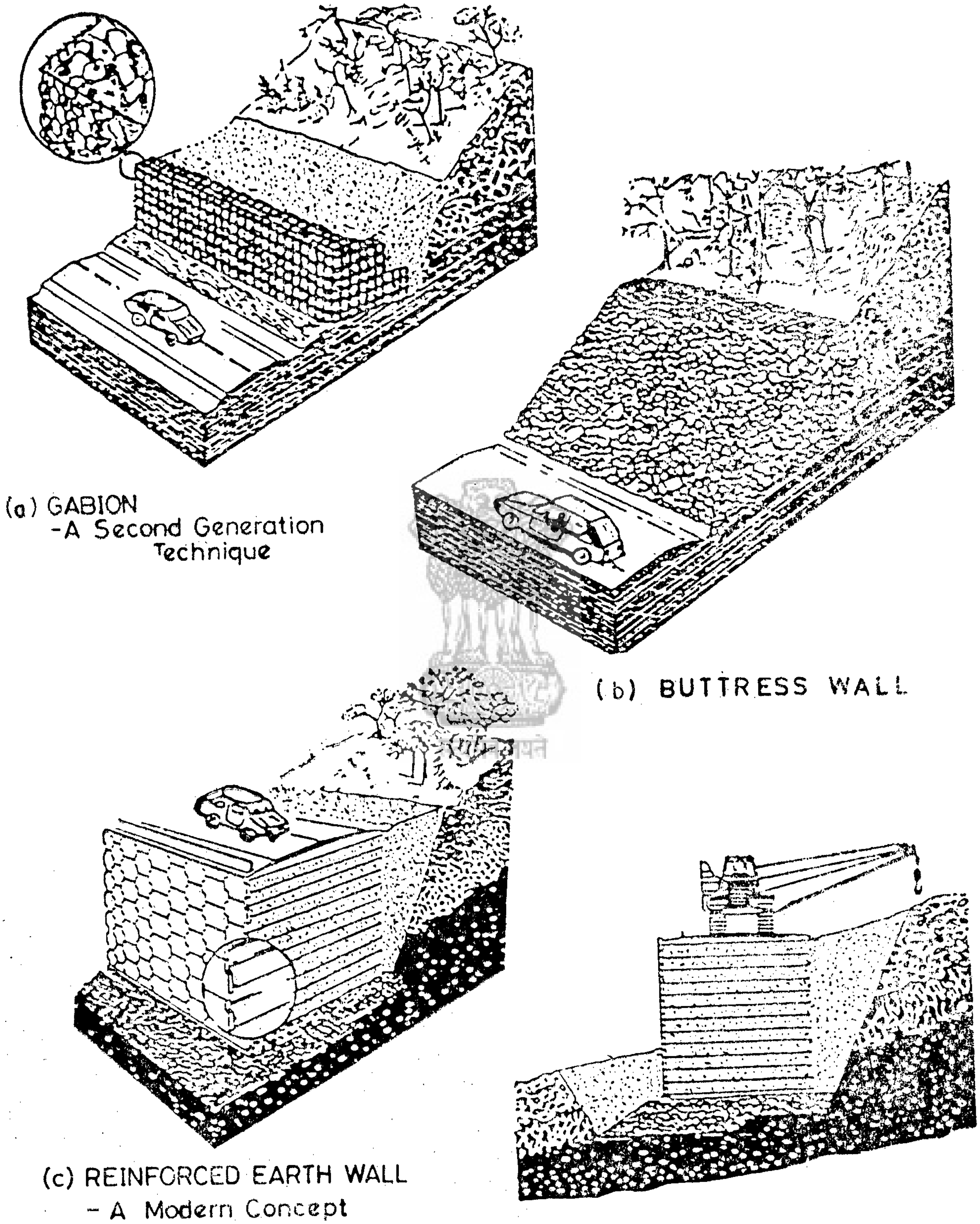
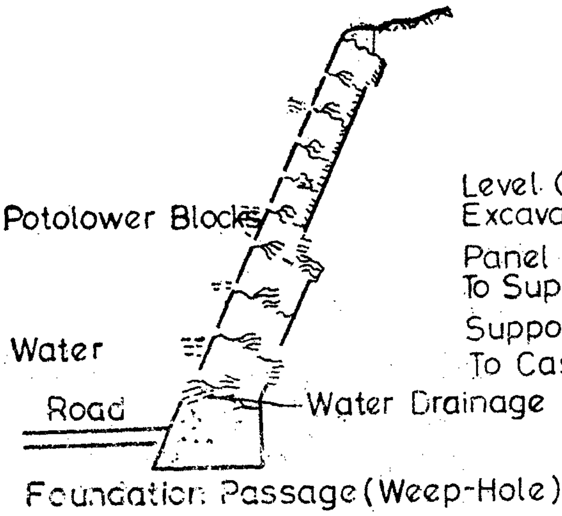
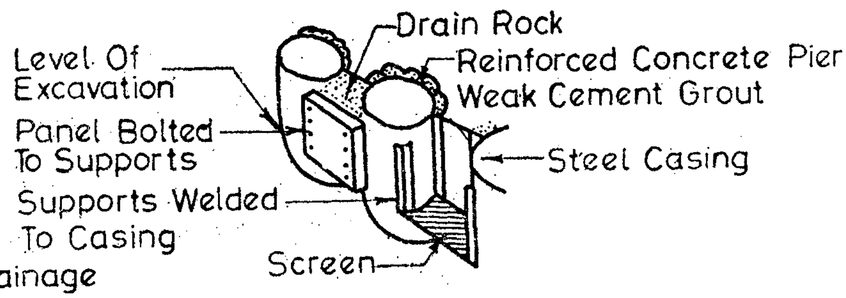


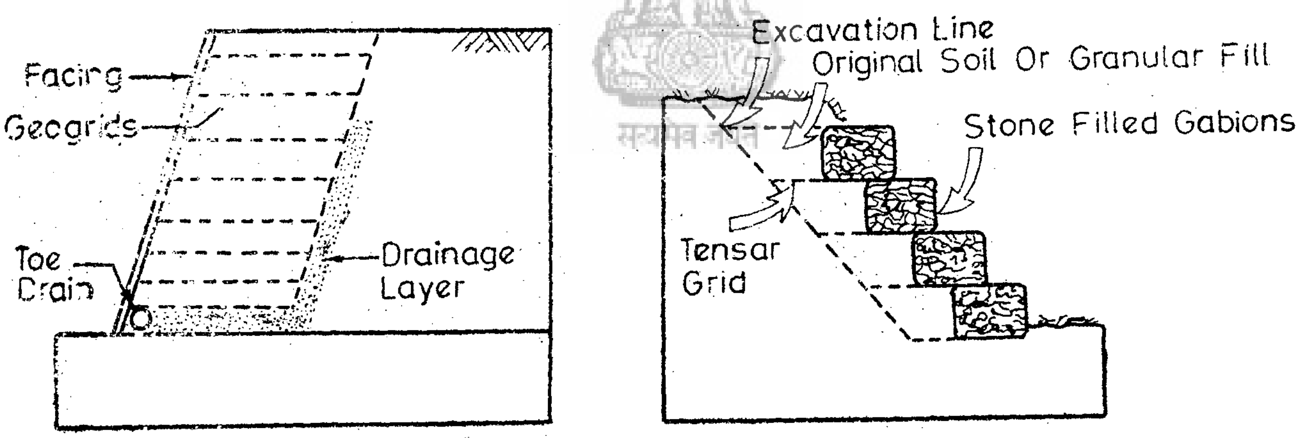
FIG. 19 FLEXIBLE RETAINING WALLS



(d) MULTI-TIER BLOCK WALL



(e) PIER WALLS



(f) GEOGRIDS & TENSAR-GRID WALLS

FIG. 20

Slope Drainage

There are a number of approaches to effective surface and sub-surface drainage of slopes for better stability. The choice is governed by geomorphology of the terrain, hydrological conditions including intensity and distribution of rainfall, permeability of the slope forming materials, vegetation, natural drainage, construction activity and sliding mechanism. Catch water drains, trench drains, drainage walls, slope ribs, drainage galleries *etc.*, are commonly adopted to improve slope drainage. The advent of new drilling tools and techniques have, however, brought about a sea change in the approach to draining the slopes with promise of better efficiency, longer life and speedier construction.

Typical sections of a trench drain, a drainage wall and a drainage gallery are shown in *Fig.* 21.

Wherever high piezometric pressures are found to trigger landslides or in situations where rainfalls are excessive, slope masses are pervious and water table is beyond the reach of trench drains sub-surface drainage becomes absolutely essential. One of the effective ways of achieving such a drainage is through drill hole drains or so called horizontal drains. In 1939 such drains were introduced and were widely used in California. Since then, they have found worldwide acceptance and are popular particularly in countries like Japan, Britain, Germany, Yoguslavia, Czechoslovakia, New Zealand, Canada, Hong Kong, and France.

Recently, such drains were introduced in India by the Central Road Research Institute, New Delhi.

Rockfall Hazards and Mitigation

For control of rockfalls, wire netting of slopes (*Fig.* 22 and fencing etc. (Fig. 23) are popular. For major slides prestressed rock anchors are commonly preferred (*Fig.* 24).

Restraining Structure

Most corrective measures are applied in combination of one another and restraining structures constitute the common measure. Principal types of the retaining walls are shown in *Fig.* 25. In the Himalayas however sausage walls are more popular for their effectiveness despite large ground movements. The effectiveness is total as a result of inherent flexibility of structure.

The newest and most innovative approach to obtain economical restraining structures in the hilly regions is to resort to reinforced soil constructions. Such walls are bound to be techno economically sound with added assurance of utilising local materials. In this case predominantly soil, bamboo or other reinforcement. Typical walls and situations are illustrated in *Fig.* 26 to 31.

CONCLUDING REMARKS

Landslide problems of the Himalayas are complex and need thorough understanding for implementation of long range corrective measures. Often a combination of corrective measures may be required to be implemented at the same time to control the slide effectively. The present chapter highlights the common causes of landslides and the commonly employed corrective measures with example of other uses with success.

Corrective measures involving applications of bamboo, ballies, jute and coir netting, wire netted sausage walls have been discussed and several others could be thought of. Promoting these application would mean cost reduction, generation of employment and fillup to cottage industry.

Application of reinforced earth and other innovative control measures by making best use of local resources and skills, seem to have greater potential in the Himalayan belt.

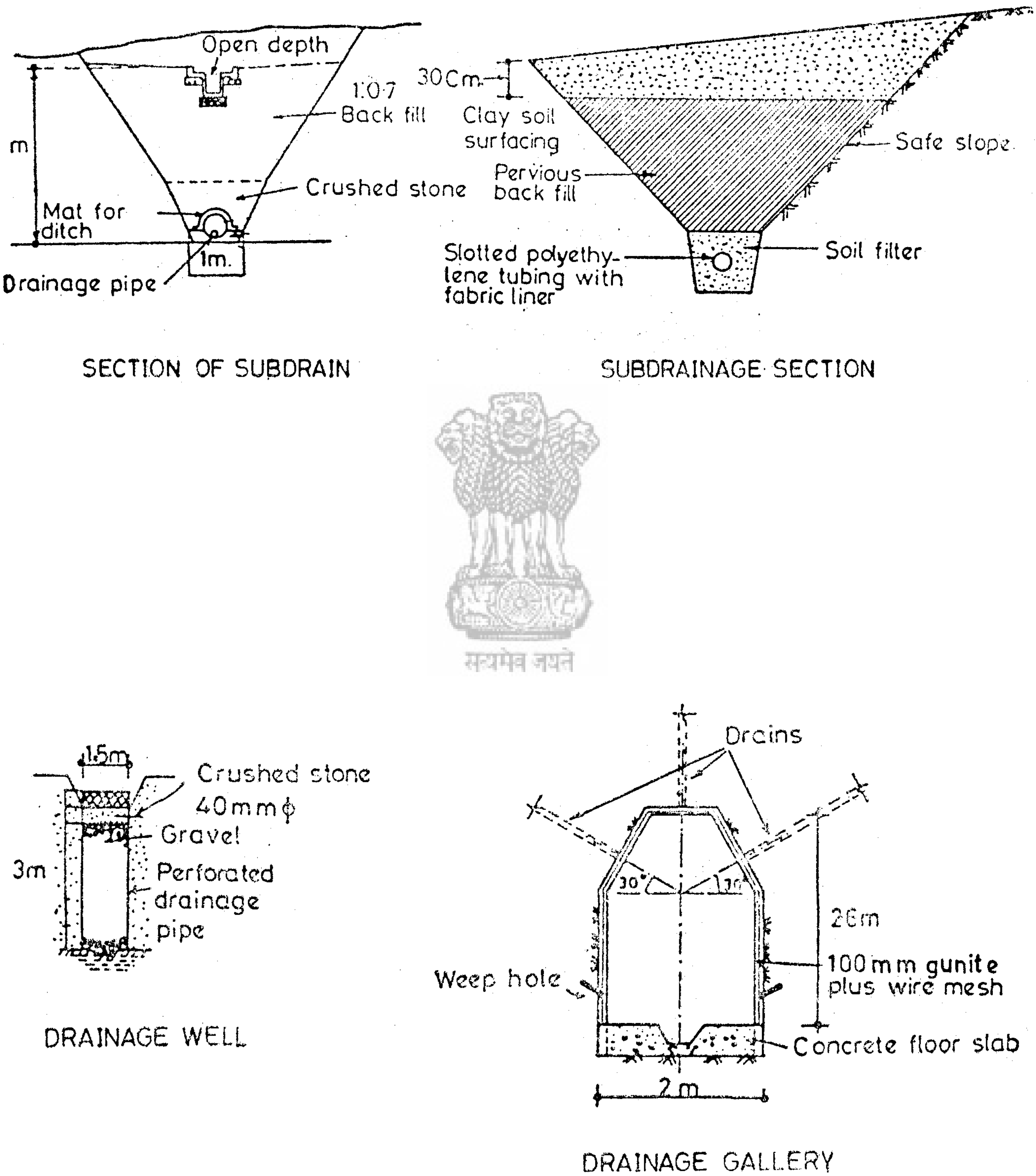


FIG. 21 DRAINAGE MEASURES

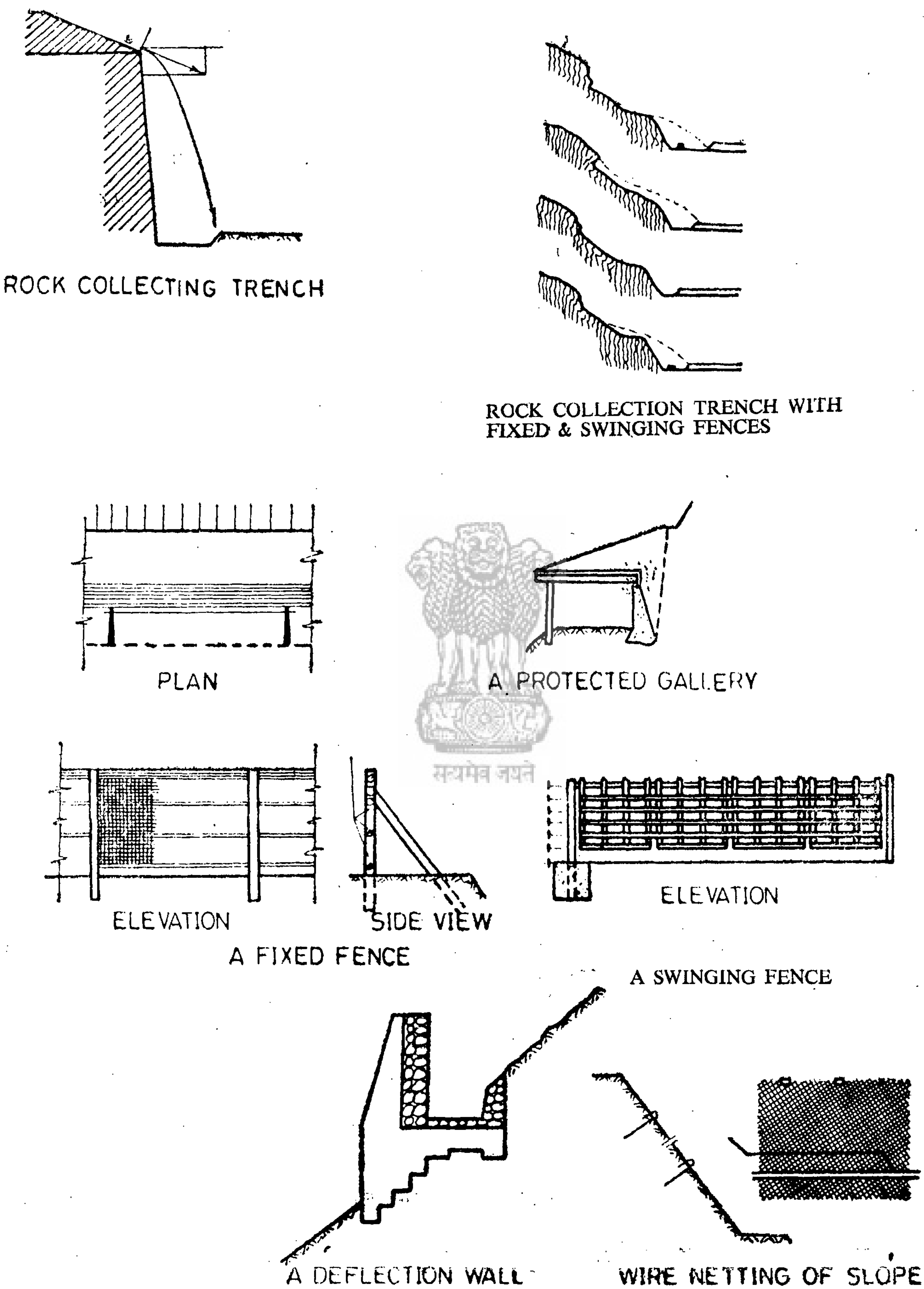


FIG. 22. ROCKFALL PROTECTION MEASURES

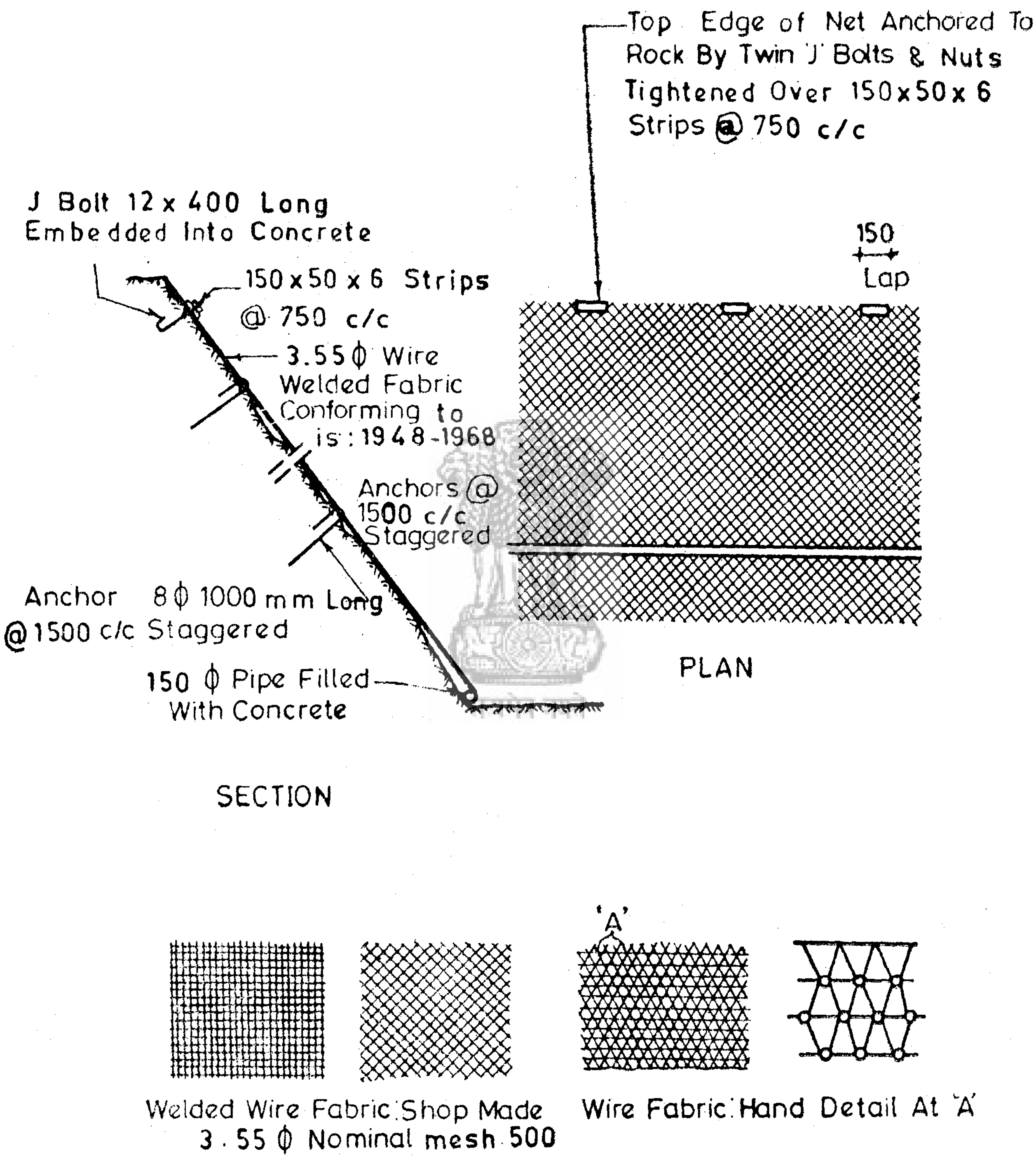
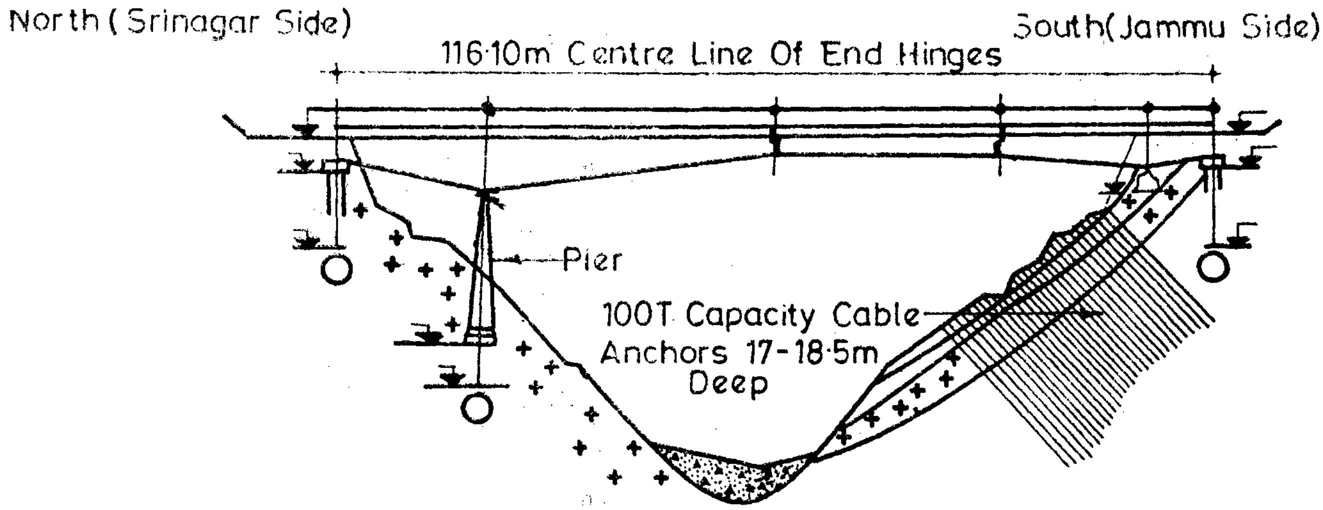
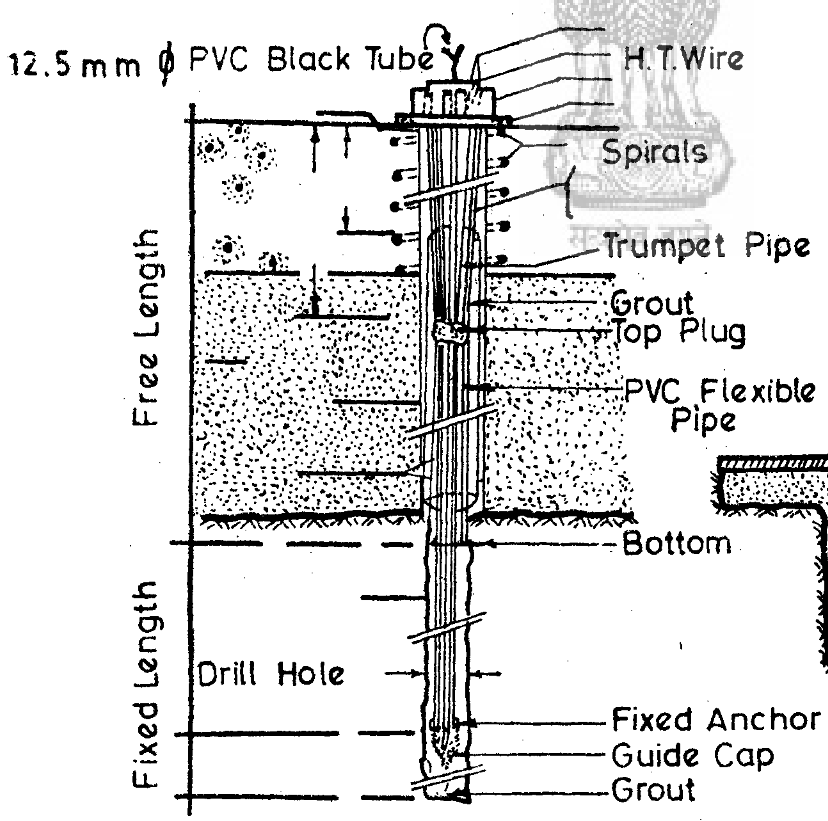


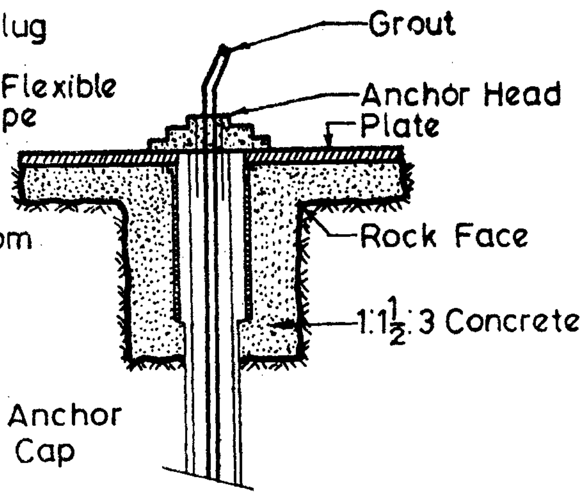
FIG. 23. DETAIL OF WIRE NETS



(A) CROSS SECTION OF KHUNI NALLAH ON CENTRE LINE OF BRIDGE

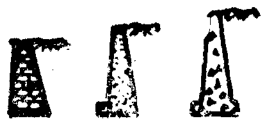


(B) TYPICAL DETAILS OF AN ANCHOR (With PVC Sheathing)



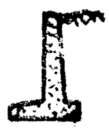
(C) TYPICAL DETAILS OF CONCRETE & BLOCK

FIG. 24 PRESTRESSED ROCK ANCHORING AT KHUNI NALLAH



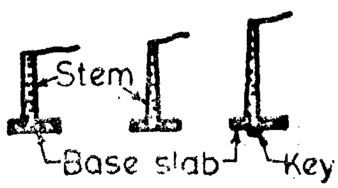
GRAVITY WALLS

Plain Concrete or rubble Rugged construction is conservative but not economical for high wall.



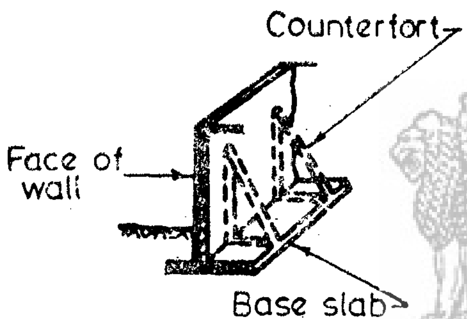
SEMIGRAVITY WALLS

A small amount of reinforcing steel is used for reducing the mass of concrete.



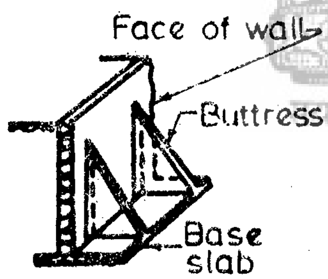
CANTILEVER WALLS

In the form of inverted T, each projecting portion act as a cantilever generally made of reinforced concrete blocks may be used. This type is economical for wall of small to moderate height. (about 6-8m).



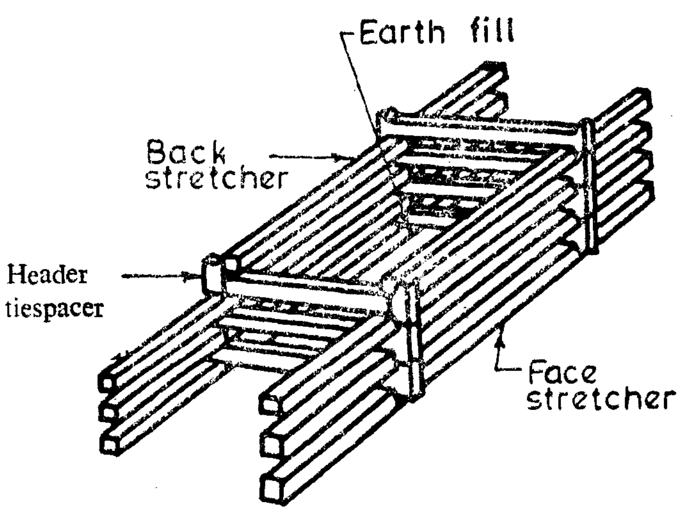
COUNTERFORT WALLS

Both base slab & face of wall span horizontally between vertical brackets known as counterforts. This type is suitable for high retaining walls, greater than about 6 m.



BUTTRESSED WALLS

Similar to counterfort walls except that the backfill is on the opposite side of vertical brackets (known as buttresses). Not commonly used because of the exposed buttresses.



CRIB WALLS

Formed by timber precast concrete or prefabricated steel members & tilled with granular soil. This type is suitable for walls of small to moderate height (about 7 m maximum) subjected to moderate earth pressure

FIG. 25 PRINCIPAL TYPES OF RETAINING WALLS

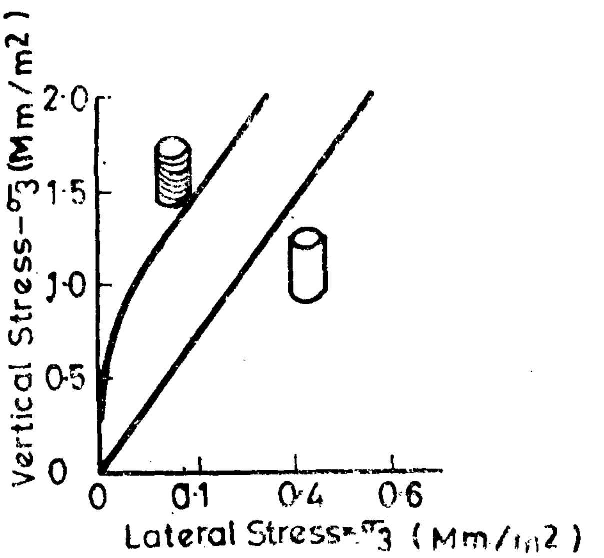


FIG. 26. TRIAXIAL TEST RESULT

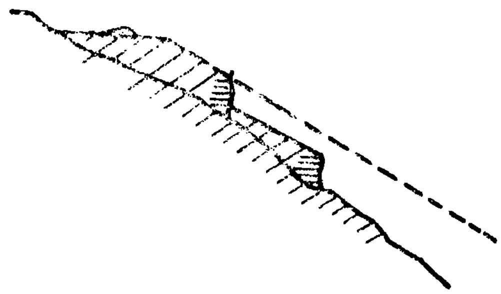


FIG. 27. DOUBLE RETAINING WALLS OF REINFORCED EARTH FOR HIGHWAY

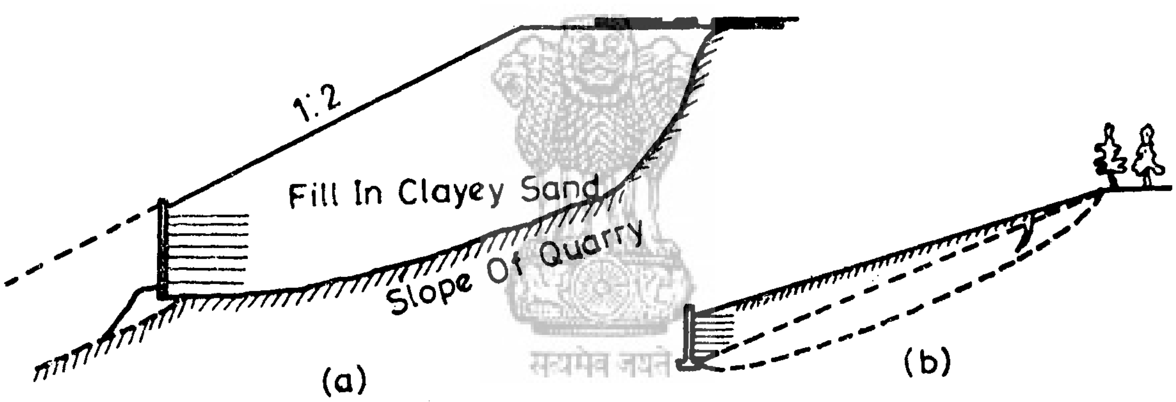


FIG. 28. REINFORCED EARTH BASE BLOCK

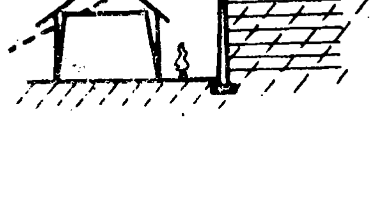


FIG. 29. REINFORCED EARTH RETAINING WALL

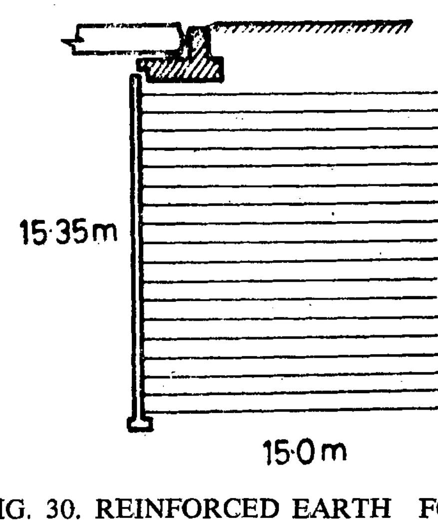
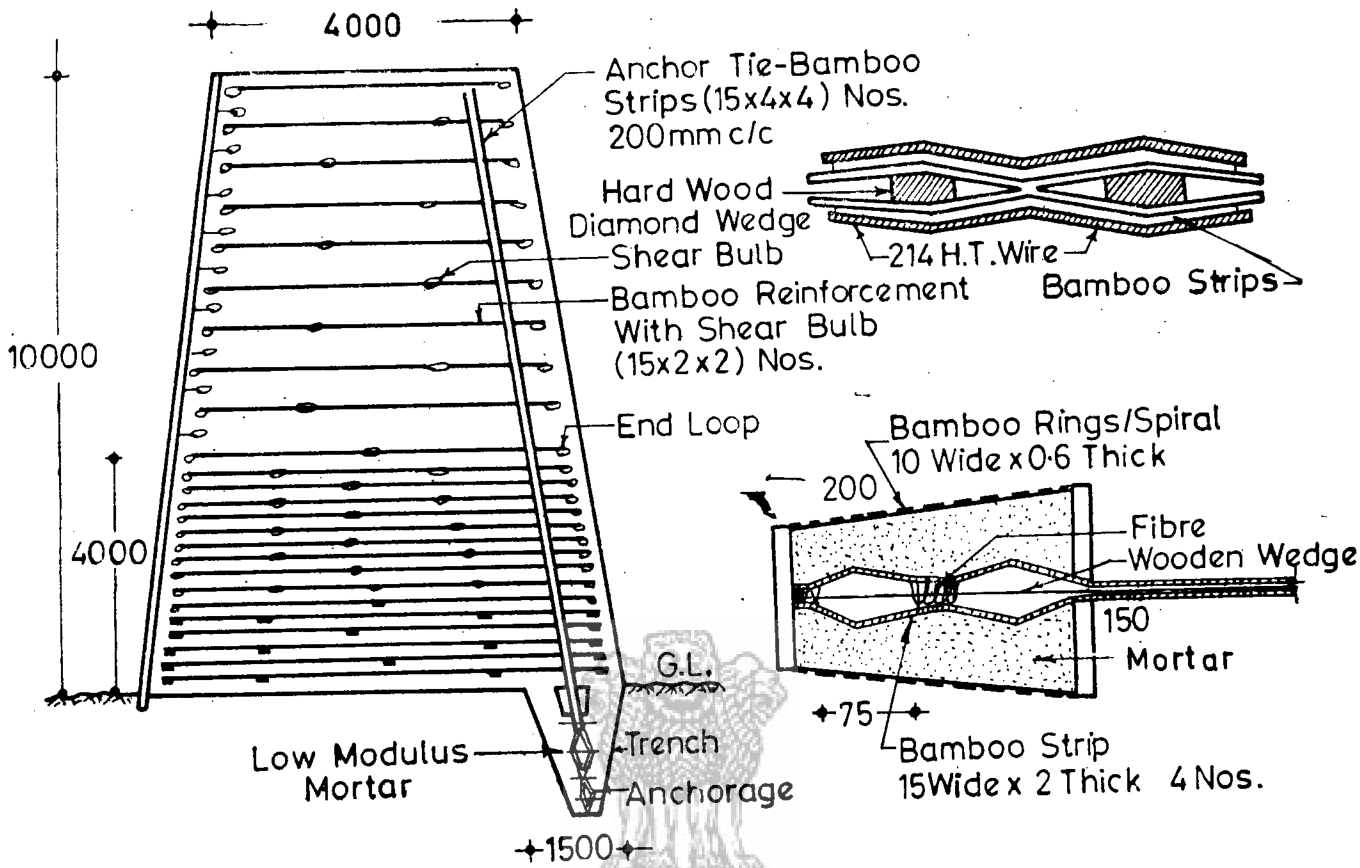
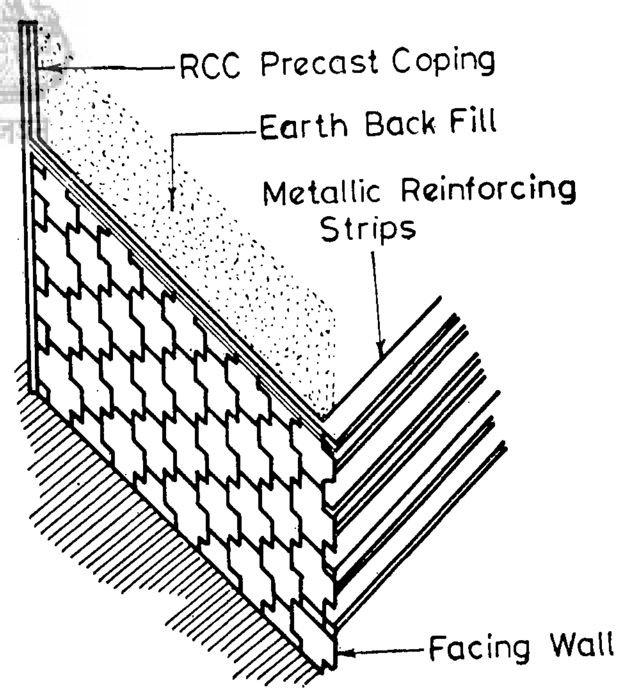


FIG. 30. REINFORCED EARTH FOR BRIDGE ABUTMENT



GRAVITY TYPE REINFORCED EARTH RETAINING WALL



REINFORCED EARTH RETAINING WALL

FIG. 31

CHAPTER 3

BUILDING BYE-LAWS AND REGULATIONS FOR HOUSING IN AREAS PRONE TO DISASTERS

The need and importance for special treatment of areas prone to natural disaster like floods, earthquakes, sinking of soil, cyclones and such other calamities has been accepted at all levels. The areas vulnerable to such disasters are required to be identified by the authorities entrusted with the task of preparation of the development plans. The zoning regulations which form an integral part of Master Plan should also include provision for treatment of such areas. The Municipal Bye-laws should provide for safety measures in such areas in the construction of houses and their design. A quick glance at some of the Master Plans prepared for various towns in the country and also the Building Bye-laws governing construction activities has revealed that no such provision exists for Disaster Prone Areas.

The Model Regional and Town Planning and Development Law formulated by the Central Town and Country Planning Organisation and recommended for adoption by the States to enact comprehensive Town Planning Legislation, is in the nature of guidelines.

It is periodically revised and updated keeping in view the experience gained in the working of the State Town Planning Acts, developments in the field in India and abroad, and case law on the subject. Many State Governments have followed this Model and enacted Town Planning Acts in their States by making such changes so as to suit individual requirements. It is suggested that the Ministry of Urban Development may consider incorporating some provisions in the Model Law to provide for areas prone to natural disasters. In this regards the planning and development authorities should at the plan preparation stage identify such areas by carrying out surveys and studies and taking expert advice of the agencies such as Geological Survey of India, Meteorological Department, Earthquake Engineering Department, Structural Engineering Research Centre etc., and include in the zoning regulations, which forms part of the Master Plan to provide for Disaster Prone Areas. The detailed development plans could also be prepared later. This should be followed by preparing special scheme for housing and other development activities in these areas keeping in view the distinct characteristics of the areas and ensure that the buildings and other types of constructions conform to the special specifications governing such construction. It is also for consideration of the Ministry of Urban Development to issue suitable advice to all the State Governments, Development Authorities and other agencies to conform to such specifications as laid down by ISI while making proposals for development in Disaster Prone Areas.

CHAPTER 4

MAPPING OF HAZARD ZONES

India has a large part of its land area lying in moderate to severe seismic zones where earthquakes of magnitudes more than 5.0 on Richter scale have been known to occur in the historical past or recorded in the last 80 years. In certain regions, even earthquake of giant size, more than 7.5 on Richter scale have also occurred and the largest magnitude earthquake with M-8.7 had its origin in the Shillong Plateau in 1897. The data pertaining to earthquakes in India is scanty before 1905 whereas those occurring during the last about 35 years is fairly complete. A very detailed catalogue of earthquakes in India and the neighbouring areas has been compiled and published by the Indian Society of Earthquak Technology, 1983, which gives 9707 entries of all known or recorded earthquakes upto the year 1979.

For considering the regional distribution of earthquake in the Indian sub-continent the whole area can be divided into the following seimic regions.

(a) Kashmir and Western Himalayas

(b) Central Himalayas (including Nepal Himalayas)

(c) North-East India

(d) Indo-Gangetic Basin and Rajasthan

(e) Cambay and the Rann of Cutch

(f) Paninsular India

(g) Andaman & Nicobar Islands

The seismic activity of these regions is briefly described below :

(a) *KASHMIR AND WESTERN HIMALAYAS*

This region covers the states of Jammu & Kashmir, Himachal Pradesh and sub-mountain parts of Punjab. More than 35 earthquakes of $M \geq 5$ are known to have occurred in the region, the maximum magnitude reaching to 8.0 in the great Kangra earthquake of April 4, 1905 which had caused large scale destruction in the region with a loss of life exceeding 20,000 mainly due to the collapse of dwellings. More recent damaging earthquakes are Badgam earthquake of Sept. 2, 1963, Anantnag earthquake of Feb. 20, 1967, Dharmshala earthquake of April 26, 1986.

(b) *CENTRAL HIMALAYAS*

This region includes the mountains and sub-mountain regions of Uttar Pradesh, the whole of Nepal and the sub-mountain regions of Bihar. The Western side of this region has given rise to earthquake of usual magnitude 6 but maximum reaching to 7.5 during Dharchula quake of 1916. The eastern side of the region has given evidence of very high seismicity and mention may be made of Bihar-Nepal earthquake of $M=8.3$ occurring on Jan. 15, 1934 in which many thousand lives were lost and thousands of homes were completely destroyed, rails were bent and sand fountains appeared on ground. More than 100 earthquakes of magnitude 5 and more are known to have occurred in this region, mostly in the western and eastern parts, the central part being relatively free.

(c) *NORTH-EAST INDIA*

This region comprises of the whole of Indian territory to the east of north Bengal. This (also other neighbouring countries like Bhutan) form the most severe seismic regions of the world having experienced more than 350 known earthquakes of Magnitude 5 and over, among which 15 had magnitude 7 or more on the Richter scale. The Assam quake of 1897 ($M=8.7$) is the largest earthquake ever known and the Sadiya earthquake of 1950 ($M=8.5$) was one which is rarely repeated in the world. These earthquakes were so large that even topographical changes of levels etc., took place but the loss of life was not so great since in 1897 the population was not so large and the 1950 earthquake occurred in rather unpopulated region. But even more so because the Assam type construction using bamboo posts and ikra-walling was light as well as strong which remained undamaged during these earthquakes. But the present situation is vastly different since population has increased tremendously non-engineered masonry and concrete constructions are replacing the Assam type construction. Hence the danger to life and property in future earthquakes is on the increase with each passing year.

(d) *INDO-GANGETIC BASIN AND RAJASTHAN*

This region is located immediately to the south of the Himalayas, covering Rajasthan, Plains of Punjab, Haryana, Uttar Pradesh and Bihar and Bengal lying north of the Vindhyas. Seismic activity has been noticed on Moradabad fault, the Sohna fault near Delhi and the Lucknow and Patna faults. About 20 earthquakes of $M \geq 5.0$ are known to have occurred in this region, the maximum intensity being 6.7. Hence this region may be seen to have moderate to minor seismic activity. To areas close to the Himalayas are of course liable to ground shake during earthquake occurrences in the Himalayan region.

(e) *CAMBAY AND THE RANN OF KUTCH*

This small region has also suffered from a number of earthquakes more than 10 of $M \geq 5.0$ but including one of $M \geq 7.0$ and the other of $M \geq 8.0$ which occurred in the Rann of Kutch in 1819 destroying the town of Bhuj and killed 2,000 people. It can be taken as having severe to moderate seismicity.

(f) *PENINSULAR INDIA INCLUDING THE ISLANDS OF LAKSHADWEEP*

This region is a pre-Cambrian shield and hence generally stable except some strips in its north, that is, along the Narbada Rift and in the Western Margin. In the whole region not more than 40 earthquakes occurrences of $M \geqslant 5.0$ are known which include the maximum magnitude of 6.5 Koyna earthquake of 1967 and its 10 aftershocks. Thus the region may be seen to have lesser seismicity except a few small sub-regions.

(g) *THE ANDAMAN-NICOBAR ISLANDS* :

This region is highly seismic having witnessed about 150 earthquakes of $M \geqslant 5.0$ among which may be mentioned the 1941 giant earthquake of magnitude 8.1. The main town of Port Blair has also experienced damage besides other civil and military installation. The vulnery of damage is increasing with the rapid rise of population and larger use of unreinforced masonry.

THE SEISMIC ZONING MAP :

It is thus seen that the seismic hazard problem in the country covers a substantial part of the land. A seismic zoning map has been standardised by ISI as given in IS : 1893—1975 as shown in *Map I* which has classified five seismic zones based on experienced as well as expected probable intensities on MM Intensity 12 point scale. Zone V with probable intensities of IX and larger covers an area of 12% zone IV with probable intensity VIII covers 18% and Zone III with probable Intensity VII covers 26% of the land area of India. In these three zones destruction and substantial damage to housing is probable. Thus an area of about 56% is liable to earthquake damage. Zone-II based on MM VI could also have minor damage in rural buildings built in field stone, that is, random rubble and adobe and clay mud, but collapse of housing in Zone II is not considered probable. Zone I may be taken as of non-damaging seismicity.

An idea of the damage to various buildings in the Zones III, IV and V may be obtained from the following *Table*.

TABLE 1

PROBABLE EARTHQUAKE DAMAGE TO BUILDINGS IN ACTIVE SEISMIC ZONES OF INDIA

Building Type	Zone III	Zone IV	Zone V.
A. Field Stone, Adobe, Mud, Rural Structures	Most buildings have heavy damage and suffer destruction.	Most buildings-suffer destruction. Few eew collapse.	Many or most are collapsed. Nearly all suffer destruction or heavy damage.
B. Ordinary Brick buildings, large block and prefeb type half timbored buildings, ordinary dressed & coursed stone houses.	Many buildings suffer moderate damage	Most buildings get heavy damage	Many buildings suffer destruction, few are collapsed too.
C. Reinforced brick buildings, reinforced concrete buildings of good design, well built wooden houses	Many buildings get slight damage.	Most buildings have moderate damage Few suffer heavy damage.	Many or Most buildings get heavy damage. Few suffer destruction or collapse.

Definations : 1. Few-about 5%, Many-about 50% Most-about 75%
2. Slight-Fine cracks in plaster, fall of small pieces of plaster.
Moderate-Small cracks in walls, fairly faliry large pieces of plaster, peatiles slip off, cracks in chimneys parts of chimneys fall.
Heavy-Large and deep cracks in walls fall of chimneys.
Destruction-Gaps in wall, parts of buildings may collapse, seprarte parts of building lose cohesion and show relative movement, inner walls collapse.
Collapse-Total collapse of Building.

CYCLONE WIND MAPPING

There are eight marine states in the country namely West Bengal, Orissa, Andhra Pradesh and Tamil Nadu on the eastern coastline and Gujarat, Maharashtra, Karnataka and Kerala on the Western Coastline. The number of cyclonic storms during the 94 year period between 1891 and 1984 was 238 in the Bay of Bengal and 32 over Arabian sea out of 424 and 118 located in the respective sea areas. Others moved towards neighbouring countries.

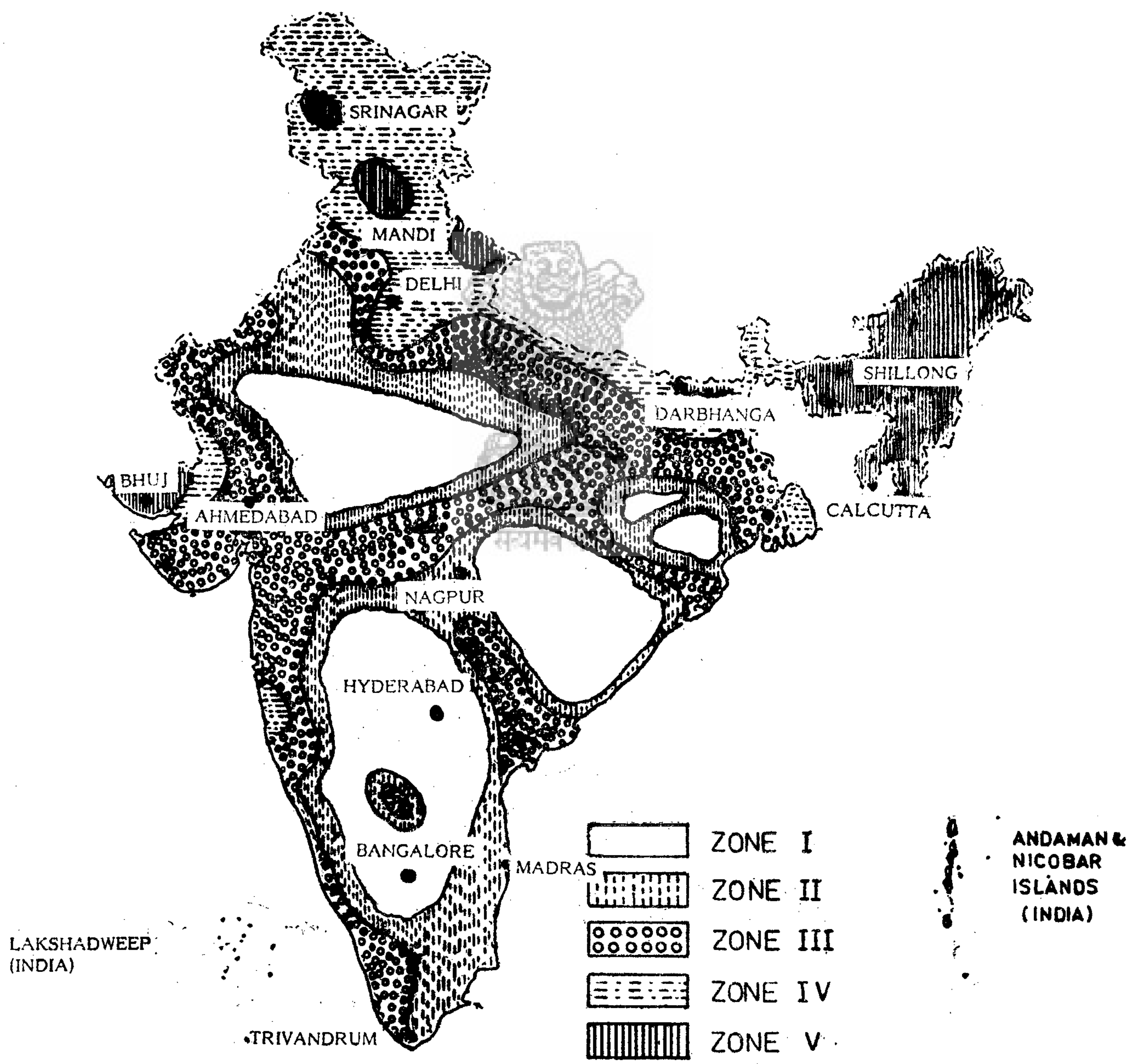
The average annual frequency of cyclonic disturbances is about 13 over Indian seas. Out of these only about 35 percent (4 to 5 per year) develop into cyclonic storms and about 10 percent (1 to 2 per year) develop into severe cyclonic storms which cross the coast.

Strong winds of hurricane speed, greater than 120 Km. per hour are frequently observed during the passage of severe cyclonic storms crossing coastal areas. These strong winds are sustained in nature and last for hours together disrupting human activities causing wide spread damage to life and property and inundate large low lying areas of coastal region due to storm surges.

The coastal areas according to estimates from damage of structures, bending of electric and telegraphic poles have experienced winds due to severe cyclonic storms of the order of 200 to 250 Km. per hour.

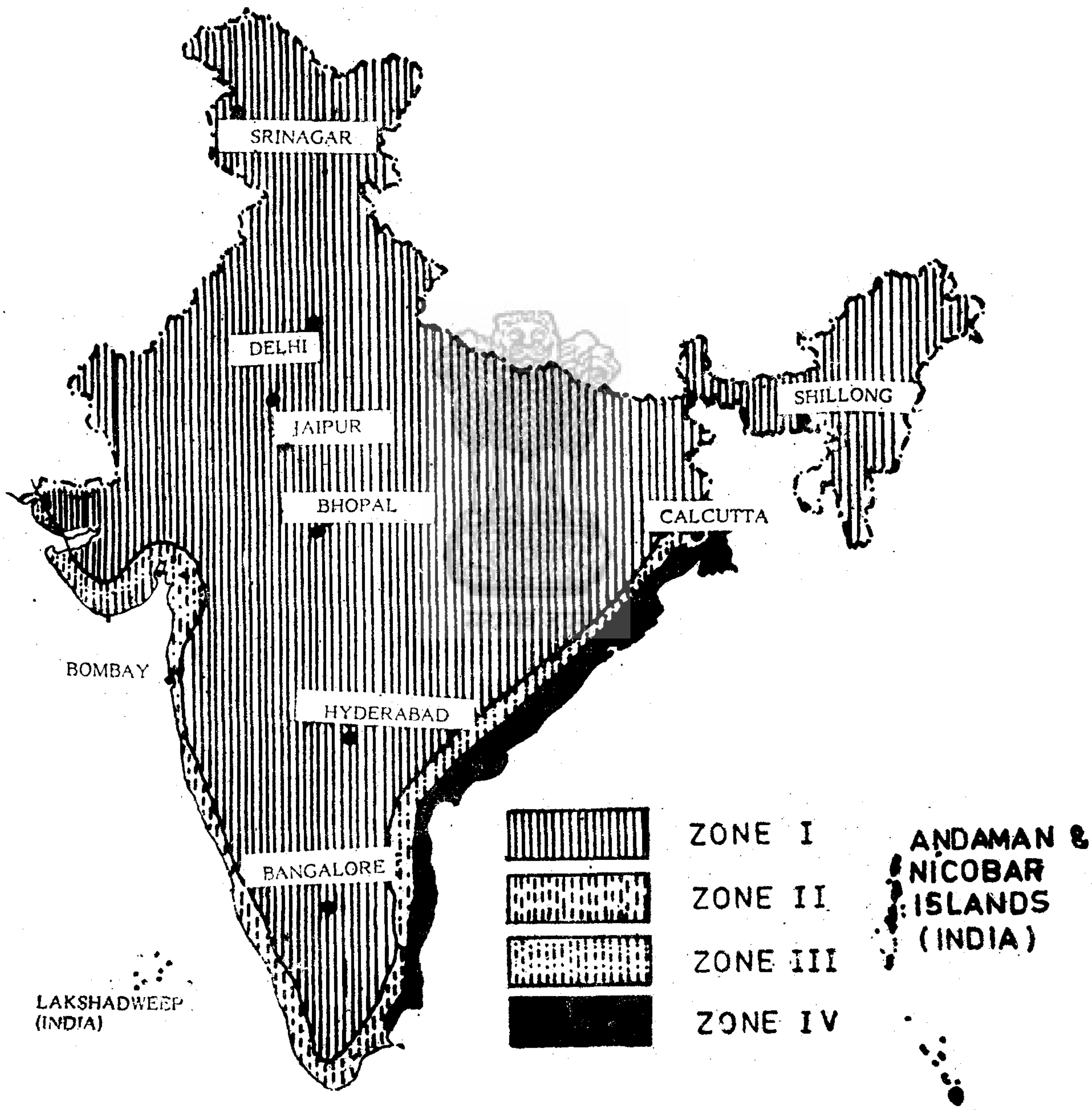
For general design purposes Indian Standards Institution has formulated the specifications in IS Code IS : 875-1964 based on the then avaliable meteorological data. The said Code contains two maps showing basic maximum wind pressure map of India one excluding and other including the winds of short duration (lasting to a few minutes generally less than 5 minutes). The maps, however, do not take into account the random nature of wind. The code is under revision based on all available data and the revised version is expected to reflect the random nature of wind return-period map of wind velocity.

MAP OF INDIA SHOWING SEISMIC ZONES



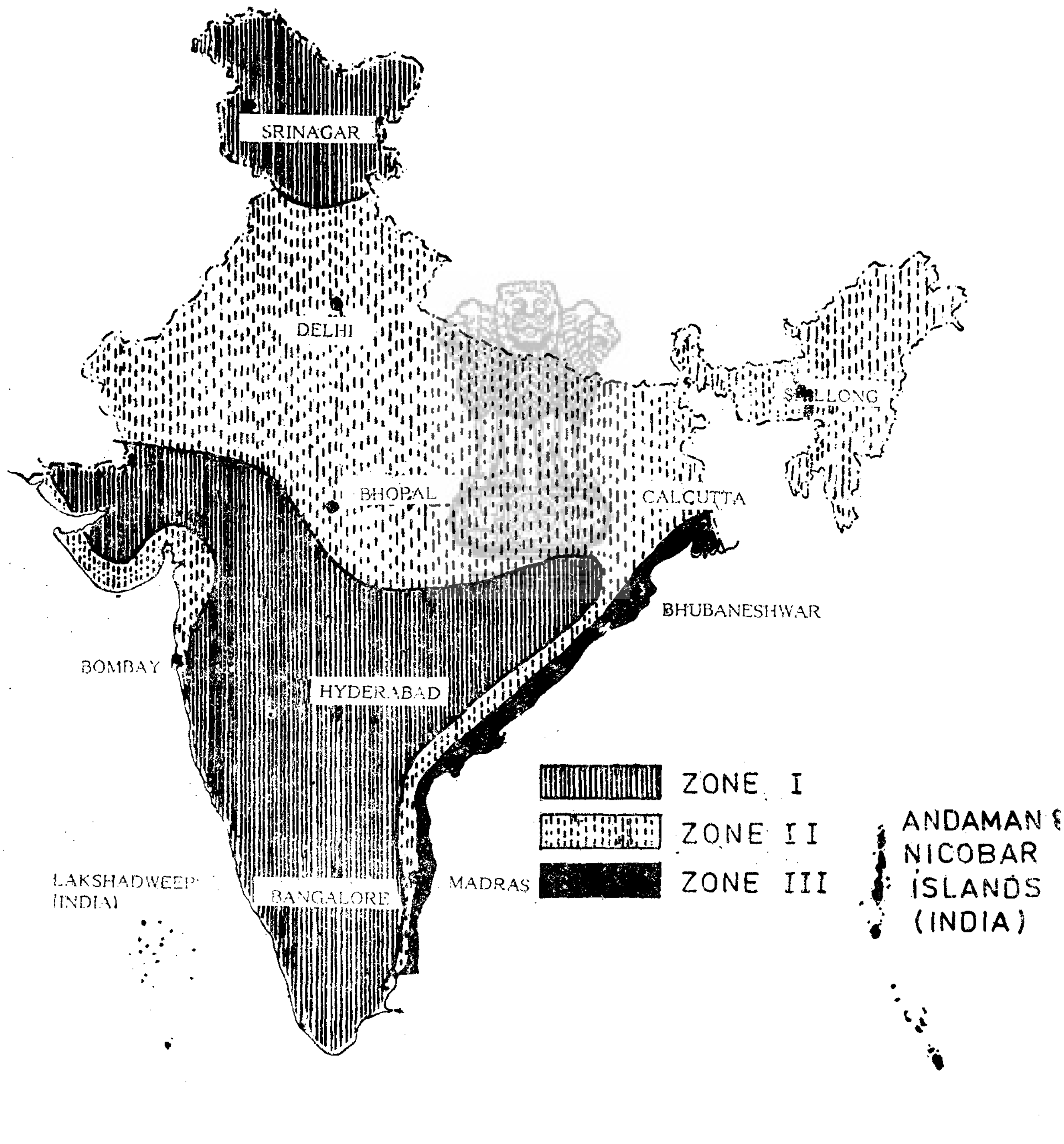
The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line

MAP OF INDIA SHOWING BASIC MAXIMUM WIND PRESSURES EXCLUDING WINDS OF SHORT DURATION



The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

MAP OF INDIA SHOWING BASIC MAXIMUM WIND PRESSURES INCLUDING WINDS OF SHORT DURATION



The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

CHAPTER 5

RECOMMENDATIONS

The subject of Disaster Mitigation with reference to housing involves numerous disciplines. The general approach, to the problem of housing in disaster prone areas varies according to the type of disaster, as each of them has its own special characteristics and varying parameters. As such the Group has given important recommendations applicable to all types of disasters and suggested areas for further action on long term as well as short term basis. Nevertheless, a few recommendations for specific type of disasters have also been included, taking into account their uniqueness in finding suitable mitigation measures.

In evolving these recommendations the terms of reference of the Group have been kept in the background and the recommendations have been grouped by and large conforming to the terms of reference.

A. *TECHNICAL MEASURES*

(1) Many buildings and houses located in disaster prone areas are structurally inadequate to resist the destructive action of natural disasters. Efforts should be made to incorporate strengthening measures in the important buildings, Hospitals, Community Shelters, Schools, Cinema Halls, Office Complexes and such type of buildings where a large number of people are exposed to risk must be considered for strengthening. The old and temporary structures, especially must be given priority. The cost benefit ratio in providing disaster resistant housing should be worked out for various types of disasters and local condition so that cost effective solution commensurate with the needs are worked out.

(2) The level of reliability of a particular structure depends on the type and quality of the disaster mitigation measures incorporated. In view of the limited resources the cost benefit ratio aspect must be given due regard, incorporating such measures.

(3) (a) In flood prone areas, the building should be constructed as far as possible on soil of the best bearing capacity. It should be constructed on the highest ground available.

(b) Houses should be constructed over raised mounds. The mounds should be prepared with locally available soil and compacted thoroughly.

(c) The roof level should be sufficiently high above the 'design flood level' in order to provide protection in the case of emergency.

(d) The walls constructed with mud and soil blocks should be protected against the flood by rendering water proofing treatment.

(4) All buildings in seismic zones should be designed and constructed for earthquake resistance as stipulated in the Building Codes. Proper architectural planning regarding shape and size of rooms and building as a whole, location and size of openings *etc.*, are found to contribute greatly to good earthquake performance of the buildings. The provision of horizontal seismic bands on all walls integrating the action of individual rooms as well as the building as a whole is an essential feature of all masonry as well as mud houses for safety against collapse during moderate earthquake.

(5) (a) Reinforced cement concrete flat roofs are suitable in cyclone prone areas because of their weight and rigidity. In other types of roof using light materials, sufficient slope should be provided.

(b) For cyclone resistance beams should be provided on all internal and external load bearing walls. Vertical reinforcement in the walls and at corners and junction should be provided.

(c) Durable structures of RCC, brick, stone and concrete block masonry are better suited in cyclone prone areas.

B. *SITING & CONTROL MEASURES*

(1) Micro-zoning pattern should be evolved for disaster prone areas to provide guidelines for planning and siting of housing and human settlements.

(2) Guidelines for working out methodology of vulnerability analysis should be prepared for land use planning.

(3) Floods :

(a) Flood storage facilities in unoccupied flood plain areas should be developed for storing peak discharge of rivers during flood.

(b) To prevent inundation of flood plains, river banks should be constructed or the existing level of river banks should be raised.

(c) To relieve the flood pressure from the normal river channel, by-pass channels should be provided.

(d) The normal river channels should be improved to increase the conveyance of flood water by re-aligning or enlarging the cross sectional area or increasing the bed slope.

(e) Well designed and maintained drainage system should be provided in towns to avoid local flooding.

(f) Growing of regular plantation in the catchment area and on the banks of the rivers as well as coastal area should be encouraged to retard run off.

(g) Plants and shrubs should be grown around the house as they provide a measure of protection by breaking the force of gushing water.

(4) The importance of flood plain zoning should be recognised for orderly settlement free from undue hazards. Survey should be taken up in flood prone areas to demarcate prohibited, restricted and warning zones and the inhabitants should be made aware of these zones with proper demarcation. The concerned authorities should develop flood plain zoning maps which should be implemented in establishing human settlements.

(5) The Building Regulation should specify incorporation of strengthening measures in building and housing in order to enable them to withstand inundation from high velocity water.

(6) Much attention should be given for drainage in forming new settlements and escape lanes should be incorporated in the layout for rapid flow out of water.

(7) There is a need for proper planning of human settlements taking into account the total effects of wind on the settlement particularly the infrastructure. Proper orientation and geometry of the structure are important for increasing the wind resisting capacity and should be given due regard. By proper siting of houses and other structures in a settlement wind concentration can be avoided or minimised.

(8) Cyclone shelter belts should be created in the coastal areas by tree plantation. Temporary/emergency shelters should be constructed in the coastal areas.

(9) The Municipal Bye-laws and Building Regulations should incorporate mandatory provisions for strengthening of houses and buildings in disaster prone areas. Strict enforcement should be ensured. Building Bye-laws and Regulations should be examined in depth to identify shortcomings in the provisions for adequate and satisfactory strengthening arrangements taking into account the type and intensity of disaster experienced locally.

(10) Repair and reconstruction of buildings and houses affected by natural disasters is a specialised subject. The National Building Code of India should include a chapter devoted to this aspect. The National Building Code should also include chapters for rural buildings and houses which should incorporate measures of strengthening houses against natural disasters.

C. *RESEARCH*

(1) (a) There is a felt need for developing the methodology of precising prediction of formation intensity and movement of tropical storms in the Indian sub-continent. Towards this end, the observations facilities like aircraft reconnaissance, special marine vessels and satellite observation should be augmented and improved.

(b) There is a felt need for collecting basic information pertaining to incidence of all types of natural disasters and their effects on different types of structures. A Data Bank should be established to collect information from all sources.

(2) Surveys of different types of houses should be carried out all over the country and mapping of housing zones and typology should be evolved. Data obtained will facilitate R & D work.

(3) Specific measures for disaster preparedness related to housing should be identified to mitigate their effects. Such measures include materials for repair and reconstruction, temporary shelters, etc.

(4) To study the structural response and optimise the design of a hazard-prone structure, reasonably large scale disaster simulation and performance facilities need to be created. Large size shaking table, wind tunnel, static and dynamic test floor, computer-controlled loading and data acquisition system, instrumentation to obtain field data on hazard loads are some of the major facilities which should be established at the national level.

(5) As the facility of wind tunnel and large scale shaking table would be available at

the SERC in Ghaziabad a close interaction between SERC and other agencies is essential to ensure that the design parameter of these facilities meets the requirement of the disaster prone structures.

(6) (a) Research work should be undertaken to develop temporary houses and instant houses for sheltering disaster victims immediately after the disaster as well as for temporary duration. The chief criteria should be (a) construction should be based on local building materials and appropriate technology (b) it should be light in construction; and (c) prefab structure should be light and amenable for dismentalling and reusing.

(b) R&D work should be carried out to study the cost effectiveness of pneumatically supported tents used as a temporary shelters. The research should aim at standardising design procedures, develop synthetic covering material and develop ancillary equipment required to maintain the shelters in operation.

(c) Mitigation of damages from natural disaster is possible through a good understanding of the structural behaviour of houses and buildings. Some of the priority areas of research are as follows :—

(i) Structural design data pertaining to the terrain and to the intensity and frequency of the type of hazard being considered,

(ii) Study of structural damages caused in different kinds of hazards,

(iii) Characteristics of locally available materials and other common building materials to evaluate their suitability for disaster housing.

(iv) Hazard resistant designs and strengthening measures,

(v) Development of design criteria,

(vi) Appropriate construction techniques.

(d) In determining the degree of reliability of a structure, the combined effect of loads and strengths which are themselves highly variable should be taken into account. The application of reliability theory to hazard resistant structure will give a clear indication of the relative influence of the parameter contributing to the risk.

(e) Study should be taken up on the behaviour of different aspects, volumes and siting of buildings subjected to natural disasters.

(f) Appropriate materials and techniques should be developed for quick repair and rehabilitation of existing old and dilapidated buildings.

(g) Model studies should be conducted with different congurations of building to study their relationship with wind effects.

(h) Studies should be undertaken to improve the durability and performance of low cost buildings and houses in rural areas to withstand the effects of cyclones.

(i) Efficient jointing, bracing and anchoring details should be developed for structural members, through research.

(j) Research work should be undertaken on structures built on silts to increase their flood resistance.

(7) (a) Data of rainfall, run off and sediment yield and other water shed characteristics should be collected over a period of time for all major rivers in order to obtain prediction models for estimating run off and sediment yield of ungauged water sheds.

(b) Flood frequency curves based on the data of frequency distribution, intensity of rainfall and water shed should be developed.

(8) (a) To utilise the enormous potentional existing in the academic and research organisations, specific research needs to be organised. The research work should be coordinated by agencies such as NBO and DST.

(b) Research work should be undertaken on the aspect of strengthening existing structures to resist anticipated earthquake forces.

Sd/
(G.C. Mathur)
Chairman

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Sd/ (S. P. Sharma) Member	Sd/ (J.L. Prashar) Member
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Sd/ (B. Venkateshwarlu) Member	Sd/ (K.S. Srinivasan Mem ber secy.

CHAPTER 6

STRATEGY FOR IMPLEMENTATION

The Group has recognised the importance and urgency of the problem of evolving appropriate and economical solutions for housing in disaster prone areas. Considering the magnitude and complexity of the problem, it is imperative that a well planned strategy has to be adopted for evolving long term and short term measures towards this end. A good amount of research and development work as well as training, extension and publicity are called for. Some of the specific measures recommended by the Group are given below.

(1) The short and long term steps for developing disaster resistant houses should be identified and implemented as per time-bound programme.

(2) (a) The NBO should make a first hand study of the work carried out in other parts of the World regarding disaster housing with a view to utilising the knowledge and experience under Indian conditions.

(b) Suggestive type designs incorporating various strengthening measures should be worked out and distributed widely to the concerned departments, etc.

(c) A permanent cell should be created in NBO to follow up and implement the recommendations of the Group. As this is a specialised job calling for multi-disciplinary approach and collaboration with a large number of departments all over the country, adequate staff should be provided to man the cell.

(d) The Regional Housing Development Centres of the NBO should play an active role by carrying out extension work to promote wide scale adoption of research and technological developments pertaining to Disaster Housing.

(e) Demonstration houses and structures incorporating disaster resistant measures should be put up at various places prone to different types of disasters. The demonstration structures should incorporate locally available materials and should be used as tools to develop skills in disaster resistant construction.

(3) (a) Guidelines for house builders should be prepared suggesting ways and means of protecting houses against natural disasters by incorporating strengthening measures suggested in Standards and Codes. The guidelines should also be brought out in regional languages. For rural areas, guidelines in simple languages with good illustration should be brought out.

(b) Engineers, architects and builders should be made aware of the latest technology available for strengthening structures in disaster prone areas, through Seminars/Symposia, lectures, distribution of publications, etc.

(c) Training Courses on Housing in Disaster Prone Areas, Disaster Mitigation and allied subjects should be organised for inservice personnel to impart knowledge on the latest technologies and innovations pertaining to construction and repairs of houses in disaster prone/affected areas.

(d) Training programme for inservice personnel in planning, design and construction of earthquake resistant buildings and houses should be organised. The training should also include the aspect of strengthening masonry buildings and mud houses.

(e) In flood prone areas, the importance of keeping the drains clean to avoid flooding should be brought home to the people.

(4) (a) Seminars, Workshops and Symposia should be organised with the duel purpose of propagating technologies and strategies on disaster housing and to provide a forum for interaction of experts in the field.

(b) Promotional work and publicity pertaining to disaster resistant construction in villages must be commensurated with the needs and keep affordability in view. It should be easily comprehended by the villagers.

(c) Audio Visual Programmes using video films, movie films, slides, etc., should be prepared for propagating information and educating people at all levels.

(d) Books instruction leaflets and manuals should be prepared for the benefits of engineering personnels as well as laymen,

(e) Mass media like TV, Radio and Press be utilised for countrywide publicity.

(5) (a) There is a great need to undertake promotional activities for transfer of technology related to construction in seismic areas. The NBO and Department of Earthquake Engineering should step up their activities. They should be adequately strengthened with the staff and requisite facilities.

(b) An Earthquake Engineering Research Centre should be established for taking up research on all aspects of seismic resistant construction and for propagational work.

(6) The ISI should take up formulation of Indian Standards and Codes of Practices on various aspects pertaining to planning, designing and construction of structures put up in vulnerable areas.

(7) The curriculum of Engineering Colleges and Architectural Schools, etc., should include the subject of housing and building in disaster prone areas.

(8) A School on Housing in Disaster prone areas should be set up to impart training to all professional people concerned with different aspects of natural disaster including house construction, restoration, retro fitting, etc.

(9) The Last Decade of Century (1991—2000) should be designated as Decade for Natural Hazard Reduction to focus World attention on this important human problem. A strategy for finding satisfactory solution by the end of the Decade should be worked out.

सत्यमेव जयते

PAPERS PRESENTED BY VARIOUS MEMBERS AND EXPERTS

(Detailed text of papers is being brought out in separate volume. Here only list of papers is being given).

1. Prefabricated Low Cost Houses using Ferro Cement Elements.

   by Prof. M. S. Shetty and Er. M. K. Varghese, College of Military Engineering, Pune.

2. Flood Plain Zoning
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3. Brief Technical Note on the Design and Construction of Cyclone Shelters in Coastal Districts of Andhra Pradesh.
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5. Cyclone—Resistant Housing
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6. Technical Discussion on Housing in Disaster Prone Areas.
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   by Shri H. K. Yadav,
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   CBRI, Roorkee.

9. Recommendations of the International Conference on 'Natural Hazards Mitigation Research & Practice, Small Buildings and Community Development' held at New Delhi from 8—11 October, 1984.

10. Notes prepared by Geological Survey of India

    (i) Housing Problem in Coastal Tract of South Gujarat.

    (ii) Andhra Coastal Cyclones of 1977 & 1979.

11. Note on Earthquake Disaster Mitigation
    by Dr. A. S. Arya,
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12. A Study on Development Prospects in Housing in Flood Prone Rural areas.
    by NBO Rural Housing Wing, Howrah.

13. Housing for Disaster Affected Areas
    by Shri Narendra Verma,
    CBRI, Roorkee.

14. Durable Mud Houses in Flood Affected Areas
    by Shri G. C. Mathur,
    Director, NBO.

15. Cyclone Damage and Rehabilitation with Reference to Housing and Human Settlements,
    by Shri G. C. Mathur and Shri A. K. Lal, NBO.

16. Appropriate Technology for Construction of Earthquake Resistant Mud Houses.
    by Shri G. C. Mathur,
    Director, NBO.

17. Problems of Housing Snow Bound Regions
    by Shri G. C. Mathur,
    Director, NBO.

18. Fire Safety in High Rise Buildings
    by Shri G. C. Mathur,
    Director, NBO.

19. Technological Options for Shelter to Disaster Victims.
    by Shri G. C. Mathur,
    Director, NBO.

20. Technical Note on the Flood Protection of Houses
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    Bangalore.

21. Map Giving Frequency of Cyclonic Storms Striking Different Sectors of Indian Coast Line During the Period 1891—1984.
    by India Meteorological Department.

22. Instant Shelter for Disaster Relief.
    by Shri Narendra Verma,
    CBRI., Roorkee.

23. Houses in Disaster Affected Areas of Andhra Pradesh.
    by Shri Narendra Verma,
    CBRI., Roorkee.

24. Reconstruction Planning
by Shri Satyendra P. Gupta and
Dr. Anand S. Arya,
Department of Earthquake Engineering,
University of Roorkee.

25. Seismic Status of School Buildings in West and South East Asian Region
by Dr. A.S. Arya, Shri Brijesh Chandra and Pratima Rani
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26. Seismic Analysis of Experimental Buildings
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—Urban Areas

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