Paper No. 37

IMPORTANCE OF EARTHQUAKE STUDIES AS PART OF INVESTIGATIONS FOR POWER PROJECTS

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SYNOPSIS

The paper points out the importance of earthquake studies as part of investigations for power projects in India which is one of the very active seismic countries of the world and emphasises the need for (i) establishment of a closer net-work of seismological observatories to demacrate the active faults and zones, (ii) installation of instruments to record the response of structures having different natural periods of vibration and damping and (iii) theoretical and experimental studies for the proper design of structures subjected to vibratory motion during earthquakes.

INTRODUCTION

India has one of the most active seismic zones in the world. Many earthquakes, matching with or even bigger than the most severe earthquakes experienced anywhere else, have occurred in this country and caused heavy damage. Fig. 1 shows the epicentres of the earthquakes that have occurred in the last 70 years or so. It will be seen that epicentres of most of the past earthquakes lie in Northern India in the states of Assam, North Bengal, North Bihar, North U.P., Punjab, Kashmir and Gujerat. These are also the areas where many large projects are sited. Assam earthquakes of 1950, Bihar-Nepal earthquake of 1934 and many other smaller but quite significant ones are very recent (list of some destructive earthquakes–App. 1). It will thus be seen that taking necessary precautions in the siting of important structures and allowing adequate earthquake forces in their design is essential. It is proposed to describe in this paper the data that should be collected in a region and its importance for the design of earthquake resistant structures.

SEISMICITY OF A REGION

Although broad geological features are indicated on the maps already available, it is necessary to make a more detailed geological and seismological study of the site in order to

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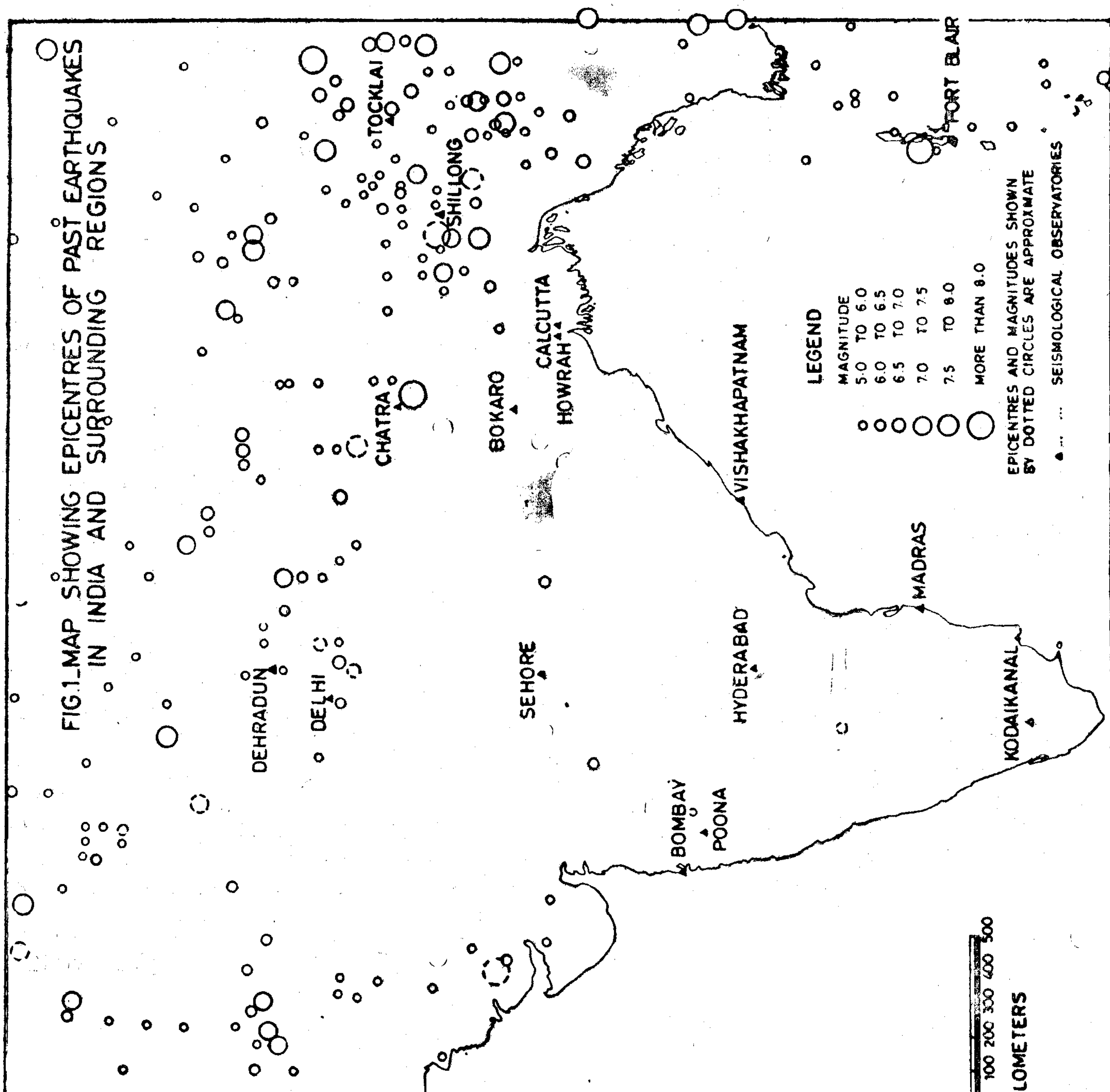

FIG.1_MAP SHOWING EPICENTRES OF PAST EARTHQUAKES IN INDIA AND SURROUNDING REGIONS

assess the possibilities of occurrence of earthquakes in future. Unfortunately, systematic records of earthquakes have been obtained and studied only recently. Before the advent of instrumental observations, it is only the very devastating shocks that are mentioned briefly in historical records. Detailed information is available only for earthquakes that have occurred in the present century, and records of hundreds of earthquakes which must have occurred earlier are not available. Even now many small earthquakes, originating from the potential active zones along which we should expect a devastating earthquake in future, are missed, as the network of seismogical stations is not close enough, and the micro-tremors die off before they reach a recording station. In India, sixteen Seismological Observatories are being maintained by the India Meteorological Department and some more areb eing established. These stations as shown in Fig. 1 are too far apart for recording locals hocks over the vast seismic areas in India with the result that the tectonic trends, which could Many be studied by recording micro-tremors, occuring frequently, cannot be studied. more earthquakes will be recorded if we have a closer network.

In the absence of sufficient data, seismic coefficients for the design of engineering structures are arbitrarily chosen. In order to have more scientific data before coefficients are chosen, it is necessary that local geologic studies assisted by seismological records are made. These alone could help in recognising the active zones along which movements have occurred during the Recent period. Sometimes apparently visible faults are found to be seismologically stable when their state of activity is ascertained through seismographs. These measurements, though not a direct indication of the maximum intensity of a future earthquake, will be useful in assessing the activity of the faults in the region and would give an idea of the dominant natural period of the ground at the project sites, which would be a useful data in estimating the vibration amplitudes of structures to be sited.

In many regions, where tectonic features have been obliterated by weathering or are covered under thick cover of alluvial materials, geophysical methods can often reveal the subsurface configurations of the various structural features, which in correlation with the alignment of the known epicentral tracts will indicate active zones.

INSTRUMENTATION

The seismological stations maintain sensitive seismographs to record primarily distant earthquakes so that the location of epicentres and their focii, kind of wave propagation in the particular part of the earth, and other data relating to the interior of the earth, could be obtalned. The requirements of these studies require highly sensitive instruments located on firm ground (preferably rock) and isolated from inhabited areas to avoid disturbances caused by local effects. Such stations do not thus provide adequate data for engineering studies. An engineer is interested in knowing the nature of strong ground motion near the site of the proposed structure and the consequent forces that the structures having different dynamic charavteristics will be subjected to on account of it. The data given by sensitive seismographs, if installed near the site, will be useful for assessing seismicity, determing epicentres of shocks, general character of ground formation and the dominant vibration characteristics of the ground. In addition there is a need for establishing stations, which will house instruments designed to record structural response due to strong ground motion in the area around. The "Structural Response" may be defined as the vibration characteristic of an idealised engineering structure, possessing certain known dynamic characteristics, to a particular earthquake. Simple Pendulum Recorders have been designed at the School of Research in Earthquake Engineering, Roorkee and are being installed towards this objective by establishing a network of stations. The list of stations that have already been built and instruments installed and those that are under construction is attached as App. 2. These stations have been built on alluvial or rock base depending upon where large scale construction is likely or where large population actually lives. The records obtained on these instruments during a strong earthquake, which is likely to cause damage at that place, will give an idea of the forces that the engineering structures which the instruments idealise, are subjected to at that place. This data is directly useful for design purposes and is the best way of obtaining information regarding the effects of earthquakes on structures, because it takes into account the geological characteristics of the area which affect the propagation of waves, and the effects due to the interaction between the foundation materials and the waves. The two major dynamic characteristics which affect the overall behaviour of a structure are its natural period of vibration and damping. These are the two properties which are reproduced in the Structural Response Recorders in order to assess the over-all response of the structure having the same dynamic characteristics. Six instruments are being placed at each stations having the following properties :

	Period	Damping % of critical
Recorder No. 1	0.40	5
Recorder No. 2	0.75	5
Recorder No. 3	1.25	5
Recorder No. 4	0.40	10
Recorder No. 5	0.75	10
Recorder No. 6	1.25	10

The records on these six instruments will give the shape of the curve relating natural period, damping and the "response" of structures in the most crucial part of the spectrum. If structures having these properties can be safeguarded against damage then those having longer periods or higher damping can be designed without difficulty, since they would be subjected to smaller forces.

Usual damping in structures is of the order as below :

1.	Steel structural frames	2 to 3 per cent
2.	Steel structures having brick panels	3 to 5 ,,
3.	Well built reinforced concrete building	5 to 10 ,,
4.	Composite construction having concrete, steel and brick work	5 to 10 ,,
5.	Poor brick masonry construction	5 to 15 per cent depending upon the nature of construction, mortar used etc.

This will explain why instruments having 5 and 10% damping have been used. In selecting the period, the consideration has been that the structures having natural period between 0.40 sec and 1.25 sec develop high forces during an earthquakes.

It may be relevant to point out here that a force to which a structure is subjected during an earthquake is not only a function of the size of the earthquake, the geology of the region and the nature of foundation but also the properties of the structure itself (Fig. 2). Thus designing all structures for some arbitrary coefficients is not scientific and will lead to incorrect assesment of safety.

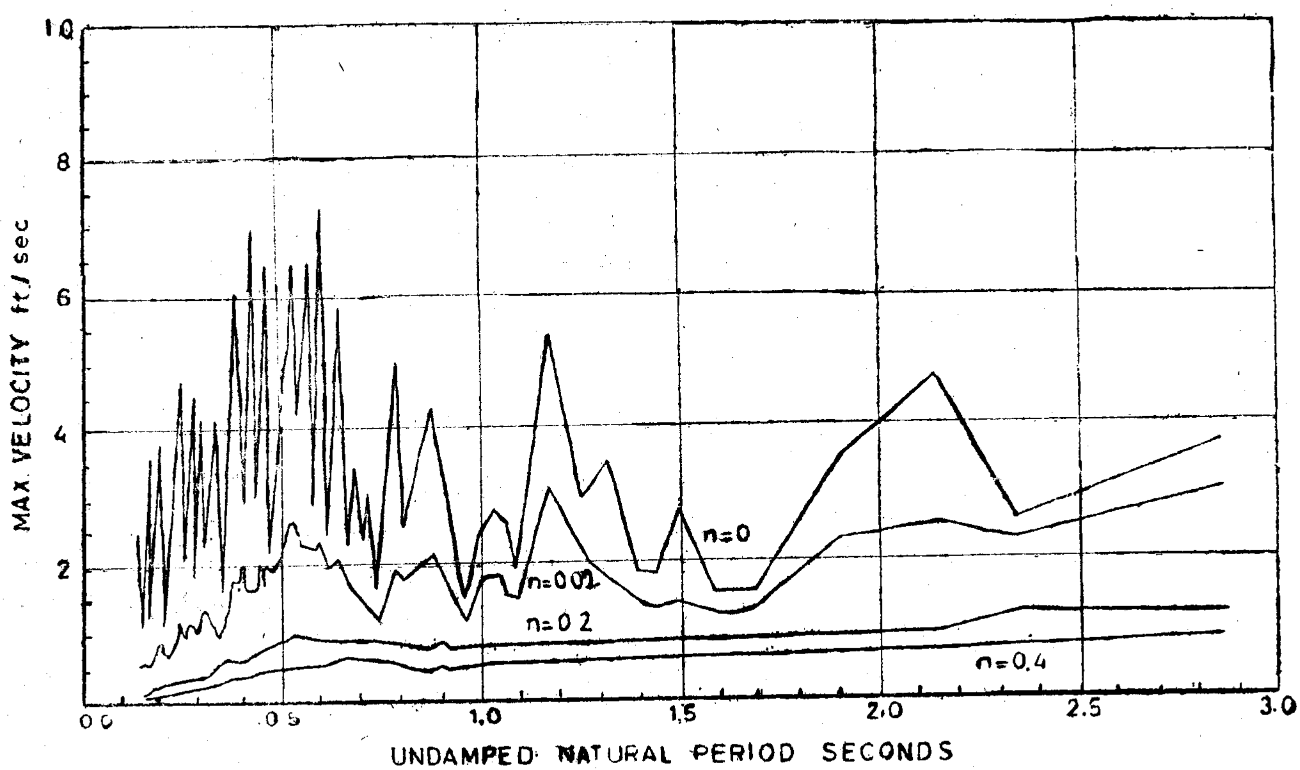

Figure 2 Spectral Response Curves of A Structure Having Single Degree Freedom with Different Damping (n) for El—Centro California Earthquake of May 18, 1940

It is thus essential that such insutrments are installed at sites where projects are likely to be taken up taking a long term view (next 50 years or so) so that adequate data is collected in course of time.

THEORETICAL AND EXPERIMENTAL STUDIES ON STRUCTURES SUBJECTED TO EARTHUQAKES

An earthquake causes vibratory motion to the ground on which a structure stands. This motlon may have components of forces and moments in any plane. A structure has to be so designed that it is capable of withstanding the effects of these reactions of the ground. Theoretical methods have been developed by which an idealised structure, subjected to certain types of vibrations, could be analysed to determine the additional moments and shears induced by the vibratory motion. The methods of analysis get complicated in composite structures. If the materials used have diflerent elastic and plastic properties or the materials are stressed in plastic range, the analysis becomes tedious. Digital computors have facilitated such analysis provided that the idealised assumptions, on which the analysis is based, repcresent adequately the physical situation. In practice, it is more appropriate to confirm the idealised analysis with model experiments. Although models themselves have their shortcomings, yet they give excellent information about the overall physical behaviour, however complicated the structure may be. Even quantitatively the models often give more realistic results than theoretical analysis. Model experiments are, therefore, an essential part of the studies that may be carried out for such complicated structures as power houses, dams and tunnels if they are situated in seismic zones.

Model experiments give reasonably accurate information regarding the natural period of vibration, damping at different stages of deformation, distribution of forces and therefore shears and moments along the height of the structure.

It may be stated here that the method of designing structures for uniform seismic coefficients irrespective of their dynamic characteristics can be improved upon considerably and the safety at different points of a structure could be more uniform.

Fig. 3 shows the unsuitability of a uniform design coefficient which leads to rigid structure being under-designed and flexible structure overdesigned.

It will thus be seen that it is essential that the structures are designed dynamically after suitable theoretical and experimental studies for maximum economy and adequate safety. In the case of power plants, where running machinery is installed it is necessary to ensure that the structure supporting the machine is not deflected beyond the amplitude that may be covered by "tolerance" otherwise the functioning of the machines could be dislocated and the machines may even be damaged. The detailed dynamic analysis and model studies have even a greater importance in their case.

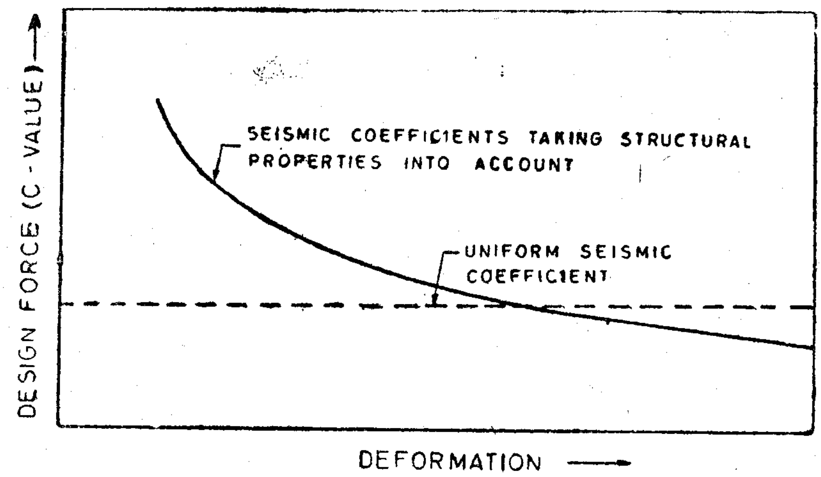

Figure 3 Graph Showing Earthquake Forces Induced in the Structure at Various Deformation Levels Taking Structural Properties into Account if Uniform Seismic Coefficient is Adopted the Structure Designed for Lower Deformation Levels (Rigid Structures) Will be Unsafe Where as Those Designed for Higher Deformation Levels (Flexible Structures) Will be Over Safe.

Appendix 1

List of Some Destructive Earthquakes in India and Neighbouring Countries.

Date	Location	Intensity	Remarks
1505, 6th July	Agra	Severe	Great Damage
1618, 26th May	Bombay	Severe	2000 Killed, Voilent sea waves and Hurricane, 30,000 houses burried
1668, May	Indus Delta	Severe	
1669, 22nd Jun.	Kashmir	Violent	Large fissures in ground
1720, 15th July	Delhi	Severe	Great Damage
1737, 11th Oct.	Calcutta	Violent	3 lacks-killed, violent Hurricane and sea waves
1761, 2nd April	East Bengal	Violent	Subsidence of 60 Sq. miles area.
1764, 4th June	Banks of Ganges (Bihar-Bengal)	Violent	Great Damage, many killed
1803. 22nd May	Upper Ganges	Severe	Rumbling noise
1803, 1st Sept.	Mathura	Very Violent	Felt up to Calcutta, Great Demage
1803, 1st Sept.	Garhwal Kumaon	Violent	200-300 killed, great damage
1819, 16th June	Cutch	Very Violnt	Earth rose by 10 feet forming Allah bund very great damage, many thousands dead.

Appendix 1 Contd.

Date	Location	Intensity	Remarks
1826, 29th Oct.	Bihar-Nepal	Severe	Damage at Kathmandu and Patna, Eight after shocks
1827, 20th Sept.	Lahore	Violent	1000 killed, slides in Ravi and floods. Buildings in Lahore destroyed
1828, 6 and 15th June	Kashmir	Very Severe	1000 killed, 1200 houses destroyed, sand fountains, 100 to 200 after-shocks per day for two months.
1833, 4th Aug.	Nepal and North Bihar	Very Violent	Great loss of life and property, fissurs, fountains, subsidence, many after shocks upto 11th September.
1833, 4th Oct.	Nepal (Kathmandu)	Violent	Great damage, followed by other shocks on 18th, 28th Oct, 8th, 16th and 26th November.
1842, 19th Feb.	Kabul	Violent	Affected an area of 216,000 sq. miles
1843, 1st April	Deccan	Severe	Preceeded by a shock on 12th March, Centre near Bellary. Felt in a widely extended area.
1848, 20th April	Mount Aboo	Violent	Damage to buildings. Felt in Madhya Pradesh and Cutch.
1861, 29th March	Darjeeling	Very Severe	Other shocks on 18th June, 8th July, 11th Aug, 21st and 17th Oct. 1863 of Light to Moderate intensity.
1863, 18th Nov.	Nimar and Burwani	Severe	Felt south of Narbada river, not felt south of Satpura range.
1869, 11th Jan.	Cachar	Violent	Felt over an area of 250,000 sq. mile, great damage.
1881, 31st Dec.	Bay of Bengal	Severe	Felt on 2,000,000 sq. miles of sea.
1885, 14th July	Bengal (Dacca)	Severe	Felt over an area of 230,000 sq. miles.
1827, 12th June	Assam	Violent	Great damage, over 1600 people killed, Felt over 175,000 sq. miles.

Appendix 1 Contd.

Date	Location	Intensity	Remarks
1905, 4the April	Kangra	Violent	Great damage, 20,000 people killed, Kangra and Dharmshala completely destroyed.
1918, 8th July	Srimangal (Assam)	Severe	Felt over area of 800,000 sq. miles.
1930, 27th Aug.	Baluchistan	Violent	Great damage, over 200 killed
1934, 15th Jan.	Bihar-Nepal	Violent	Great damage, over 10,000 killed. Total area affected 1,900,000 sq. miles.
1938, 14th April	Chindwin (Burma)	Severe	Damage in Upper Burma
1943, 23rd Oct.	N.E. Assam	Severe	Destructive in N.E. Assam
1947, 29th July	Assam	Severe	Destructive in N.E. Assam
1950, 15th Aug.	Assam	Violent	Great damage in Upper Assam, felt over 650,000 sq. miles, many killed
1954, 22nd March	Manipur-Burma Border	Severe	Felt over a very large area
1956, 21st July	Anjar	Severe	Damage to property
1958, 28th Dec.	Kapkote	Severe	Damage to buildings
1960, 27th Aug.	Delhi	Severe	Damage to buildings
1963, 2nd Sept.	Badgam (Kashmir)	Severe	Great damage in poorly constructed houses, more than 60 killed.

Appendix 2

Structural Response Recorder Stations in India

State	Established till	To be established
1	2	3
1. Assam	1. Dhubri	1. Aijal
	2. Dibrugarh	2. Barpeta
	3. Gauhati	3. Bishanath Charali

(Appendix 2 continued)

Appendix 2 continued

1	2	3
	4. Cherrapunji 5. Jorhat 6. Margherita 7. Nausadia 8. Silchar 9. Shillong	4. Darugiri 5. Dimapur 6. Goalpara 7. Langting 8. Lungleh 9. North Lakhimpur 10. Nowgong 11. Udelguri
2. Bengal		12. Berhampur Court 13. Calcutta 14. Cooch Bihar 15. Darjeeling 16. Jaldhaka 17. Jalpaiguri
3. Bihar	10. Darbhanga 11. Dhanbad 12. Dumka 13. Forbesganj	18. Motihari 19. Monghyr 20. Muzaffarpur 21. Sahebganj
4. Delhi	14. New Delhi	
5. Gujerat	15. Ahmedabad 16. Bhuj	22. Bhavanagar 23. Dwarka 24. Kaira 25. Morvi 26. Palanpur 27. Somnath
6. Himachal Pradesh		28. Mandi 29. Simla
7. Jammu and Kashmir	17. Gulmarg 18. Pahalgam	30. Jammu

Apdendix 2 continued

1	2	3
	19. Srinagar 20. Udhampur	
8. Manipur		31. Imphal
9. Nagaland		32. Kohima 33. Makok-Chung
10. N.E.F.A.		34. Bomdila 35. Pasighat 36. Tezu 37. Ziro
11. Punjab	21. Chamba 22. Chandigrah 23. Sonepat	38. Kangra
12. Tripura		39. Agartala
13. Uttar Pradesh	24. Bageshwar (Almora) 25. Banbasa 26. Dehradun 27. Gorakhpur 28. Kalagarh (Bijnor) 29. Roorkee	40. Nanpara