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# Recent studies in Seismology in the India Meteorological Department

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## 1. Introduction

In two previous articles (Agarwala 1950, 1959), the author had given reviews of studies in seismology undertaken in the India Meteorological Department upto the year 1958. Considerable amount of work in seismology and further development of seismological organisation have since been carried out in the Department during the past six years and in the present article a review has been made of the work done during this period.

## 2. Development during the Third Five-Year Plan

During the Third Five-Year Plan period considerable development in the seismological organisation in India has taken place. Seven new seismological observatories (at Srinagar, Bhuj, Imphal, Dibrugarh, Ajmer, Bhaisalotan and Allahabad) are being started in seismic regions which are not already covered by the existing network. A small workshop at the Central Seismological Observatory at Shillong has been developed. Investigational work on earthquakes of Indian origin, on vibration problems and study of microseisms in relation to weather is also being continued and further developed at the headquarters of the seismological organisation at New Delhi as well as at the Central Seismological Observatory at Shillong.

Standardised seismographs received from the U.S. Coast and Geodetic Survey, Washington have been put into commission at Delhi and Shillong. The Press-Ewing long period seismographs which were loaned by the Lamont Geological Observatory, U.S.A. during the I.G.Y. and were operating at the seismological observatory at the Ridge, Delhi, were calibrated by Rev. H. J. Miller of the above observatory in April 1962. These instruments were later shifted and installed at Bokaro. The programme of development and construction of seismological instruments and their components has gone apace and delicate instruments such as vertical and horizontal electromagnetic seismographs and recording units, photographic recorders and amplifiers for use with visible recorder and Wood-Anderson Seismographs have been developed and constructed in the seismological workshop at New Delhi resulting in considerable saving in foreign exchange.

In connection with the calibration of electromagneitc seismographs satisfying Galitzin conditions, an important contribution has been made by Chakrabarty and Tandon (1961). In this paper theoretical results have been given for the response of the seismographs to different tests required in the calibration of the eletromagnetic seismographs, and also to sinusoidal ground

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motion. Final results have been given for the special types of seismographs in which the seismometer period and galvanometer period are equal and the galvanometer is critically damped. The variation of the magnification curve as well as that of the response to different tests, with changes in the reaction and seismometer damping, have been obtained and methods have been indicated by which the instrumental constants can be determined and the seismographs adjusted to any prescribed condition.

### 3. Microseismic studies

Study of microseisms associated with weather disturbances such as cyclones, nor'-westers etc has been made by a number of workers in the India Meteorological Department. Microseisms associated with the Bay of Bengal cyclone during September 1959 have been studied by Iyer and Kartha (1960)*, Pisharoty and Srivastava (1961 a) and by Banerji (1962). While Iyer and Kartha (1960) presented data on the microseisms associated with this cyclone in respect of Cochin, Pisharoty and Srivastava (1961b) have presented similar data in respect of Colaba and Madras. The microseismic record of Shillong for the same cyclone was later examined by Banerji (1962). Shillong is more suitable for such a study as it is free from the local short period noise caused by surf effects due to the proximity of the sea which is the case of Cochin, Colaba and Madras. Maximum microseismic activity was recorded at Colaba and Madras and Shillong on 30 September and 1 October which was in keeping with the synoptic situation. Cochin records, however, indicated decreased activity on 30 September and 1 October. Detailed study of microseisms at Madras associated with disturbances in the Bay of Bengal has also been made by Anjaneyulu (1961). A paper on microseismic "Highs" and "Lows" in the Bay of Bengal has been published by Iyer and Punton (1962)†. Reference may also be made to a paper by Saha (1960) on microseismic evidence for the existence of cold fronts in association with the nor'westers. Saha (1962 a ) has also observed that short period group microseisms of period very close to one second occur in the records of the short period vertical component Benioff Seismograph at Shillong on some occasions. These have not been found to be associated with each and every convective activity at the station but are believed to be connected with the passage of cold fronts in association with the secondaries of the western disturbances which move from west to east during the premonsoon months. Saha (1963) has also discussed the problem of determination of sedimentary thickness in the Shillong plateau by microseisms and has made use of the observed periods of microseisms of land origin recorded by short period Benioff Seismograph at Shillong for making an estimate of the low velocity superficial sedimentary rock thickness.

### 4. Seismic recording of Nuclear Test Explosions

A recent line of study in India has been the recording of nuclear test explosions and a number of papers have been published on the subject. The question was first discussed in a paper by Tandon (1958). The Russian nuclear explosion tests conducted on 23 and 30 October 1961 in the Novaya Zemlya region were recorded by seismographs at a few stations in India and a study of these has been made by Tandon (1961) and by Saha (1962 b). On 5 August 1962, the Soviet Union carried out its second biggest nuclear bomb test in the atmosphere in the same region and seismic records of the same have been studied by Tandon and Chaudhury (1962). Comparative estimated values for the yield of the explosion for 23 and 30 October 1961 and 5 August 1962 have been worked out by them as 30 megatons, 57 megatons and "less than 50 and much more than 30 megatons" respectively. Seismic waves from high yield atmospheric explosions have also been studied by Tandon and Chaudhury (1963). Mention may also be made of a paper published by Pisharoty and Srivastava (1961 b) on microbarograms and

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seismograms of supersonic bangs — 3 April 1960.

#### 5. Study of important earthquakes

The Rann of Kutch earthquake of 21 July 1956 has been studied by Tandon (1959). Saha (1962 c) has studied the depth of focus of Delhi earthquake of 27 August 1960. A note on the sense of the first PKP motion for the Peru-Brazil border earthquake of 19 August 1961 has been published by Saha and Mohan (1963). A study of the Coimbatore earthquake of 8 February 1900 has been made by Basu (1964); this earthquake was found to have a magnitude of the order of 6 and depth of 70 km which is significant as earthquakes of such depth are rare in south India.

#### 6. Study of seismic waves and earth's crust

A study of the seismic *Lg* waves and their propagation along with the granite layer of the crust of Indian sub-continent has been made by Saha (1961). Saha (1962 d) has also discussed the seismic channel *P* waves $\pi g$ or $\bar{P}$ and their propagation along the crust of the Indian sub-continent. Saha (1962 e) has also studied the *PcS* or *ScP* phase and the depth of earthquake focus. *T*-phase as recorded by two component short period Wood-Anderson seismograph at Visakhapatnam has also been studied by Saha (1963) and he found that the characteristic feature of the phase is that the motion increased and decreased somewhat in the fashion of beats. Saha (1964) has also discussed the seismological evidence on the intermediate layer in the crust in a paper presented in the symposium on 'Problems in Geophysics relating to the crust of the earth' held under the auspices of the Geophysics Research Board (CSIR) in January 1964. A study of the seismic waves recorded by the Press-Ewing seismographs at the Delhi Seismological Observatory during the high yield test nuclear explosions in the atmosphere carried out in 1962 by the U.S.S.R. over Novaya Zemlya has been made by Tandon and Chaudhury (1963) and they have found that long period Rayleigh waves were the most prominent and could be detected for most of the explosions. The body phases *P*, *PP* and *S* were also recorded on a few occasions when the yield of the explosions was about 20 megatons or more. A prominent wave recorded on most of the days has been shown to be the *Sa* (Caloi) wave and has been discussed at some length. *M*2–waves in the range of periods 8-15 seconds could be clearly detected. The records also showed the presence of longer period *M*2–waves, which were analysed. It has been estimated that the thickness of the average continental crust along the path (Novaya Zemlya — Delhi) is 45 km whereas that under the mountain range across the path is 55-60 km. The pressure wave travelling with the speed of sound was well recorded on a number of days and these waves showed clear normal dispersion.

#### 7. Engineering Seismology

Assessment of maximum seismic intensity and ground acceleration has been discussed by Tandon (1962) in a paper presented at the Second Symposium on Earthquake Engineering held at the University of Roorkee. In order to evaluate the seismic intensity and ground acceleration at a place, it is necessary not only to know the magnitude, the distance of the place from the epicentre and depth of the earthquake under consideration, but also the type of foundation on which the structure is going to be based. The effects of these parameters on the seismic intensity have been discussed and values of expected ground accelerations for shocks of different magnitudes for different distances have been given. The actual seismic coefficient to be used for design of structures can be worked out from these values from a knowledge of the characteristics of the structure and its spectral response.

In connection with the drawing up of Indian standard recommendations (1962) for earthquake resistant design of structures applicable to buildings, elevated structures,

bridges, concrete, masonry and earth dams, embankments and retaining walls, the seismological organisation in India under the India Meteorological Department fully collaborated with the Indian Standard Institution and supplied the necessary seismological data and maps of India showing seismic zones and epicentres etc for the use of the Earthquake Engineering Sub-Committee with which Dr. Tandon, Director of Seismology, was closely associated as a Member.

**8. Seismological collaboration for multi-purpose and water-power projects**

As several large multi-purpose and water-power projects are being undertaken in the earthquake zone of India in recent years in connection with the Five-Year development plans of the country, the need for seismological collaboration for such projects cannot be over-emphasised. To meet these requirements, the seismological organisation has been playing its part. A seismological observatory was established at Bokaro and 3 components of long period Press-Ewing Seismograph have been recently installed there, in addition to the instruments already there. A tiltmeter has been installed in the body of the Bhakra Dam to find the tilt of the dam. A study of the seismographic recording of blasts at Bhakra has also been made by Tandon (1962). Two sets of Wood-Anderson seismographs were also set up in the body of the Bhakra dam for recording the vibrations of the dam and results obtained were furnished to the Director (Design), Bhakra Dam. In connection with the Beas Dam project a number of seismological observatories are planned to be opened in the region and a suitable scheme has been drawn up for the purpose, which is being financed by the State Government of Punjab. Under the Beas Project Scheme a seismological station has already been set up at Pong and arrangements are being made to open nine more stations in the area. In connection with the determination of ground coefficient for the construction of Beas Dam, the seismological organisation of this Department participated in the experiments with controlled blasts conducted at the Dam site in September 1962. Advice on the seismic factor to be adopted for construction of dams and on the adequacy of the seismic factor used in the design of dams such as the Ramganga Dam and the Koyana Dam has been freely given as and when required by the authorities concerned. Similarly seismicity data of areas concerned are also being compiled and furnished to the different project authorities on demand.

**9. Seismological training**

In connection with the future development of seismology in India, it is very essential that adequate arrangements should be made for imparting training in seismology at different levels. Although certain facilities are already available for such training in the Central Seismological Observatory at Shillong and at the Headquarters of the Seismological Organisation in India at New Delhi, these require to be improved and expanded to meet the increased demands. It is hoped that the proposed Seismological Institute at New Delhi (*vide* Section 10) will play a notable part in fulfilling this requirement. In this connection it may be mentioned that the Department has been sending officers abroad for advanced training in seismology from time to time; one officer was deputed for such training in 1963-1964. It is also interesting to note that an officer of the Burma Meteorological Service arrived in India in March 1960 for 22 weeks' training in seismology and underwent training at the Central Seismological Observatory, Shillong in theoretical and practical aspects of seismology and visit to the Headquarters of the Seismological Organisation at New Delhi as well as observational tours to important seismological observatories were also included in his training programme.

**10. Future plans for development**

Reference may be made to an article entitled "Development of Seismological Organisation in India" contributed by Tandon (1959) to the "Earthquake Engineering Seminar" held at the University of Roorkee in February 1959 in which the position of development of the seismological organisation in India upto that time had been indicated. During the Third Plan period emphasis was given to strengthen the existing and already-sanctioned observatories with more modern instruments as well as for opening a few new observatories with a view to collect data from seismic zones yet unrepresented. A further programme of development under the Fourth Five-Year Plan has now been drawn up under the direction of Shri P.R. Krishna Rao, Director General of Observatories. Under this plan (1966-1971) it is proposed to lay special emphasis on fundamental and applied research in seismology utilising the large volume of seismological data that would be available from the existing and proposed observatories of the Department upto the end of the Third Five-Year Plan period. It is also planned to improve the seismological equipment of the various seismological observatories by constructing a large part of the equipment in the departmental workshops thereby saving foreign exchange. The research scheme contemplated will enable a proper understanding of the phenomenon of earthquakes and throw much light on physics of the interior of the earth. Studies of destructive earthquakes of Indian origin with special reference to the location of major River Valley Projects and assessment of maximum seismic intensities experienced by the various types of foundations are also envisaged during the Fourth Plan period. It is also planned to consolidate and expand the seismological organisation by forming it into a Seismological Institute at New Delhi with a number of Research Divisions including one for advanced training in seismology.

Before concluding this review, it must be emphasised that all possible steps should be taken to implement the programme of development in the field of seismology in this country.

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