

Scientific discussions on Koyna Earthquake*

Introduction

Under the joint auspices of the Indian Meteorological Department and the Indian Geophysical Union, a meeting was convened on 19 December 1967 in the Meteorological Office, New Delhi to have a scientific discussion on the Koyna earthquake of 11 December 1967.

The meeting was attended by representatives of the India Meteorological Department, Geological Survey of India, Central Water and Power Com-

mission, Central Water and Power Research Station, National Geophysical Research Institute, Oil and Natural Gas Commission, Irrigation & Power Ministry, "Operation Hard Rock" and other interests and was presided over by Dr. S. Bhagwantam, Scientific Adviser to the Govt. of India. Dr. K. L. Rao, Minister for Irrigation and Power, Government of India and Shri V. P. Naik, Chief Minister, Maharashtra, were also present.

Proceedings

DR. L. S. MATHUR, Director General of Observatories welcoming the Honourable Cabinet Minister, Dr. K. L. Rao, the Chief Minister of Maharashtra, Shri V. P. Naik, Prof. S. Bhagwantam and the distinguished scientists said that a disastrous earthquake had visited Koynanagar near the Koyna dam and the scientific discussions on this happening had been jointly sponsored by the India Meteorological Department and the Indian Geophysical Union. Various statements had since appeared in the press and the radio. He himself had appeared on a T. V. interview and contributed an article in *Sunday Standard* for giving the public the current and factual position regarding this disastrous earthquake. In order to enlighten the public opinion it was necessary to hold a scientific discussion on all the aspects of Koyna earthquake. He also referred to the radio interview given by Dr. A. N. Tandon and his visit to the site of disaster. This earthquake of magnitude 7 to 7.5 which occurred in an area considered to be one of the most stable parts of the world had surprised the seismologists, geologists and engineers alike. The world scientists were also inquisitive about this happening. In the end he thanked the Hon'ble Minister who spared his valuable time and also Prof. Bhagwantam and the Chief Minister of Maharashtra for their presence and the encouragement they gave in the matter.

PROF. S. BHAGAWANTAM, President of the Indian Geophysical Union, and Chairman of the meeting while opening the discussion said that this meeting was arranged to discuss all scientific aspects of Koyna earthquake. After the Koyna tragedy,

various statements that appeared in the press caused confusion. It was most peculiar that an earthquake of such a magnitude occurred in an area which was so long considered to be comparatively stable. Since now the phenomenon had taken place in an area, where it was least expected, it needed a thorough scientific enquiry. He said that we should now have a forward look at the phenomena and advise government on various measures to be taken. He regretted the short notice given for the meeting and urged the gathering to appreciate the urgency.

He expressed the hope that a concerted effort would be made to study the problem. In the end he hoped that the correct view of the picture would be obtained and tangible results achieved.

DR. K. L. RAO, Minister for Irrigation and Power, who spoke next expressed satisfaction that a scientific discussion had been organised by the Indian Geophysical Union and India Meteorological Department on this phenomenon of earthquake. He was greatly relieved that the dam was safe after this disastrous earthquake. He referred to the stability of the Koyna region as shown in the zoning map, which suggested that no special precautions were required to be taken against earthquakes in the design of engineering structures. He desired the geologists to give a new thought and recast the map.

The problem, he said, was to find reasons for the occurrence of this earthquake and further highlight the steps that were required now to be taken to investigate and record the visual marks left behind by the earthquake. He added that

*Prepared by Dr. A. N. Tandon, Director, Seismology, Meteorological Office, New Delhi

the UNESCO normally sends earthquake reconnaissance teams on such events and the Ministry of Irrigation and Power had already taken steps to invite one such expert mission.

Central Water and Power Research Station had already been advised by him to map the area and record the visual effects left by the shock. He requested the Director General, Geological Survey of India to immediately despatch a team for the field study before the visual effects were obliterated. He referred to a report regarding the *Varna* crack about 50 miles away from Karad and wanted a party to be sent there to record its features.

He recommended a reconnaissance flight to be organised from Karad, which the Chief Minister Shri Naik had kindly agreed to. He expressed the hope that the observations of scientific teams would be valuable.

The Minister urged the invitees to discuss the problem frankly and freely. The meeting was convened not to finalise the causes of the event but crystallise what different scientists feel about it.

The most significant feature, he emphasised, was that a huge structure (Koyna dam) had withstood the shock which originated probably not far from the dam area and there was no other parallel instance of this type anywhere in the world. This was significant from the point of view of a scientific discussion. Finally he thanked both Dr. Bhagawantam and Dr. Mathur whose respective organisations, the Indian Geophysical Union and the India Meteorological Department arranged to convene this meeting on such a short notice.

SHRI P. M. MANE, Central Water and Power Commission said that he was associated with the dam for a very long time and he gave a brief resume of the historical background from the period of the survey of the area, construction of the dam, filling up of the reservoir and finally the earthquake incidence. Such a picture was expected to help the scientific discussions. To his knowledge there was no recorded earthquake in that area and he did not experience any shock during the period of survey and construction. With the help of the State geologists the area was fully charted with a view to locate the shear zones and all the geological and geophysical investigations were made in great detail to the west of the river site and upto about 200 ft to east of the river. All the tunnels were charted and a few shear zones were detected. In fact, a gallery had been constructed on a shear

zone where instruments had been kept to study the behaviour.

Water was let into the reservoir for the first time in 1961, but the tremors were detected from 1963 onwards. Soon after the occurrence of earth tremors, the Govt. of Maharashtra, constituted an Expert Committee with himself as Chairman and the State geologist, Dr. Tandon, Seismologist of India Meteorological Department and others as members. The committee members could not find any plausible cause. Similar phenomenon had come to notice at some other sites in other areas, *e.g.*, in Lake Mead and in South India. But such tremors subsided after sometime. The committee felt that minor tremors in Koyna were due to the crustal readjustment due to the impounding of the water load. It was surmised that the crustal adjustment might be due to plastic deformation of the 50-ft layer of tuff breccia.

He narrated the steps undertaken for further study of the minor tremors such as the installation of seismometers, accelerographs etc.

It was noticed that all the epicentres were chartered in lake area to the north of the dam. The number of tremors and total energy release had a tendency to decay. In no tremor the acceleration recorded was found to be more than 5 per cent *g*.

Slight increase in the number of earth tremors was noticed in 1966 and with the knowledge of local geology there was no apprehension in the opinion of the Expert Committee members of a major shock, as the area was known to be free from major faults.

The shock of 13 September 1967, however, came as a great surprise. During this shock acceleration of 15 per cent *g* along the axis of the dam and of $7\frac{1}{2}$ per cent *g* at right angles to the dam were recorded. Some structures got damaged to the south of the Koynanagar. Arrangements were being made for the study of the area with the help of aerial photographs already available, with a view to locate faults or other significant features and at that stage the earthquake under discussion occurred.

It was a common knowledge, Mr. Mane continued, that in an area where major shocks occurred, a number of after-shocks follow and that there was no immediate possibility of another major shock taking place. He wondered whether it would be possible to put acoustic instruments by boring holes in the lake area and to predict

about future earth tremors from the records of these instruments.

SHRI N. G. MURTHY, Chairman Bhakra Control Board, gave the picture of the Deccan traps after Dr. Widia, which is available in his book. He proceeded to explain the foundation of the dam area with the help of a sketch about the shear zone below the dam which Shri Mane had also mentioned.

Quoting various eminent international authorities he said that the possibility of failure of gravity dams due to earthquakes was negligible.

As regards the particular earthquake of 11 December, he was surprised to hear that acceleration of 40 per cent of g was recorded although the dam was designed for 5 per cent g .

He further said that crustal settlements do take place where rocks or reservoirs rest on cretaceous or mesozoic formations only. On the prediction of earthquakes he said, while it was somewhat possible to predict a major volcanic eruption on the basis of minor fore-tremors that precede the volcanic shock, it was not possible with our present knowledge to predict the tectonic or plutonic earthquakes.

DR. D. N. WADIA, Geological Adviser to the Govt. of India, Department of Atomic Energy, spoke next and said that the Koyna earthquake caused a great blow to the known geological theories entertained so far. He hoped that those theories will survive the shock.

In India, during the past 200 years about 78 very destructive earthquakes had been experienced but these were located on the main Himalayan boundary fault zone from Mekran coast to Assam. There were 20 major destructive earthquakes along Satpura mountains and there had been none in the Deccan trap.

He later expressed the following provisional views on the present earthquake.

(1) That it was a tectonic earthquake—not merely due to collapse of any underground chamber nor due to seepage of water.

(2) It was a deep focus earthquake. The area shaken by the earthquake from Surat to Bellary and Goa to Hyderabad consisting of 70 to 75 thousands sq. miles could not be shaken by a shallow focus earthquake. The focus probably lay in the archaic crystalline basement of Karwar rocks.

(3) The Malabar coast which runs from Kutch to Cape Comorin is a fault formed during the

pliocene period. Since the major fault like this have parallel satellite faults, so naturally there must be minor faults running parallel to the Malabar coast complex. This is supported by the fact that several hot springs are present from Ratnagiri to Bombay. He suggested that the behaviour of hot springs during this earthquake may be studied, as in such a earthquake it is likely that some new springs would appear on the surface. The other proof of parallel fault is that the high temperature gradient found in the Gulf of Cambay by the Oil and Natural Gas Commission as compared to temperature gradient in other areas. One of these minor parallel satellite faults of the Malabar fault complex has caused the seepage.

There has been considerable exaggeration about the damage caused by the earthquake. Except for Koynanagar no other neighbouring city has been subjected to damage. Damage at Koynanagar may be due to the weak and faulty constructions of buildings. This fact is supported by the observation that Bombay with several tall structures like chimneys and towers has suffered no damage which could have been the first casualties with the earthquake of such a high magnitude as 7.5. He found it difficult to accept the magnitude of the earthquake as 7.5.

DR. M. S. KRISHNAN, former President of the Indian Geophysical Union did not feel it necessary to theorise on the origin of this earthquake and remarked that the ideas about the Deccan shield have not been connected with the geologically recent formations along the western coast. For example, the Mysore region and the West Coast are reported to have been uplifted which would have an important bearing on the geological concepts held so far.

He regretted that the water spread area of the Koyna dam had not been geologically mapped and he suggested that this should be done immediately. He said that the course of the Koyna river which runs from north to south, may be connected with some significant geological feature.

He urged that the exact focus of the earthquake should be found out, for in case of shallow focus, the local destruction could be attributed to the long-period surface waves. It had not been possible to predict earthquakes, even in an advanced country like Japan where earthquakes visit frequently and earthquake proof buildings are constructed to prevent earthquake damage.

DR. A. N. TANDON, Director, Seismology, India Meteorological Department, said that as

the Chairman had already pointed out his main aim was to acquaint the gathering with the factual information such as epicentre, depth of focus, magnitude etc.

(1) *Epicentre* : On the basis of data received from the Indian stations he had tentatively located the epicentre within about 10 km of Koyna dam. The precise epicentre would be known only after he had studied the various records personally.

(2) *Depth* : For the correct determination of depth, it was necessary to have a precise knowledge of the origin time. Further, he said that the records obtained at Delhi pointed to some contradiction and from these he was inclined to conclude that it was the case of the incidence of two shocks, a weak one followed by a severe shock. But he had his own apprehensions until these observations were supported by records of other stations.

(3) *Magnitude* : From the isoseismal map which he had tentatively prepared on the basis of press reports he found that the earthquake had a radius of perceptibility of about 700 km which justified the magnitude 7.5. However, after his visit to the site of damage he felt that the damage did not justify such a large magnitude inferred from the radius of perceptibility of around 700 km. The depth of focus was worked out by the empirical formula to about 30 km. Normally, the earthquake capable of large destruction occur near about the depth of 10—15 km. Even earthquakes of smaller magnitude are destructive when their focus is shallow. So in view of the contradiction in the present earthquake he felt that precise information on the origin time, depth, magnitude etc could be given only after examining data from other observatories.

His observations on intensity were that it would be less than IX on the Modified Mercalli Scale in the epicentral area. The equivalent energy released by a shock of magnitude 7.5 comes to about 10^{22} ergs which is a colossal amount. Such a large amount of energy could not be released by any sort of local crustal readjustment or subsidence of bed etc. Instrumental depth would also be determined after examining the records and solving the riddle of two shocks having followed each other.

He remarked that this earthquake was unique and would be better studied because various instruments had been installed in and around the dam not far from the scene of destruction and the earthquake epicentre. It is unique also

from the engineering point of view because an accelerograph had recorded the shock with its epicentre very close to it. The accelerograph had recorded both the earthquakes, i.e., of 13 September and 11 December and the records were available with Central Water and Power Commission.

Dr. Tandon showed the photographs of damage for the benefit of the audience to draw their own inferences about the intensity of the earthquake. While showing the diagrams of isoseismal map he explained how he had concluded the magnitude and depth factors discussed by him earlier.

He pointed out, while showing a map giving the epicentres of significant earthquakes during the last 2 years in Ratnagiri area along the West Coast for the benefit of the geologists that the Malabar coast was not so quiet but there were no records of earthquake of such a magnitude. A map of earthquake epicentres in the Peninsular India since the recorded history was also shown.

Dr. S. K. GUHA, Senior Research Officer, Central Water and Power Research Station narrated his visit to the site of destruction near Koynanagar. The isoseismals of the shock which he had drawn generally agreed with that drawn by Dr. Tandon. He showed a diagram giving the lines of force prior to this earthquake. These lines reversed after the shock. The diagram, which he displayed, indicating relationship between the water level and the incidence of small tremors since the filling of reservoir did not show any particular inter-relationship.

He had noticed a peculiar relation that after the monsoon there was an increase in the number of shocks and the present series of shocks in November and December had also taken place after the monsoons. On this he observed that the shocks might not be entirely unrelated to the reservoir level and that the same could have triggered up the big earthquake.

The values of acceleration and the frequency from the accelerograph records were worked out. While the maximum acceleration value of 0.40 g had been recorded along the axis of the dam, the acceleration value perpendicular to the axis of the dam was 0.34 g. The frequencies experienced were of a high order which explained the comparatively low damage inspite of the large magnitude. Damage is not related to earthquake forces alone but to the geology of the land as well, he said.

Dr. Guha showed a map of South India giving the occurrence of earthquakes during the last 200 years in the peninsular shield. There was no record of an earthquake of magnitude more than 6.5 and so the present earthquake was a unique one.

Comparing the earthquake epicentre map of Boulder dam and Koyna dam he said, while the small tremors were located around Boulder dam the earth tremors in Koynanagar had been largely located north of the dam. This may be due to the peculiarity of the faulting at Koyna dam site. In all about 5000 earth tremors had been recorded since the filling up of the reservoir and most of the earth tremors for which the epicentres had been determined lay to the north of the dam.

In order to see if these earthquakes had volcanic origin he said that he had applied Gutenberg Richter relation in respect of these shocks and his opinion was that these were not due to volcanic origin.

DR. B. G. DESHPANDE of Oil & Natural Gas Commission said that the West Coast of India is not only faulted but also has been the subsequent recipient of tertiary sediments. High temperatures of the order of 150° at 300 m had been observed by ONGC in the wells dug by them in Cambay basin. The geomorphological work done by ONGC provided enough evidence that part of Cambay basin was rising. The Indian Ocean Expedition had confirmed that further south of Ceylon a continent is rising. If such was the case, some such micro-movement might be taking place in Deccan also. If we had aerial photographs taken before and after the earthquake, a comparison of the two aerial photographs would be instructive in finding out if there was any tilt and if so, in what direction it was taking place in the area.

He said that the fact that at the two ends of the West Coast, we had rising sediments, indicated that the movement had not stopped and it was a continuous process. The sense of stability of the Deccan plateau might be only apparent. It was quite possible that portion of the crust was unstable in the dam area.

DR. M. S. BALASUNDARAM, Deputy Director General, Central Region, Geological Survey of India spoke next. He said that as a member of the Expert Committee appointed by Maharashtra Government to enquire into the Koyna tremors and also in the capacity of a geologist who was intimately associated with the Koyna Project, he wanted to express his ideas.

At the time of the Koyna earthquake of 11 December 1967 a geological party was working in the neighbourhood. On hearing the earthquake they quickly moved into the affected area and started collecting information about the same. He made a reference to the fissure reported in the press. It was to the south of the dam and according to his officials, it was confined to the alluvium only. In any case the matter would be investigated now fully. At the time of survey of the area for construction of the dam he did not observe any displacement of the traps. There was a shear of zone 15-ft wide and it was suitably treated to make it harmless. He admitted that the survey for reservoir area was not done. So far as the dam site was concerned, it was surveyed in detail. Although aerial survey maps were available, no serious study was undertaken. Even after 3 years of observation of the earthquakes at Koyna, the Expert Committee could not come to any definite conclusions about causes of the earth tremors. The most surprising fact was that after an earthquake of magnitude 6.5 which occurred in September 1967 a higher magnitude earthquake had followed after 3 months. He posed the question why there should be accumulation of epicentres to the north of the dam, how far is the reservoir causing the deep seated earthquakes as the major earthquake of September 1967 and the present one? The mild tremors were possible as was noticed in the case of Lake Mead. He wondered how far 300-ft of water in the reservoir could cause a major earthquake and whether the water load could act even as a trigger as Dr. Guha suggested. He pointed out that the presence of big caverns underground in this area which might collapse and cause earthquakes was difficult to believe. He desired that more aerial photographs should be taken.

In answer to a specific question by Dr. K.L. Rao, he expressed the opinion that the aerial photographs should cover an area upto Mahabaleswar in the north. Dr. Balasundaram said that the important question was whether the earthquakes were confined to the trap or below.

SHRI N. G. K. MURTHI pointed out that in the case of the dam constructed during 1920-28, 70 miles to the north of Koyna at Bhadgarh and another dam 70 miles to the south of the dam constructed during 1948-54, no such tremors were observed although both these dams are in the same longitude as Koyna dam and the course of the river in both the cases is from north to south and the foundations in both the cases are the same as in Koyna. Hence the study of the tremors

occurring only in the case of Koyna would be interesting.

Referring to Dr. Wadia's suggestion of a satellite fault parallel to the West Coast fault, Shri Murthi said that they were thinking of the possibility of the satellite faults but only to the west of Ghats and not on the plateau side. It may be the mistaken notion but the *Radhanagri* river flows from north to south as *Koyna* and the dam built across it did not show any tremors. It never occurred to him that N-S course of the river could be due to a satellite crack to the east of the Ghats.

DR. JACOB from "Operation Hardrock" said that he received a few aerial photographs of a limited area of the dam from Shri Mane for detailed study. The photos covered an area from the place where the river takes a sharp east bend to the north of the dam 30 to 35 miles in stretch. After a rapid and cursory study of the aerial photographs, Dr. Jacob had the following remarks to offer—

(1) The 25-mile north-south stretch of *Koyna* river appears to be a fault.

(2) The reported fissure after the occurrence of the earthquake extending from a hill on the east embankment cutting across the river and extending upto *Varna* is important. It is a parallel surface expression of the fault zone.

(3) Certain circular features were recognised to the north of the dam and very close to the north-south trend of the river. There appeared to be some volcanic ash around the circular features.

Dr. Jacob emphasised that it was necessary to carry out a regional photo interpretation of a much wider area from Poona to *Varna* river and from the West Coast to Karad or beyond. The photos should be taken immediately to get a better perspective before they were wiped out.

Dr. Jacob was followed by SHRI KRISHNAMURTHY, from "Operation Hardrock". He showed the aerial photographs and explained the significance of the course of the river *Koyna*. He said that the 25 miles north-south course of the river pointed to an important tectonic feature. Shri Krishnamurthy also referred to the accumulation of epicentres to the north of the dam. He would assume that the present major earthquake was due to activation of the fault and was not due to the reservoir.

DR. S. L. BANERJEE from Central Water and Power Research Station expressed the view that

it was difficult to visualise that the water load in the reservoir had triggered the tectonic earthquake or that the Deccan shield had suddenly become active. To get over the difficulty, Dr. Banerjee drew the attention of the terrain of the dam and its surroundings. In his opinion, the water in the reservoir had entered the lower strata of decomposed lava which lost its elastic properties and subsided a few inches. Thus it was not a tectonic earthquake but a gravitational settlement. The gravitational energy got converted into seismic energy. Since the radius of destruction was only about 6 km, it was not possible to visualise a depth of 30 km.

SHRI V. S. KRISHNASWAMY from the Geological Survey of India said that he had special interest in the topic as President of the Indian Society of Earthquake Technology. He said in case of long stretches of fault, it is not necessary that the entire fault should be active simultaneously. Certain segments of the fault might not be active. The north-south course of the *Koyna* river was indicative of a fault. But he posed the question how far was this fault responsible for this large earthquake? As regards the crater type features pointed out by the team from "Operation Hardrock", this had been explained by Shri R. B. Gupte in a paper presented before the Indian Society of Earthquake Engineering. As regards reservoir loading, he compared the 2.3 billion tons of water in *Koyna* reservoir to 9 billions in *Bhakra* and 42 billion in *Boulder* dam. If loading alone should cause tremors in *Koyna*, it should have meant more severe earthquakes in the case of the other dams.

DR. HARI NARAIN, Director, National Geophysical Research Institute, addressed the gathering and said that the recent *Koyna* earthquake with the reported magnitude of 7.5 had created serious problems relating to the stability of the Deccan plateau. He had personally visited the *Koyna* dam area and observed that the damage was very localised say 6 to 7 km in radius. The north-south course of the river fitted in with the existence of a fault in the area. He pointed out that the *Upsala* Observatory reported that the magnitude of the large earthquake was about 6.5. The reports in press in India indicated that the earthquake was felt over a large area. He continued that these reports so far available may not be totally accepted as such. He said that determination of depth was a serious problem. He urged that a detailed study should be made of world data in order to determine the depth of the earthquake accurately. In his opinion it was a tectonic earth

quake with release of a lot of energy and had nothing to do with the storage of water in the reservoir. If by future study the magnitude of the earthquake was fixed at about 6.5 and the depth of focus was

also found to be small, then it might be worthwhile examining whether the present earthquake as well as the past earthquakes in the dam area could in any way be connected with the reservoir storage.

Discussions

In the course of discussions, Shri Mane pointed out that the seismograph records of 11 December when compared with the records of 13 September 1967 clearly showed that there was no possibility of the two earthquakes being of the same magnitude and that the one of 11 December 1967 was clearly of a higher magnitude.

Dr. Hari Narain emphasised that the available data should be fully scrutinised before coming to any specific decision about its magnitude and depth. He also suggested that a study of strain and its release in the region along with seismic study would be very useful. It would also be very useful to have a few holes drilled in the area to measure and study the thermal gradient and its variation.

Shri G.S. Iyer, India Meteorological Department drew attention to the contradiction that the felt area for the earthquakes was very large suggesting a high magnitude while the destruction was comparatively over a small area. To account for the large magnitude, he pointed out that it might be due to two earthquakes in quick succession and the waves of the two earthquakes arriving in phase at the recording station might have caused the unusually large amplitude on the seismograms. The amplitudes taken individually for the two earthquakes might not be so large. Thus the apparently large amplitudes recorded on the seismograms might have led to the calculation of the magnitude of the earthquake as high as 7.5. He also pointed out the fact that Upsala Observatory reported a magnitude of 6.5 for this earthquake. A shock of similar magnitude was recorded on 13 September and its record was different in appearance. He therefore urged that the possibility of two shocks in quick succession would be worth looking into.

Dr. Tandon explained that he had provisionally calculated the depth of focus from the known radius of perceptibility of the earthquake by applying empirical formulae of Gutenberg. There were two formulae and one gave the depth as 40 km and the other as 25 km. This gave an average figure of 30 km. Calculation of depth was a ticklish

problem and unless the calculation was based on data of near stations, depth could not be accurately calculated. In the present case he said, we were fortunate to have records of near stations and so it was only a question of time before the exact depth could be determined. As regards the magnitude of the earthquake, he said the value of 7.5 fitted with the felt area and also with the records of the Standard Wood-Anderson seismographs. He drew attention to the fact that magnitude determined from various observatories in the world did differ generally by a factor of 1/2 and sometimes by even unity. The usual practice was to determine the magnitude from different observatories and statistically analyse the data to come to a decision about the best value. He also mentioned that the pattern of damage in the case of deep-focus earthquakes was peculiar. It was not always that the epicentre area got more damage. As an example he said that in the case of deep-focus Hindukush earthquakes there was no damage in Kashmir but damage was observed in Lahore. This pointed to some channelisation of energy in such a manner that certain pockets did receive more energy. Further a depth of 33 km was not at all considered deep by any seismologist since it was the usual depth for tectonic phenomenon to occur. Dr. Tandon stated that the origin time of the earthquake calculated provisionally from the records of Ridge seismographs and Lodi Road seismographs at New Delhi did not agree with one another and it was a very surprising thing. The main difficulty was that the travel times for earthquake waves in this part of India (*viz.*, Koyna area) were not known definitely and therefore the first problem was to determine the travel times and later to find out epicentre, origin time, depth etc based on the travel times thus found out. He said that once the origin time was correctly fixed, the depth of focus would be accurately determined.

Shri Mane was confident that the earthquakes of 13 September and 11 December were so large that the hypothesis of plastic deformation of the lake bed on account of water load could never be sustained by any calculation of associated energy release.

The Chairman Dr. Bhagawantam summed up the discussion and the various opinion expressed during the meeting. He said that one or two major points attracted his attention apart from a number of contradictions pointed out and discussed. The most important point was that the major earthquake occurred at a place which was all along considered stable. He referred to the seismic experiments undertaken in Cambay region. He further pointed out that the radius of perceptibility of 100 km suggested a depth of 30 km but a visual inspection of the damage in the dam area made one doubt the large intensity.

He said that the possibility of two shocks occurring one after the other in quick succession might also be looked into. A party of geologists was asked to visit the Koyna dam area the next day and names of persons who were to participate in the reconnaissance and study were initiated. Dr. K. L. Rao desired that the party should particularly study the *Varna* crack.

Shri K. P. Mathrani, Secretary, Ministry of Irrigation and Power, Govt. of India, proposed a vote of thanks. The meeting came to an end after more than three hours of deliberations.
