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# MICROEARTHQUAKE STUDIES AT RAMGANGA PROJECT, KALAGARH, U. P., INDIA

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## INTRODUCTION

The Ramganga earth and rock fill dam across the river Ramganga at Kalagarh 125.6m high, 12m wide at the top and is 625.8m long at its crest, was completed in 1974. The Ramganga Reservoir having a storage capacity of $2.49 \times 10m^3$ was partially filled for the first time during 1974 summer monsoon. The following studies were taken up in order to determine the effect if any of reservoir filling on the seismic activity; (i) the study of six months records of the Kalagarh observatory and (ii) the study through the microearthquake recording at site for two months during the 1974 summer monsoon. The first study had its merit in the fact that the recording through conventional type of instruments is available uniformly for several years prior to reservoir filling and has been continued during and after the reservoir filling. The second study was to detect low level seismic activity, which could not be detected by the conventional recording (at limited gain) and is expected to show the effect of reservoir filling. Also, generally small earthquakes are expected to occur more frequently then the larger ones ond therefore the microearthquake recording spread over even short time intervals permits collection of data on larger number of local events.

The seismograms of the Kalagarh observatory for the months of April to September 1974 have been analysed and the results are reported here. Microearthquake recording for 65 days from July 16 to September 19, 1974 has been done by the School of Research and Training in Earthquake Engineering using a sensitive portable seismograph system. The entire details of the work and a discussion of results with the possible conclusions are reported in the paper.

## GEOLOGY AND GEO-TECTONICS OF THE RESERVOIR AREA

The geology of the reservoir region has been studied in detail by the Geological Survey of India (Verma, 1962). The main tectonic features have been shown in Fig. 1. The site of microearthquake recording and also the main dam are supported by rocks which perhaps belong to Middle Siwalik age and consist of poorly consolidated and rock with bands of clay and shales. The rocks exposed at about 10 km north of this site are perhaps of lower Siwalik age and dip at an angle of 60° towards north. Thus, the upper Siwaliks are overlain by the older Middle Siwalik rocks and their contact has been described earlier (Verma, 1962) as the Sarpduli-Dhikala thrust. Another fault, namely Halduparao fault, has been mapped to the north of this feature as shown in Fig. 1.

Some parts of the surface exposure of Halduparao fault and Sarpduli-Dhikala thrust would lie submerged under the reservoir and deserve special attention. Those sections of these features which got submerged during the 1974 summer monsoon season lie at distances of about 15 km and 10 to 15 km respectively from the site of recording. A probable fault namely, the north west limit of the Moradabad fault system (Krishnaswamy and Verma, 1963) is located to the south of the recording site at a distance of about 15 km. This has also been shown in the map. The Krol thrust lies within the close proximity and its shortest distance is 25 km. Some other features which are at larger distances are marked in the Fig. 1, of which the Moradabad-fault which is at

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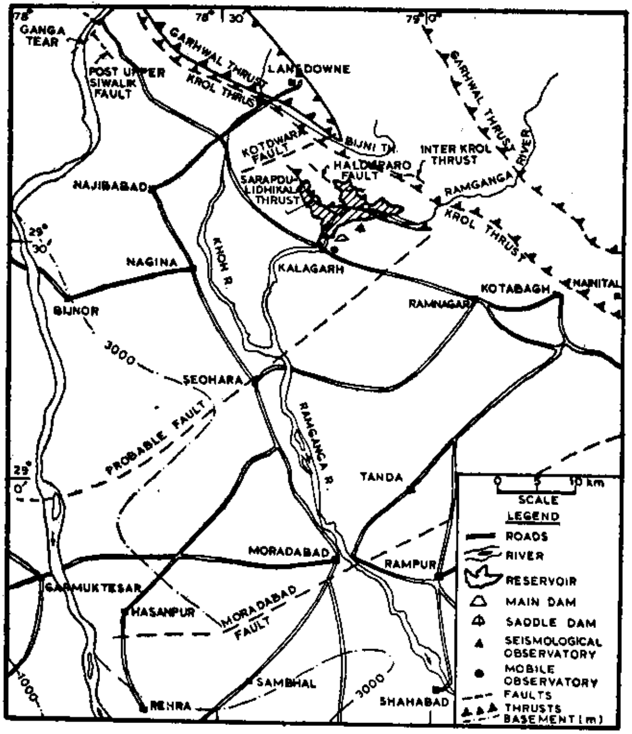



Fig. 1. Map Showing Location of Dam, its Reservoir, Seismological Observatories, Important Tectonic Features etc. Around Kalagarh.

about 65 km distance deserves mention on account of its more recent activity. On the basis of the geomorphological evidences the Sarpduli-Dhikala thrust has been described as active in geological recent times (Verma, 1962) and also that activity has continued in the historical times.

The possible association of some of the recorded earthquakes to these features has been discussed later in the paper.

## STUDY OF RECORDS FROM KALAGARH OBSERVATORY

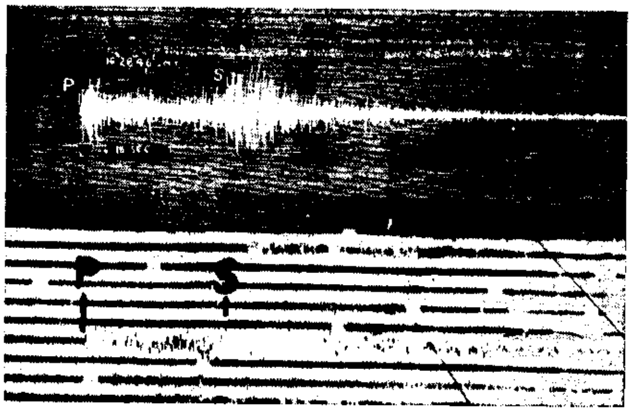
### General:

The seismological observatory at Kalagarh, located near the main dam and not far away from the site of microearthquake recording, is equipped with three component Benioff seismographs. These are capable of being operated with magnifications of upto $10^5$, but due to the ground noise present at this site the instruments are operated at a magnification of $4 \times 10^3$ only. The noise is largely due to the movements on the road near the observatory and the construction activity at the dam site. The noise due to ground excitation by wind and other similar natural phenomena is also appreciable. The recording is on photographic paper with 60 mm/min recording speed.

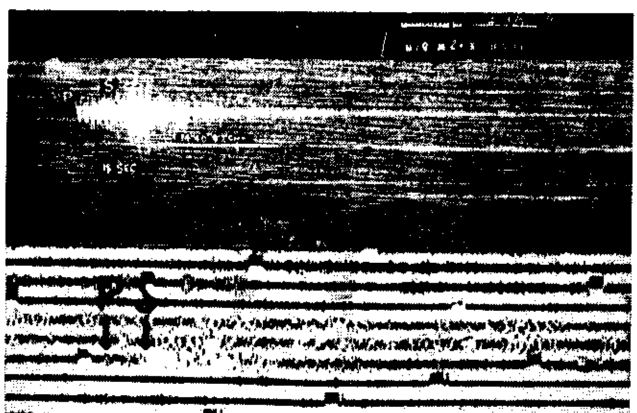
### Analysis of Data :

A set of six months records from this observatory for the months of April to September 1974 was selected for this initial study. This period was chosen to study the the recorded seismic activity if any in the reservoir region prior to reservoir filling, and provide overlap with the period of microearthquake recording with a mobile and sensitive system to permit comparison of the data through the two systems of recording. A detailed scrutiny of these records has been done and a station seismological bulletin prepared.

The total number of earthquakes recorded at Kalagarh observatory within a hypocentral distance of 200 km was only 12 over the period of study of six months. The gap in data due to missing charts or improper recording was about 20% of the total duration of recording. Also the general noise present on records was high and even on days when charts were available it is most likely that the identification of some of the events was missed. Only 5 out of the 12 events recorded were during the period of overlap recording by the mobile observatory and some of these would have perhaps escaped their identification without the charts of the mobile observatory. This is clearly demonstrated by the comparative traces obtained by the two systems given in Fig. 2a and b for two different earthquakes.




From Seismogram Dated 7-8 9.1974
P–Time 17*H* 81*M* 56.5*S* (G.M.T.)
(a)




From Seismogram Dated 2–3.9.1974
P–Time 14*H* 09*M* 44.0*S* (G.M.T)
(b)

Fig. 2. Sections of Seismograms Showing Corresponding Records of Two Earthquake Records during the Period of Overlap Recording at Mobile Observatory and Kalagarh Observatory

A histogram showing the distribution of number of events with the S–P time is given in Fig. 3(a). Taking the longitudinal and transverse velocities as 5.5 km/sec and 3.2 km/sec respectively the S–P times have also been expressed in terms of focal distances

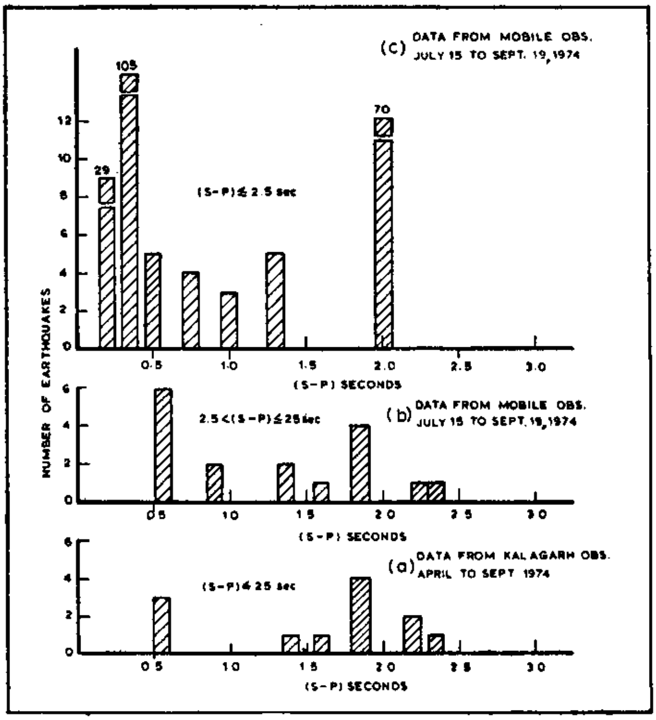



Fig. 3. Histograms Showing Distribution of Earthquakes with S–P Times (Distance)

at places in this paper. The small magnitude events within 20 km distance that have been recorded by the mobile observatory could not produce identifiable records on Kalagarh observatory due to the limited gain of the instruments. Thus, it could be stated here that the records from Kalagarh observatory could not be used for the purpose of the study of small size events that are occurring within reservoir region and possible change in their number due to reservoir filling.

The events recorded at distances upto 200 km were in general indicative of the seismic activity of Moradabad-fault, the Himalayan-main-boundary-fault and perhaps some may have occurred in the Delhi region. The number of events at larger distances were from—Hindukush region, Afganistan USSR border region, Kashmir-Tibet border region and Sinkiang border region.

## STUDY OF RECORDS FROM MOBILE OBSERVATORY

### Description of Equipment

A block diagram of the complete microearthquake recording system (MEQ-800-Portable Seismic system of W. F. Sprengnether Instruments Co. Inc.) used at Kalagarh is given in Figure 4. A variable period seismometer whose period has been adjusted to 0.5 sec has been employed. The output of the seismometer is coupled to a portable smoke paper recorder, which has builtin amplifier, filter and time marking arrangements. A recording speed of 240 mm/min (one revolution of the drum in 2.5 min) has been employed in order to permit easy resolution of frequencies upto about

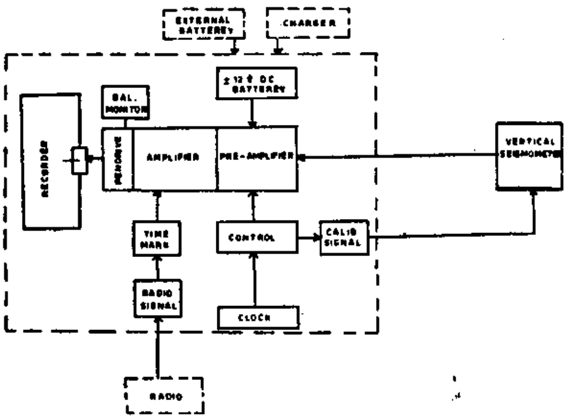



Fig. 4. Block Diagram of the Portable Microearthquake Recording System Used

15 cps. This involved changing paper twice a day. The system can run for shorter time intervals on rechargeable batteries within the system. However, for recording at Kalagarh two 12 volts car batteries were used to permit continuous running of the system for about three weeks. The gain of the amplifier and the setting of the filter can be adjusted at the desired level. The system was caliberated at site and also emloyed for recording at Kalagarh using the amplifier and filter settings at 66 db and 5/out respectively. The magnification curve is shown in Fig. 5. The time marks provided by the crystal clock in the system were compared with a time signal from B. B. C. which was directly marked on the charts.

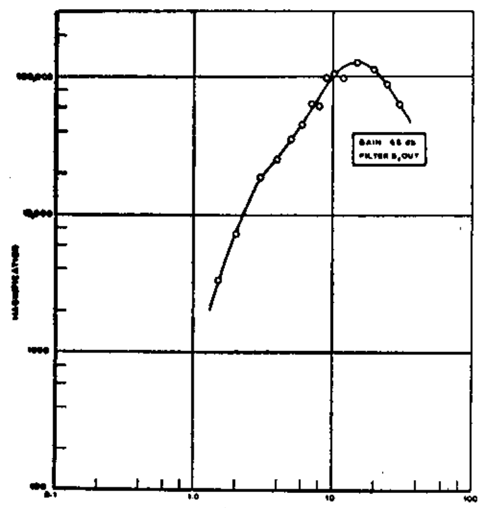



Fig. 5. Magnification Curve of the System Drawn on the Basis of Dynamic Caliberation Tests

## Selection of Site for Recording

Initial test recording of the ground noise was carried out at the following locations surrounding the Kalagarh dam and its reservoir in order to select a suitable site with low level noise for continuous recording. (1) Near the Kalagarh seismological observatory, (2) Right drainage tunnel of the main dam, (3) Left clay borrow area, (4) Kangrochor clay borrow area, (5) near saddle dam, (6) Kotdwara road side, (7) Noongarh temple, and (8) Near workcharge staff colony.

The ground noise at sites 1, 2 and 5 was high, mainly due to movements of heavy vehicles and the activity at the dam site. The noise at site 3 was comparatively less than at sites 2, 1 and 5, but still appreciable. The ground noise level at sites 4, 6 and 7 was found to be low. But these sites were not chosen finally since no suitable and protected seismometer housing was readily available. Also the possible arrangements for stay of the observer at some of these locations were a bit inconvenient. The site near workcharge staff colony was found suitable. A 3 feet long drift in the weathered rock was made to expose the hard rocks on which the seismometer was directly installed.

## Analysis of Data

The mobile seismological observatory was continuously operated from July 15, to September 13, 1974. A bulletin was prepared only for those events that were within 200 km. hypocentral distance.

The distribution of events within 200 km hypocentral distance over the period of recording is shown in Fig. 6 through a histogram. The histogram does not indicate any

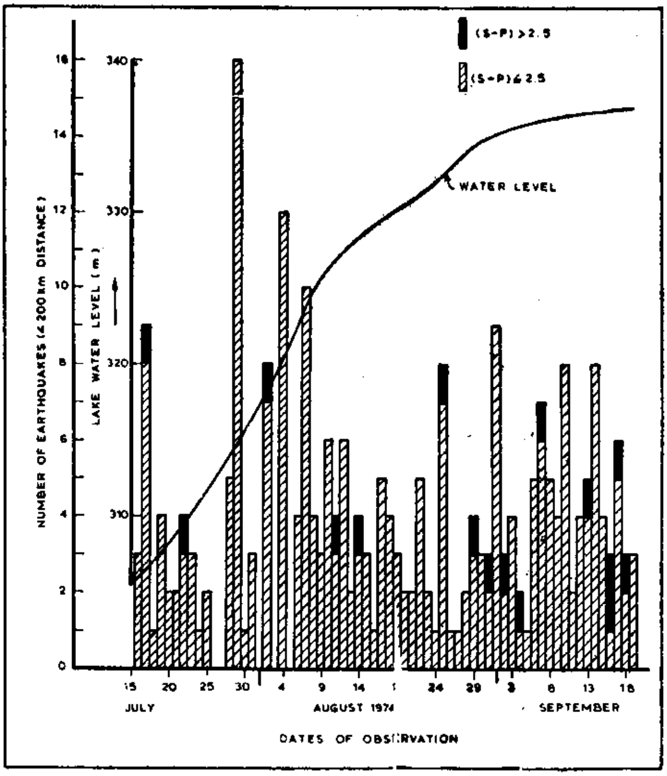



Fig. 6. Histogram Showing Daily Frequency of Earthquakes Within 200 km Distance. Rise in Lake water level is also shown.

statistical trend in the variation of number of earthquakes with time. The rise of the lake water level through about 30m during the period of recording is also shown in Fig. 6. The lake water level and the number of earthquakes recorded did not seem to bear any correlation and their combined presentation should not be taken as a suggestion of their inter relationship.

In order to appreciate the distribution of earthquakes with hypocentral distance over [redacted] the traces of these events having by and large equal hypocentral distance is suggestive of variation in their focal depths. Howevre, these are very shallow events and certainly the focal depths do not exceed 3 km in any case. A typical trace of events at 15–18 km distance is given in Fig. 7c. The P is not at all clear where as S has appeared prominently. Since the vertical seismometer has been used, this could perhaps be taken to be suggestive of a more or less horizontal arrival of P-wave energy implying a very shallow focus. A typical trace for event at 1.5 km is given in Fig. 7d where only P onset is clearly seen.

These events with hypocentral distances within 20 km did not show any increasing trend with the partial filling of the lake. However, these are certainly indicative of the activity of tectonic features close to the site of recording and some of these may be lying submerged in the reservoir. It is not possible to locate the epicentres of these events on the basis of the present study. It is quite likely that the events at 15 km focal distance may be associated with Sarpduli-Dhikala thrust which has been described as active on the basis of tectonic study. A small sample consisting of only three typical sections of seismograms containing the records of earthquakes two at distance of 35 to 40 km and one at about 140 km are given in Fig. 8 to show the general quality of recording at the mobile observatory.

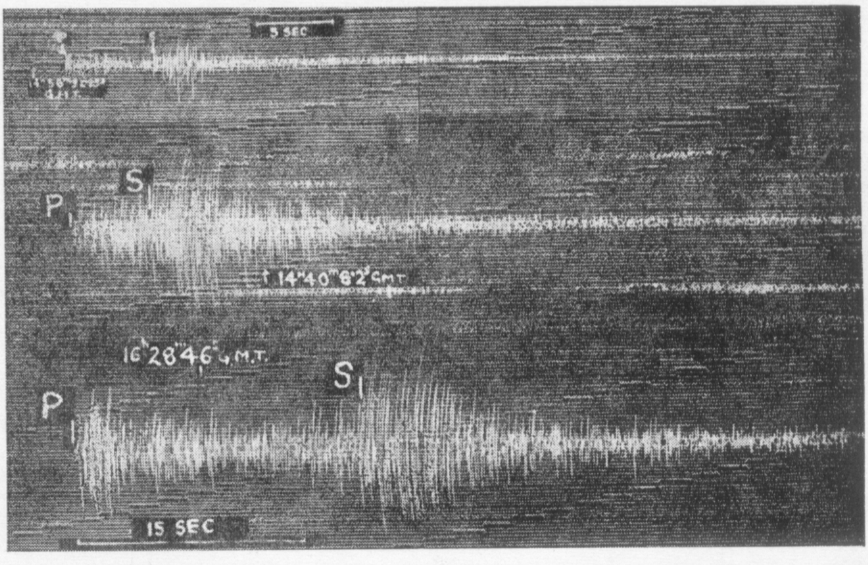



Fig. 8. Copies of Section of Seismogram Showing Three Typical Traces of Earthquakes Recorded at Mobile Observatory

An interesting phenomenon has been recorded by the mobile observatory on July 29, 1974 during the night hours. A section of the seismogram given in Fig. 7(e) shows a number of closely spaced events at 'a' for about half an hour. Similar, but a bit feeble traces have appeared again for about half an hour (not seen in the section) on the same day within about 5 hours. Initially, this was taken to be some kind of noise. However the identical waveform in each event and significantly different frequency character from that of any noise recorded, did not support the initial apprehension. A critical study of seismograms on other dates indicated that on August 7, 1974 at night again similar kind of swarm of events was registered. The number of events was limited on this chart as shown in its section in Fig. 7(f). The background was quite on both these charts since the recording times were during nights. Even the beginning of some of the events could be imperfectly identified. This led to the identification of the phenomenon as swarm of earthquakes. On the basis of the broad similarity of the S-wave portion of these to some other clearly recorded events, the hypocentral distance is estimated to be 30 km. The number of these earthquakes on July 29, 1974 have not been included in the listing of earthquakes given due to their uncertain and mixed up beginning and large number. It would be very appropriate to mention here that isolated traces of similar type have appeared on other dates and have been tabulated in the bulletin. It is very likely that some more have been missed when superimposed with the noise.

## MAGNITUDE DETERMINATIONS

The instrument was caliberated at site for its gain setting at 66 db with low pass filter at 5 cps (as was actually used in recording) and for input signals with frequencies in range of 2 to 30 cps. The results from this actual caliberation and the following formula have been used to calculate the magnitudes of various earthquakes:

$$M=\log \frac{A_m \times 2800}{DM_E} - \log A_0$$

where $A_m$ is the measured trace amplitude, $DM_E$ is the magnification of the instrument at the corresponding frequency, and $\log A_0$ is a function of distance. The values of measured trace amplitude ($2A_m$), the associated frequency, the corresponding dynamic magnification ($DM_E$) and the values of $\log A_0$ have been given in Table I. The calculated magnitudes so obtained are also given in Table I.

The errors in the determination of magnitudes may be on account of the following:

(i) The frequencies associated with the largest amplitude in the traces of earthquakes recorded could be actually measured only upto about 15 cps whereas the events at short distances were certainly associated with higher frequencies which could not be measured but have been estimated. This might have led to the choice of an incorrect value of dynamic magnification. But, the errors on this account are expected to be small.

(ii) It is likely that the error on account of the differences in the response of the standard Wood-Anderson seismograph and the portable system used (Thatcher, 1973) may be greater than as at (i). The trace amplitude from the portable system having peak gain at 15 cps when empirically reduced to the Wood-Anderson trace amplitude (peak gain only arround 1 cps) may be in general an over estimate for local events associated with high frequencies. The extent of error on this account would increase with increasing frequencies.

(iii) The values of $\log A_0$ have been taken from Richter's table (Richter 1958) which are actually valid for California region and may not be truely applicable to the region under study. The errors on this account are expected to be larger than those at (i) and may be comparable to those at (ii) atleast for the earthquakes within 40 km distance and could perhaps be considered more or less uniform irrespective of actual magnitude.

In view of these limitations of the magnitude determination for small size events in the absence of availability of suitable empirical constants in the region under study which are not easily determinable, it would generally be considered better to determine magnitude on the basis of coda length (Real et al. 1973). The coda length and magnitude are inter-related and this again is dependent on the region of recording. However, in this case data from only one Wood-Anderson instrument in the region is sufficient to arrive at an empirical relation between the magnitude and the coda length. This method has the advantage of avoiding the possible errors as at (i) and (ii). Since, no standard Wood-Anderson seismograph is operating in the region, this relationship could not be determined for the Kalagarh region. Results of study from Koyna region (Arya et. al., 1974a) have been used for the calculation of magnitude for some of the

**TABLE I**

**Number of Events with Different Magnitudes at Various Distances**

| (S−P) Time Range (sec) | Number of Events with traces amplitudes (2 AM) mm | | | Corresponding freq. range (cps) | Effective dynamic Magni. ($DM_E$) $X\ 10^5$ | log $A_0$* (−) | Number of Events with Magnitudes | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | <5 | 5−10 | >10 | | | | <−0.5 — | −0.5 to 0.5 | 0.5 to 1.5 | 1.5 to 2.5 | 3.0 — |
| 0.00−0.20 | 28 | 1 | — | 16−25 | 1.00 | | 1 | 28 | — | — | — |
| 0.25−0.40 | 87 | 17 | 1 | | | 1.4 | — | 105 | — | — | — |
| 0.50−0.57 | 6 | 3 | — | 14−20 | 1.20 | | — | 9 | — | — | — |
| 1.00−1.30 | 7 | 1 | — | | | 1.5 | — | 8 | — | — | — |
| 1.50−2.50 | 70 | — | — | 12−14 | 1.20 | 1.6 | 13 | 57 | — | — | — |
| 5.75 | 2 | 1 | 3 | 10−12 | 1.12 | 2.4 | — | — | 3 | 3 | — |
| 9.00 | 2 | — | — | | | 2.8 | — | — | 1 | 1 | — |
| 14.00 | 1 | — | 1 | 08−10 | 1.00 | 3.0 | — | — | — | 2 | — |
| 16.00 | 1 | — | — | | | 3.1 | — | — | — | 1 | — |
| 18.50 | — | 1 | 3 | 07−9 | 0.90 | 3.2 | — | — | — | 3 | 1 |
| 22.50 | — | 1 | — | | | 3.4 | — | — | — | 1 | — |
| Total Number | 204 | 25 | 8 | | | | 14 | 207 | 4 | 11 | 1 |

*From Richter, 1958.

Kalagarh events. Naturally, this is again not expected to give correct magnitude determination but was attempted to check whether the respective determinations in the two different manner showed consistent departures from each other or not. It was found that the magnitudes calculated on the basis of coda length were consistently lower by about 0.4 then those obtained by using Richter formula. Thus the magnitude values given in Table 1 could perhaps be considered the upper bound of magnitude.

## 5. DISCUSSION OF RESULTS AND CONCLUSIONS

The results obtained in the study are discussed and some broad conclusions that can be made on this basis are presented in the following paragraphs.

(1) The general level of seismic activity in the Kalagarh region is low and therefore in order to detect any change in the same, the microearthquake study should continue over next few years.

(2) The reservoir was only partially filled in the 1974 monsoon season. The partially filled reservoir condition does not appear to bear any correlation with the seismic activity. But it is not possible to conclude any thing about the possible influence of the complete reservoir filling in future on seismic activity on the basis of this limited study.

(3) The number of earthquakes (221) within hypocentral distances upto 20 km is considerably large compared to the number of events (16) with distances 20 to 200 km. This is indicative of the potential of the mobile system to detect very small events at short distances. The small events of similar type which may also be occurring at distances 20 to 200 km could not be expected to produce identifiable records at the recording site.

(4) Small earthquakes with very small hypocentral distances have quite often appeared more in number on some days whereas on some other days they are absent. However, there seems to be no statistical trend in this behaviour and hence no scientific significance could be attached to this feature at this stage.

(5) The distances at which Sarpduli-Dhikala thrust and Halduparao faults lie submerged in the reservoir are comparable to the distances at which a number of events have been registered. The possible association of earthquakes with these features could not be established on the basis of one instrument since epicentres could not be located without a minimum of three to five instruments.

(6) An interesting phenomenon has been recorded by the micro-earthquake recording system on July 29, 1974 which would ordinarily be interpreted as a swarm of earthquakes of very small magnitudes (0.50). The focal distance is estimated to be about 30 km for these events. Isolated events of this type have also occurred on other dates. However, it is not possible to relate this swarm to the reservoir filling at this stage.

(7) The Benioff seismograph system in the Kalagarh observatory is capable of recording with gains upto $10^5$. But in view of the site noise at the Kalagarh observatory the instruments are operated only with a magnification of $4\times10^3$. In view of this the small earthquakes within 20 km distance escape detection altogether.

(8) It would emerge from this study that the earthquakes occurring very close to the reservoir region should be located by simultaneous recording by at least three or more stations. This would allow identification of those active tectonic features that would lie submerged in the lake.

## ACKNOWLEDGEMENT

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