Bhoo-Kampan Vol. 4, pp. 7-15, December 2017

Journal of Indian Society of Earthquake Science
ISSN: 2320-6217

Seismicity Near Bhatsa Dam, Maharashtra, India

B.K Rastogi

House No. 1-2-63/3, Habsiguda, Street No.1, Kakatiyanagar, Hyderabad 50007, India

bkrastogi12@gmail.com

Abstract

Bhatsa dam of height 88.5m and capacity 957Mm^3 is 90km NE of Mumbai and 200km north of Koyna with a similar geological setting as that of Koyna. Filling of Bhatsa reservoir started in 1977 and triggered seismicity started in 1983 after water level reached height 57.5m and had a rapid rise of 18m in one month. Three earthquakes of ML 4.4, 4.9 and 3.9 on Aug 17, 1983, Sep 15, 1983 and Jan 7, 1984, respectively caused damage in nearby villages. There were 342 felt earthquakes (two of ML >4, sixteen of ML 3-4 and other felt earthquakes may be of ML 2-3). One station starting July 1983 and eight analog stations from October 1983 recorded over 13,000 shocks of magnitude nearly zero (coda a few seconds) to 2.9 in 18 months' period out of which some 400 were well located in the vicinity of the reservoir. Epicenters were mostly concentrated in 5kmx7km area over the western part of the reservoir and some distance west of it. Epicenters are related to major and small NW-SE trending faults which are part of Ghod lineament and a rift system.

Initiation of seismicity near the dam, confinement of shocks in close vicinity of the reservoir at shallow depths, correlation of seismicity with water level indicate that the seismicity is reservoir induced. Seismic characteristics like foreshock-aftershock pattern, slow decay of aftershocks and epicentral area growth with time further support that the seismicity is reservoir induced.

1. Introduction

Bhatsa dam (19º 30'N 73º 25'E) of height 88.5m and capacity 957Mm^3 is 90km NE of Mumbai and 200km north of Koyna. It has a similar geological setting as that of Koyna, being in a junction area of rift valleys of Deccan Traps (Fig.1). Supplying 50% water needs, it is a life line for Mumbai and irrigates 23,000 ha land in Thane district. Further, the seismicity being close to main railway, road and electric supply lines was of much concern. Filling started in 1977 and triggered seismicity started in May 1983. However, after the water level reached height 57.5m with a rapid rise of 18m, three earthquakes of ML 4.4, 4.9 and 3.9 on Aug 17, 1983, Sep 15, 1983 and Jan 7, 1984 caused damage in nearby villages. Most affected village was Khardi, 4km west of the Bhatsa reservoir (Rastogi et al., 1986).

2. Geology

The Bhatsa-Khardi area is within the Deccan Traps region. The lavas erupted around 62 My back during Cretaceous and covered a large area of half a million sq. km. Bhatsa is near the junction of Koyna and Kurduvadi rifts (Krishna Brahmam and Negi, 1973; Krishna Brahmam and Sarma, 1985, Powar et al., 1979, Powar, 1981) as well as a prominent Ghod lineament (Fig. 1) all trending NW-SE. Locally a number of NW-SE trending faults (Talekhan, Kengri and Kalu-Surya) have been mapped with normal faulting.

Some lineaments trend N-S or NE-SW (Fig. 2) (Officers of Geological Survey of India, 1984 and Peshwa, 1984).

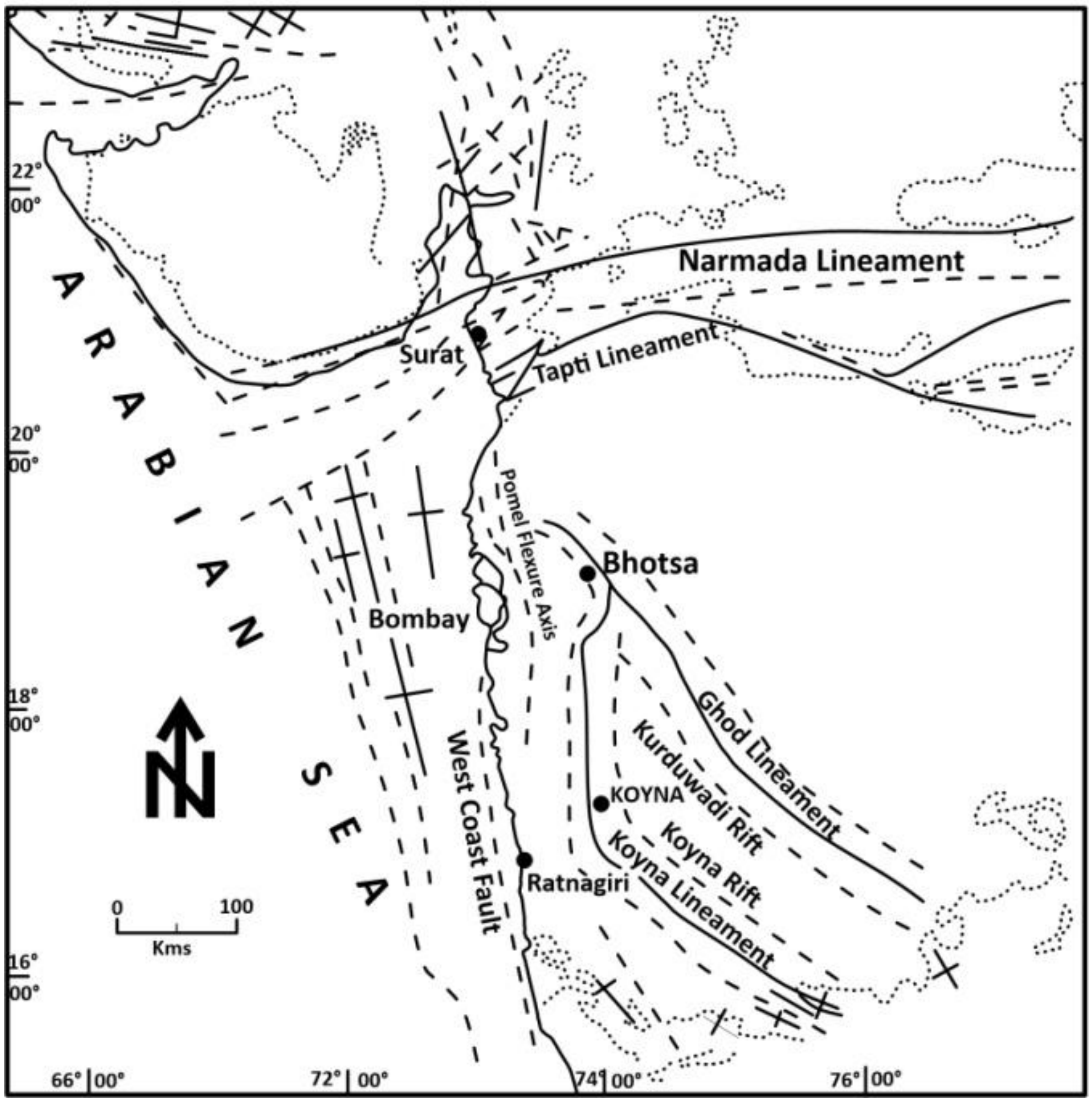

Fig. 1. Tectonic framework of the western part of Deccan volcanic province (after Powar, 1981). Locations of Bhatsa and Koyna are also shown

The Kengri Nadi and Talekhan faults pass north of reservoir. Geomorphology in the northeast indicates youthful topography characterized by deep gorges, narrow V-shaped valleys, rapids and waterfalls. Southwest side, the topography is mature to old with rolling water divides and broad V or U-shaped valleys. This suggests that the northeastern block is being uplifted in relation to a sinking southwestern block. The elevation in the area drops from 608m to 80m above mean sea level. The southwestward flowing Bhatsa river system is the main drainage system in the area. The Tansa and Vaitarna streams in north and west are west-southwestward flowing.

3. Seismicity

On May 17, 1983 a tremor was felt at Khardi and nearby villages west of reservoir (No earthquake is known to have occurred earlier in the area). Its magnitude is estimated ~3. This was followed by 342 felt earthquakes (for one year during July 1983 to August 1984) following a rapid rise in reservoir water level by 18m and achieving a water height 58m. There were two earthquakes of M4-5 and 16 tremors of M3-4 within first six months. Over 13,000 micro earthquakes of magnitude nearly zero to 3 were recorded for about 2 years' period. Some 400 shocks were well recorded by a local network of eight analog seismograph stations (Fig. 2). Locations are in the western part of the reservoir and some distance west of it but concentrating in 5kmx7km area. The epicenters are related to NW-SE trending faults mapped by Officers of Geological Survey of India (1984) and Peshwa (1984).

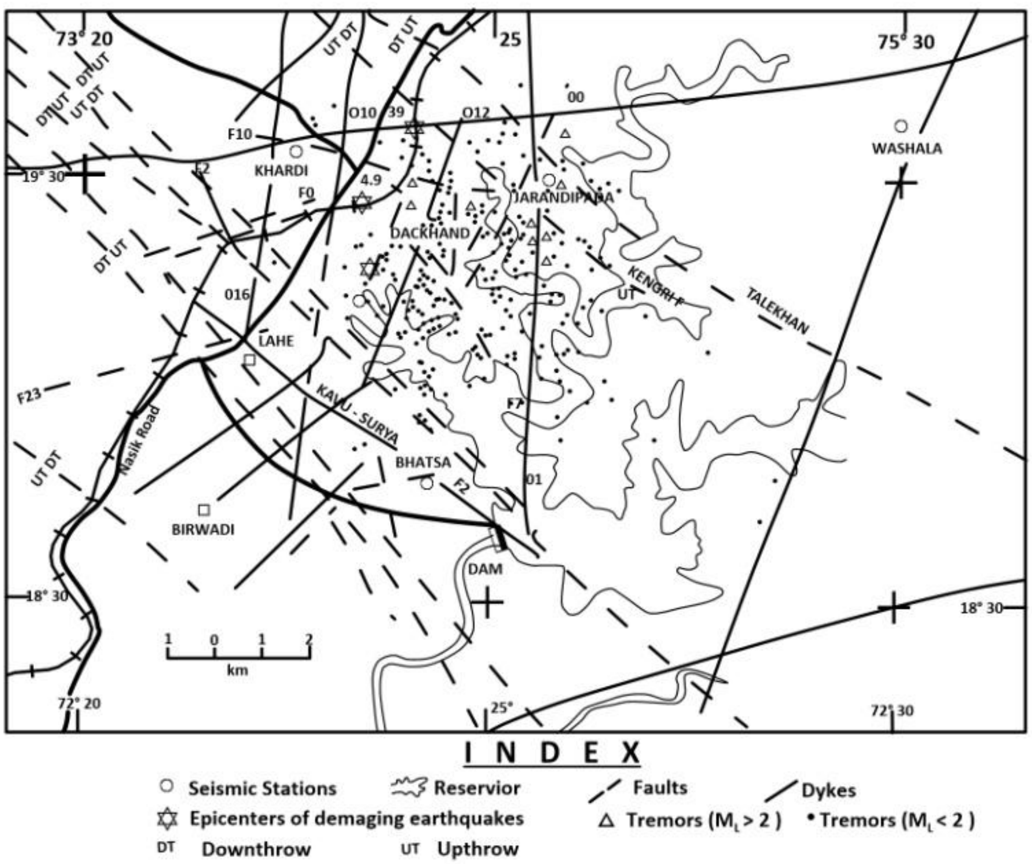

Fig. 2. Seismic activity at Bhatsa Reservoir, Maharashtra, India from October 1983 to April 1985. The epicenters were located with eight local seismic stations network operated from October 1983. The faults, fractures and dykes shown in the map are taken from GSI and Poona University reports

During August 1983, over 2000 micro shocks and during September 1983 about 5000 micro shocks were recorded. For one year period there were several hundred shocks every month, decreasing to about 100 – 150 per month October 1984 to April 1985. Such low level seismicity continued for some more years and was recorded with additional digital stations. Locations were determined with HYPO71 program (Lee and Lahr, 1972). Magnitudes were estimated from coda with a scale homogenized to Ms. The average root mean square (RMS) of travel-time residual is 0.1s. The average horizontal error (ERH) is <1km and average vertical error in depth (ERZ) is <3km. The focal depths are 1-6km (Fig. 3).

The velocity model used is simplified model of the one obtained by Deep Seismic Sounding profile some 200km south of Bhatsa (Kaila et al. 1981) (Table 1).

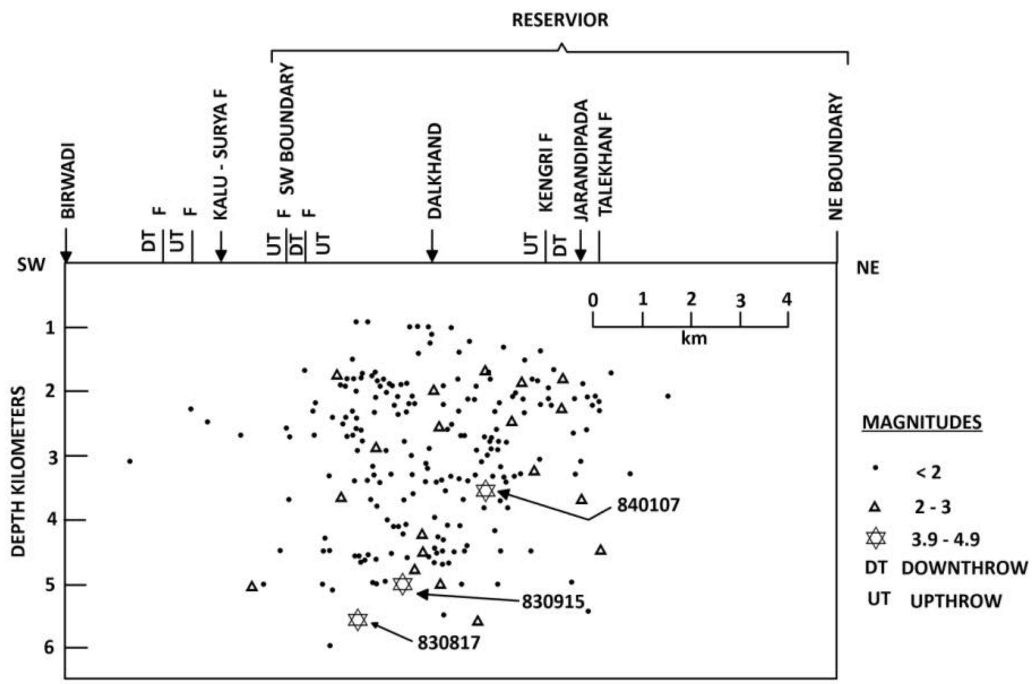

Fig. 3. Depth section along SW-NE direction. Locations of major faults are shown at the top of the profile.

Table 1: Velocity model used for location of hypocenters. Vp/Vs is assumed 1.73.

Vp, km/s	Depth in km to the top of the layer
4.95	0.0
6.20	1.0
6.60	20.5
6.90	30.0
8.26	37.0

Composite fault plane solution indicates normal faulting along north-northwest nodal plane with the western block going down relative to the eastern block in conformity with the local tectonics.

4. Correlation of Seismicity with Water Levels

The first impounding up to 17m was done in 1977. The dam was subsequently raised in stages enabling water depth 51m in 1982, 58m in 1983 and 63m in 1984 (Fig. 4). In 1983, the water level was raised rapidly by 18m in about a month from July second week to August first week (Fig. 5). It was followed by intense seismicity for three months starting third week of July. Seismicity during the years to come increases near any reservoir if the water level surpasses the previous year's maximum. It is called

Kaiser Effect (Talwani and Acree, 1985). In 1984, the increased seismicity during August followed closely an increase in water level in July-August. During 1985 the maximum level was maintained at previous year level and there was no increase in seismicity (Fig. 6). It was noticed that seismicity increased if rate of water level rise was high and previous year's maximum surpassed by 5m. Hence, it was advised to raise the dam height at the rate of less than 5 m/year and keep rate of impoundment low. Seismicity waned off may be as this advice was adhered to. The first felt earthquake in the area in May 1983 was when water level was lowest of that year. The onset of seismicity may be due to previous year's impoundment.

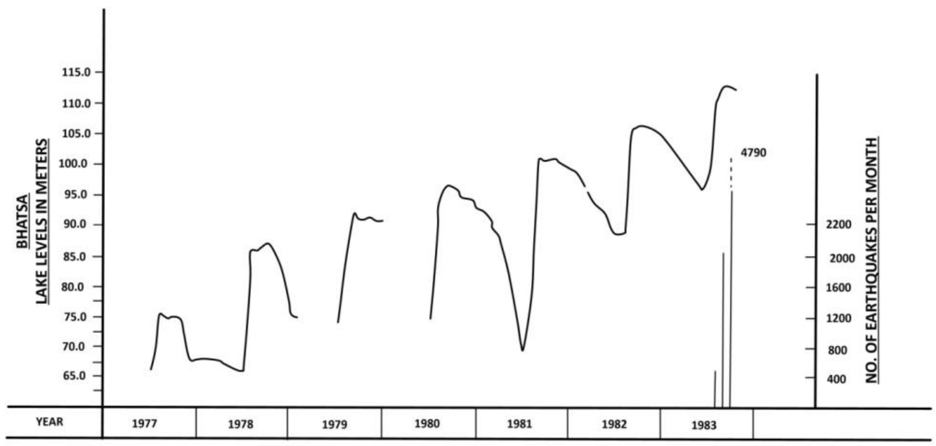

Fig. 4. Reservoir level from 1977 to 1983. The seismic activity started in middle of 1983 (provided by Maharashtra Engg. Res. Inst., Nasik).

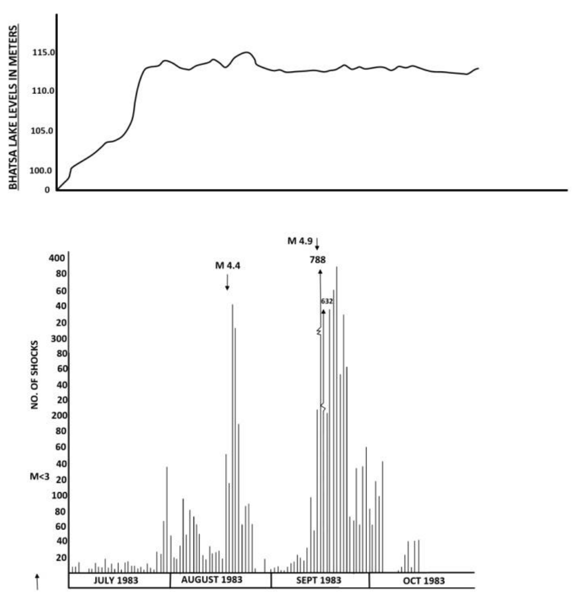

Fig. 5. Daily frequency of microearthquakes from July to October 1983. Two earthquakes of magnitude > 4 are shown by arrow marks. Water levels are also shown (provided by MERI, Nasik).

Seismicity which occurs in the vicinity of a new reservoir is believed to be triggered by increase in pore pressure due to rise in water level which reduces effective stress across faults. The faults have to be critically stressed before hand as contribution of a reservoir is at the most 10%. Initially it may take some years for percolation of water in the area along the existing fractures thus delay in triggered/induced seismicity. Once the channels of fluid flow are established the delay between water level rise causing migration of pore pressure pulse and triggering of seismicity may be 1 or 2 months.

5. Growth of Epicentral Area with Time and Seismic Hydraulic Diffusivity

Space-time pattern of epicenters indicates prominent growth in NW-SE direction along NW-SE trending faults viz. Talekhan, Kengri and Kalu-Surya. Strong growth is in SW direction also (Fig. 7). Average growth rate is 1.3km/month giving seismic hydraulic diffusivity ($\alpha = L^2/t$) 6.5x104cm^2/s as defined by Talwani and Acree (1985).

6. Intensity and Isoseismals

The three strong earthquakes of Aug 17, 183 (M4.4), Sep 15, 1983 (M4.9) and Jan 7, 1984 (M3.9) caused maximum damage (big cracks in large no. of houses, panic and evacuation) at Khardi village located 5 km west of reservoir and moderate damage in other villages at similar distances in NW and south of reservoir. Maximum intensity was VI (MM scale) for September tremor but maximum intensity was V for other two tremors. The tremors were strongly felt for 15-20 km distances. Isoseismals VI, V, IV and III were drawn. The isoseismals are elongated in NW-SE for the two tremors of 1983 and in NE-SW direction for Jan 1984 tremor.

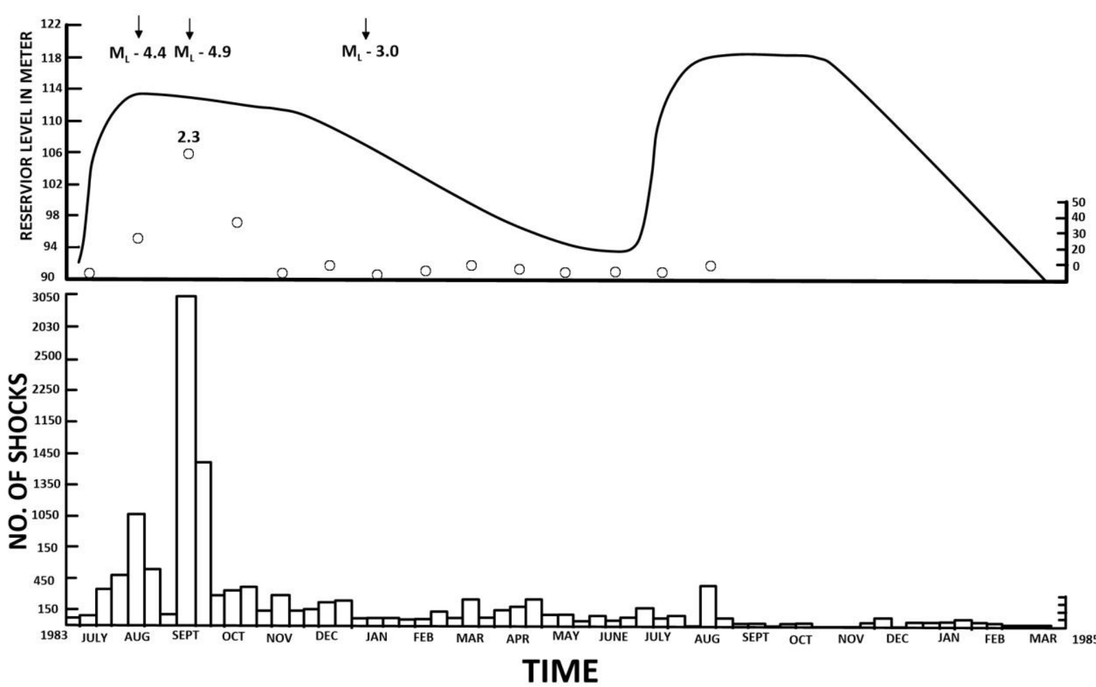

Fig. 6. Water levels of Bhatsa reservoir and monthly no. of recorded shocks from July 1983 to March 1985

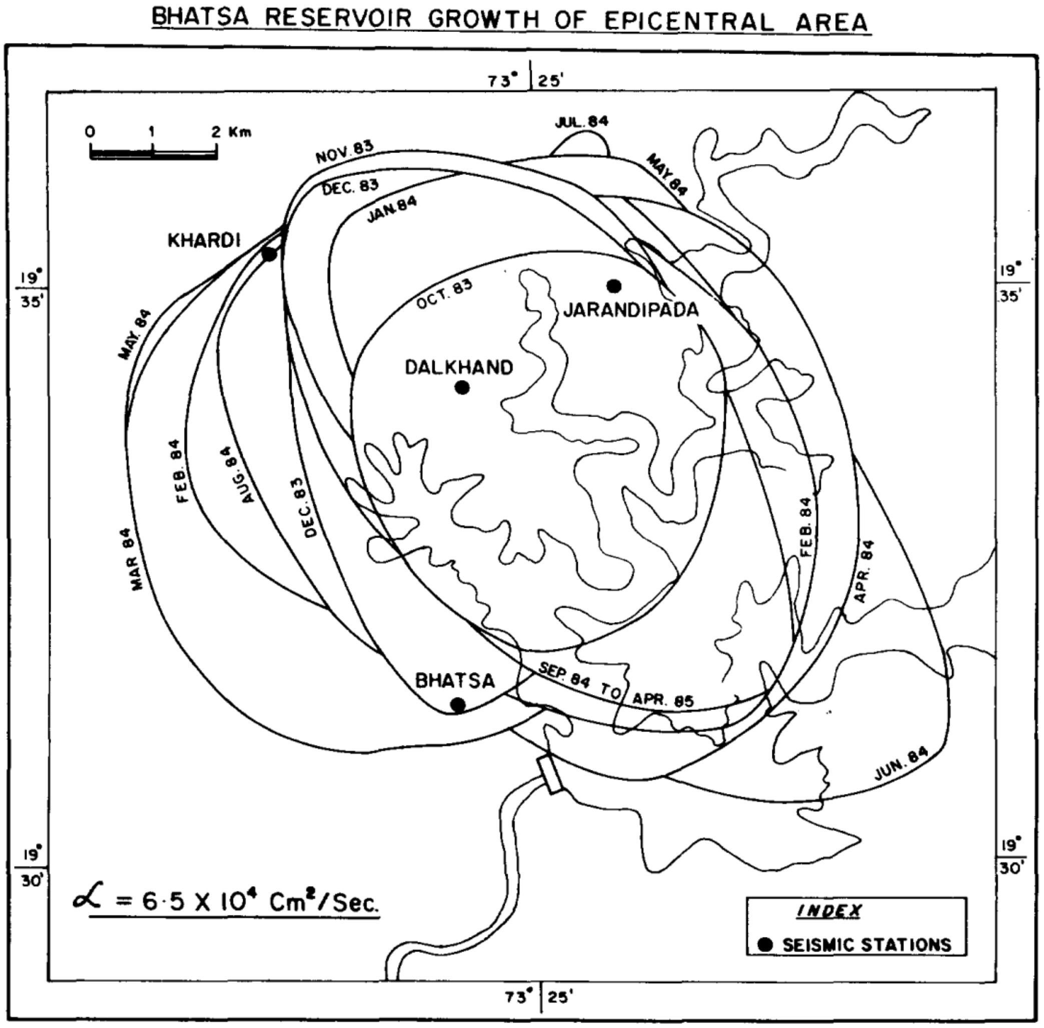

Fig. 7. Growth of the epicentral area around the Bhatsa reservoir. Prominent growth directions are NW-SE and SW

7. Foreshocks-Aftershocks Pattern

The foreshocks-aftershocks patterns for the two large tremors of M 4.4 and 4.9 are shown in Fig. 4. The foreshocks for Aug 17, 1983 tremor started in July. Aftershocks were many but waned off in one week. For the Sep 15, 1983 tremor, foreshocks started two weeks before and aftershocks lasted for 3 weeks. Such patterns of large number of foreshocks and aftershocks are classified as Type II of Mogi (1963). Areas showing such pattern may have rather heterogeneous material (having many faults/fractures) and / or the applied stress is not uniform, a typical behavior encountered in areas of reservoir-induced earthquakes (Gupta et al., 1972, Gupta and Rastogi, 1976).

The rate of decay of aftershocks is slow (decay constant <1) as seismicity has continued for several years as per Mogi (1963).

8. Discussion

Both Bhatsa and Koyna areas are in similar geological setting and there are similarities in seismicities as described below:

1. Koyna and Bhatsa areas are in the same geological setting of ~1km thick Volcanic Deccan Traps. There are pre-exisiting shallow faults from 1-9km depth. The faults are likely to be critically stressed as evidenced by some small shocks prevalent in the region.
2. There are circumstantial evidences in both the areas which indicate that seismicity is induced by reservoir filling - like substantial increase in seismicity soon after filling, bursts of seismicity after rapid filling to high levels for several years.
3. Seismicity is close to reservoirs. Rate of growth of epicentral area by distance as well as area is similar to hydraulic diffusivity indicating that percolation of water / migration of pore pressure influences seismicity.
4. Seismicity patterns in both the areas display discriminatory seismic characteristics as proposed by Gupta et al. (1971), like:
   i. Higher b-values ~1 or more in a region of low b value of ~0.5 (Gupta and Rastogi 1976). This indicates large number of smaller shocks along pre-existing as well as newly generated small faults.
   ii. Occurrence of numerous foreshocks and large number of aftershocks that continued for long period at slow decay rates.
   iii. The predominant faulting mechanism is strike-slip in Koyna area while normal faulting in Bhatsa area. Both types of mechanism are conducive to reservoir-triggered seismicity.

9. Conclusions

1. Seismicity is found to have been initiated and then became intense immediately after impoundment to over 50m level with a rapid rate of 18m/month. The epicenters are beneath the reservoir and up to 4km away, but more concentrated in 5kmx7km area with focal depths of 1-6km.
2. Bhatsa, though 200km north of Koyna is in the same geological environment of inferred NW-SE trending Koyna-Kurudvadi rift system in Cretaceous age Deccan volcanics. Locally a NW trending Kengri river fault is found to be geomorphologically active. The dam design of Bhatsa dam has been modified and strengthened for the possibility of a magnitude 6 earthquake. Moreover, a controlled raising of the dam height by <5m/yr and not too high rate of filling on our advice might have helped in avoiding any possible moderate earthquake in Bhatsa.

References

Gupta, H.K., B.K. Rastogi and Hari Narain, 1972. Some discriminatory characteristics of earthquakes near the Kariba, Kremasta, and Koyna artificial lakes, Bull. Seismol. Soc. Am., 62, 493-507.

Gupta, H.K. and Rastogi, B.K., 1976. Dams and Earthquakes. Elsevier, Netherlands, 227 pp.

Kaila, K.L., Murthy, P.R.K., Rao, V.K. and Kharetchko, G.E., 1981a. Crustal structure from deep seismic sounding along the Koyna II (Kelsi-loni) profile in the Deccan Trap area, India. Tectonophysics, 73: 365-384.

Krishna Brahmam, N. and Negi, J.G., 1973. Rift valleys beneath Deccan Traps (India). Geophys. Res. Bull., 1: 207-238.

Krishna Brahmam, N. and Sarma, J.R.K., 1985. Earth tremors near Bhatsa Project area (Maharashtra State) India. J. Assoc. Expl. Geophys., 6: 23-27.

Lee, W.H.K. and Lahr, J.C., 1972. A computer Program for determining the hypocenter, magnitude and first motion pattern of local earthquake. Revision of HYPO 71, U.S. Geol. Surv., open file report, 100 pp.

Mogi, K., 1963. Some discussion on aftershocks, foreshocks and earthquake swarms--the fracture of a semi-infinite body caused by an inner stress origin and its relation to the earthquake phenomena (third paper). Bull. Earthq. Res. Inst., 41: 615-658.

Officers of Geological Survey India, 1984. A note on geology and structure of Bhatsa-Khardi area of Maharashtra in the Regional Perspective, 12 pp.

Patil, D.N., Bhosale, V.N., Guha, S.K. and Powar, K.B., 1984. The Khardi Earthquakes, 1983. Current Sci., 53: 805-806. Peshwa, V.V., 1984. Photogeological Studies of Bhatsanagar area. Report, Dept. Geol. University of Poona, 60 pp.

Powar, K.B., 1981. Lineament fabric and dyke pattern in the western part of the Deccan volcanic province. Proc. Int. Symp. on Deccan Volcanism and Related Basalt Provinces in Other Parts of the World. Mem. Geol. Surv. India. No. 3: 46-57.

Powar, K.B., Sukhtanakar, R.K. and Patil, D.N., 1979. Geomorphology and Tectonics of the west coast of India between Palghan and Revas, Maharashtra. Technical Report No. 2, Univ. Poona, Pune, 60 pp.

Rastogi, B.K., R.K. Chadha and I.P. Raju, 1986. Seismicity near Bhatsa reservoir, Maharashtra, India, Phys. Earth and Planetary Interiors, 44, 179-199.

Talwani, P. and Acree, S., 1985. Pore pressure diffusion and the mechanism of reservoir induced seismicity. Pageoph., 122: 947-965.