4. SEISMICITY OF KOYNA-WARNA REGION: A CASE STUDY

4.1 General

The several devastating earthquakes occurred in India, resulting in massive damage to the buildings and huge deaths. Particularly, the Koyna-Warna region of Maharashtra is one of the most significant worldwide examples of reservoir-induced seismicity. The area is highly vulnerable to earthquake shocks and it has experienced total number of shocks over one lakh since 1963. The largest induced known earthquake of magnitude is 6.5 (Richter scale) on 10th December 1967. Also, the persistent low & moderate earthquake events occurred over the last 50 years. So, there is a need to do the study on the effect of seismic activity on the built environment of this Koyna-Warna region.

4.2 Description of study area: Koyna-Warna Region

Koyna-Warna region is situated in the Maharashtra state in India, the Koyna-Warna (latitude 16.750–17.70 N and longitude 73.450–74.250 E) is encompassing a combined area of about 2,600 km^2 (Koyna-1,994 km^2 and Warna-663 km^2). Seismic activity has been experiencing continuously for more than 50 years in the Koyna-Warna region (Zone-IV). There have been 9 earthquakes of Magnitude greater than 5, about 96 earthquakes in between 4 to 5 magnitude, and thousands of smaller earthquakes since 1963 (Seismic activity in Koyna region annual report, 2018-19). Understanding the seismic activity in the Koyna-Warna region is important because the region has been experiencing continuous earthquakes since 1963. The epicenter map of Koyna-Warna region is shown in figure 4.1

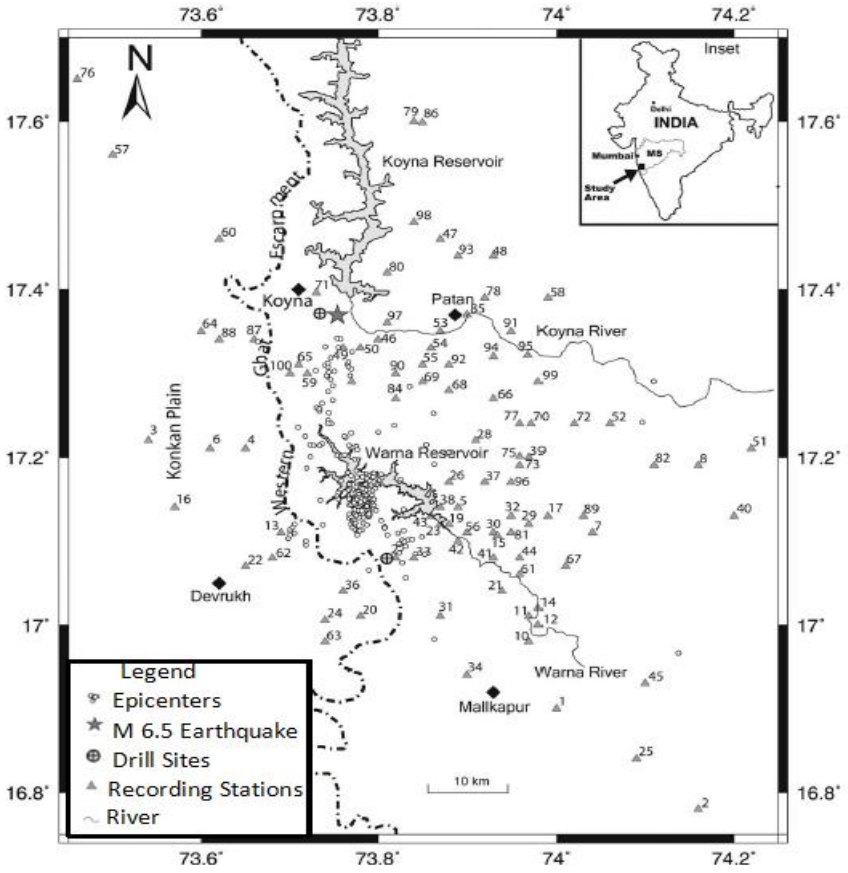


Figure 4.1 Epicenter map of the Koyna-Warna region (Dixit, 2014)

As per the figure 4.1, the triangles show the locations of the seismograph, diamonds show the major geographic features nearby towns, and tomoDD determined epicenters. The inset shows outlines of India and the state of Maharashtra (MS) (Dixit, 2014). There are 30 villages surveyed in Koyna-Warna region for the risk assessment study based on the map of Koyna-Warna region. The type of soil is medium considered for buildings construction in the Koyna-Warna region as per the seismic activity in Koyna region annual report, 2018-19.

4.2.1 History of earthquake records

Table 4.1 shows the detail earthquake record history of Koyna-Warna region. As per the Table 4.1, the total number of earthquake events in the Koyna-Warna region was 121026 till 2020 year. The total number of shocks recorded of magnitude less than three is 119263,

similarly for the magnitude of three and above, four and above & five and above the number of shocks is 1658, 96, & 9 respectively.

Table 4.1 Earthquake record of Koyna-Warna region

Year	Total No. of shocks	No. of shocks recorded as per magnitude			
		< 3	3 and Above	4 and Above	5 and Above
1963	13	9	4	0	0
1964	262	246	16	0	0
1965	169	153	16	0	0
1966	152	137	15	0	0
1967	5049	4800	228	18	3
1968	8558	8396	151	10	1
1969	3314	3252	58	4	0
1970	2507	2472	31	4	0
1971	1833	1773	56	4	0
1972	1705	1659	46	0	0
1973	2182	2151	30	0	1
1974	2773	2719	52	2	0
1975	1522	1476	45	1	0
1976	2245	2206	38	1	0
1977	2631	2606	24	1	0
1978	2612	2587	24	1	0
1979	3255	3230	25	0	0
1980	8071	7933	133	5	0
1981	3477	3434	43	0	0
1982	3310	3289	19	2	0
1983	3250	3211	37	2	0
1984	2233	2219	12	2	0
1985	2387	2356	31	0	0
1986	2540	2529	11	0	0
1987	3751	3739	12	0	0
1988	3507	3491	15	1	0
1989	1995	1984	10	1	0
1990	2130	2119	11	0	0
1991	2195	2179	14	2	0
1992	2774	2764	10	0	0
1993	5050	5005	39	5	1
1994	3820	3771	48	0	1
1995	2084	2053	29	2	0

1996	1394	1364	29	1	0
1997	1607	1588	18	1	0
1998	2336	2312	22	2	0
1999	1974	1954	19	1	0
2000	3870	3800	66	3	1
2001	2158	2146	11	1	0
2002	1286	1284	2	0	0
2003	1286	1275	10	1	0
2004	1353	1345	8	0	0
2005	1201	1168	28	5	0
2006	1261	1239	21	1	0
2007	1269	1253	13	3	0
2008	1120	1111	7	2	0
2009	823	809	11	3	0
2010	826	810	16	0	0
2011	618	610	8	0	0
2012	1140	1136	3	0	1
2013	403	396	6	1	0
2014	402	400	2	0	0
2015	253	250	3	0	0
2016	53	46	6	1	0
2017	353	346	5	2	0
2018	314	308	6	0	0
2019	333	328	5	0	0
2020	37	37	0	0	0
	121026	119263	1658	96	9

4.2.2 General context of field survey

There are 120 reinforced concrete buildings surveyed in the Koyna-Warna region. The buildings are involved in one storey to five storeys. Most of the buildings are in pitched roof shapes due to heavy rainfall condition. In this field study, we have been covered a total 30 villages from three districts, viz., (1) Satara, (2) Sangli , and (3) Ratnagiri around Koyna-Warna region based on the epicenter map. The name of the villages are: Koynanagar colony, Goshtwadi, Rammala, Chafer (Mirgaon), Karate, Helwak, Kadoli, Taloshi, Waghane, Devghar, Gavare, Nav, Gothane, Maneri, Lendhori, Kille-Morgiri, Gunjale, Nehmbe-

chirambe, Humbarli, Kamargaon, Chandoli, Charan, Arala, Shedgewadi, Mandure, Pophali, Taliye, Sangamnagar, Wanjoli, Patan Town. While doing the surveying of each building we have taken the photographs and noted the structural and construction deficiencies. Also, we have conducted the rebound hammer test on different columns to get present material strength and measured the column and beam dimensions to check the current construction practice in an earthquake prone area. The built-up area and plot area of buildings are measured to compute the floor area ratio (FAR), and finally the data collection form (i.e., RVS form) has been filled based on the visual observation of the building. The sample buildings of the Koyna-Warna Region are shown in Figure 4.2.

(a) (b) (c)

(d)

Figure 4.2 Sample RC buildings of Koyna-Warna Region

4.2.3 Site specific response spectrum of Koyna-Warna region

4.2.3.1 Steps for the construction of site specific response spectrum

Step 1: Determine the maximum considered earthquake (MCE) spectral response acceleration at 0.2 s (short period) & 1 s (long period) as:

$$S_{MS} = F_a S_S \tag{4.1}$$

$$S_{M1} = F_V S_1 \tag{4.2}$$

F_a & F_v are site dependent coefficients. S_s and S_1 are the mapped spectral acceleration at short and long periods respectively.

Step-2: Design spectral response acceleration at 0.2 s & 1 s as:

$$S_{DS} = \frac{2}{3} S_{MS} \tag{4.3}$$

$$S_{D1} = \frac{2}{3} S_{M1} \tag{4.4}$$

Step-3: Calculate characteristic time period:

$$T_0 = 0.2 T_S \tag{4.5}$$

$$T_S = S_{D1} / S_{DS} \tag{4.6}$$

Step-4: Construction of design spectra

1) For period less than T_0

$$S_a = 0.6(S_{DS} / T_0)T + 0.4 S_{DS} \tag{4.7}$$

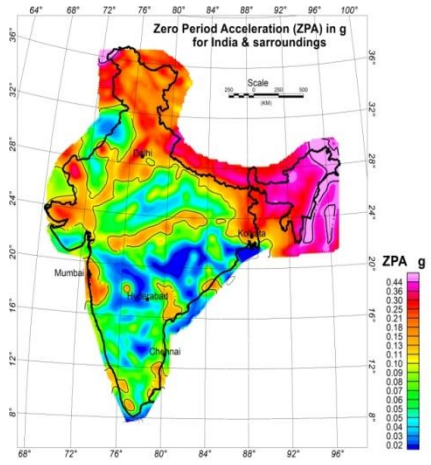
2) For periods greater than or equal to T_0 and less than or equal to T_S

$$S_a = S_{DS} \tag{4.8}$$

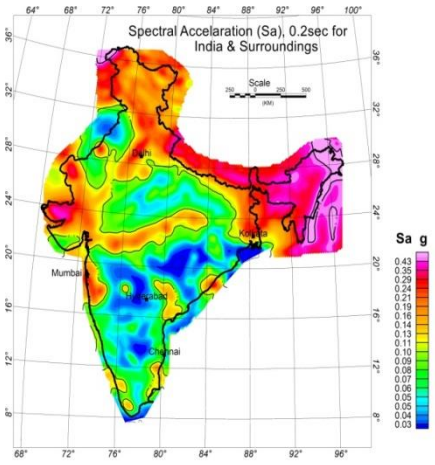
3) For period greater than T_S

$$S_a = S_{D1} / T \tag{4.9}$$

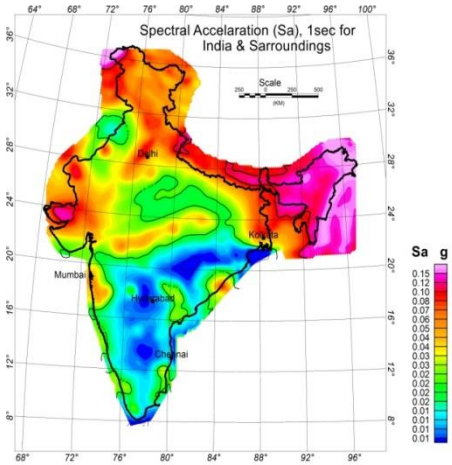
Where, T = Fundamental time period of structure



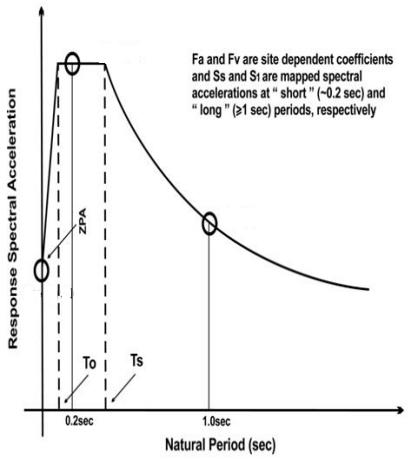
(a)



(b)



(c)



(d)

Figure 4.3 (**a)** Zero period acceleration (ZPA), **(b)** 0.2 sec, and **(c)** 1 sec (Sa) for 2% probability of exceedance in 50 years period, **(d)** Spectral acceleration for maximum considered earthquakes (IBC, 2009; NDMA, 2011) arrows indicate ZPA, and at broken vertical lines T_0 and T_S; Circles indicate in figure to identify the maps of ZPA (Fig.4.3 a), 0.2 sec (Fig.4.3 b) and 1 sec (Fig.4.3 c) (Ramaliigeswara Rao, 2015).

Zero period acceleration (ZPA), 0.2s, & 1s maps as shown in figure 4.3 are prepared by NDMA (2011) and Iyengar (2011) using Geosoft software for India and surrounding regions

for 2 % probability of exceedance in 50 years. Figure 4.4 shows the acceleration response spectrum of Koyna-Warna region for the design basis earthquake (DBE), and maximum considered earthquake (MCE) based on the above described procedure.

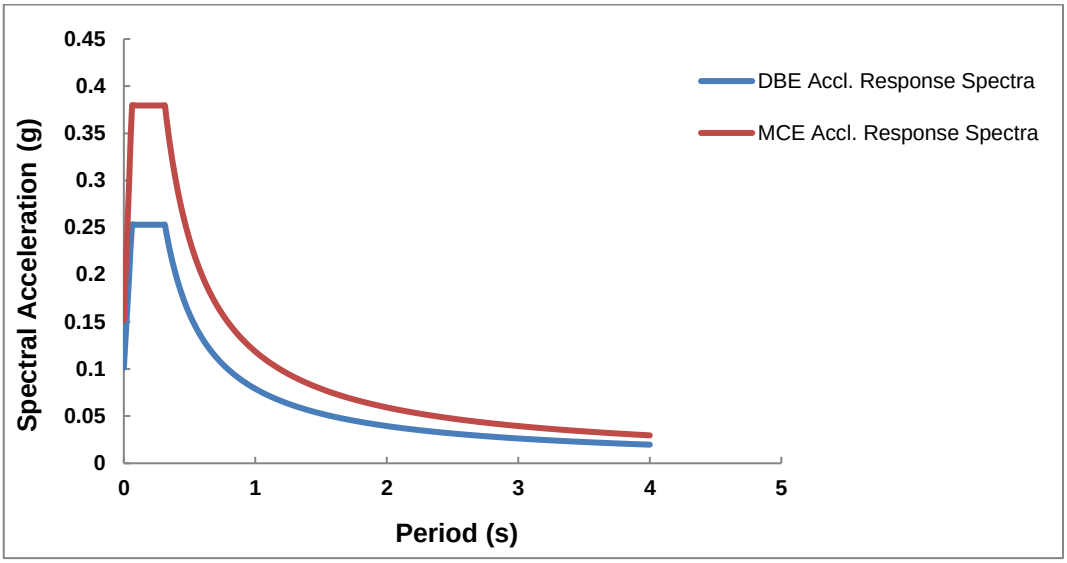


Figure 4.4 Acceleration response spectrum of Koyna-Warna region

4.3 Concluding remarks

This chapter gives the construction procedure for site specific response spectrum of Koyna-Warna region, and generated the response spectrum for design basis earthquake (DBE) and maximum considered earthquake (MCE). Also we have been discussed the earthquake record history and field survey of the Koyna-Warna region.