SEISMIC HAZARD ASSESSMENT OF PALGHAR DISTRICT -A STRUCTURAL PERSPECTIVE

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ABSTRACT

Seismic Hazard Assessment study has been carried out for many parts of India by several authors to study the seismic safety of the existing/proposed engineering structures. Palghar district in the western Maharashtra, recently has been witnessing with an unusual frequency of earthquakes since November, 2018. More than 3000 earthquakes were reported by several agencies with a range of M 1.0 to ~M 4.0 on the Richter scale. The causative mechanism of the seismic activity is a debate among experts in seismology. Scientists have different opinions on the mechanism responsible to the seismic activity in Palghar. A large number of buildings are being hit by these earthquakes in the area. Keeping in view the safety of structures and threat to life in the area, seismic hazard assessment study has been carried out for Palghar district. Probabilistic seismic hazard study has been carried out for 2% and 10% probability of exceedance of MCE and DBE level of ground motion corresponding to 2500 years and 500 years of return period for 50 years of exposure period. Peak Ground Acceleration (PGA), Spectral Amplitude (SA) values at 0.2 Sec and 1sec have been computed at a grid interval of 0.01°× 0.01° within the Palghar district. Seismic hazard maps have been prepared at bed rock level for PGA and SA at 0.2 sec and 1 sec. The study identified vulnerable areas within the Palghar district and simulated the acceleration time history and spectral amplitudes for several important dams for strengthening in the Palghar district.

1. INTRODUCTION

The seismic activity and frequency of earthquakes in last few decades in the Indian sub continent, south of Himalayan region in particular, have raised the necessity of evaluation of seismic hazard in urban areas. Palghar district in western Maharashtra, which lies in seismic zone-III (IS: 1893 2016) witnessing unusual seismic activity since November 2018 and drawing the attention of earth scientists in India. The area is witnessed with a series of earthquakes with magnitude range of 1.0 to ~4.0 as reported by renowned Institutes in India. National Geophysical research Institute (NGRI) has set up six seismological observatories in the Palghar district and recorded 3637 seismic events of micro to moderate nature since January, 2019. National Center of Seismology (NCS) reported that since these earthquakes are restricted to a small region of 4-5 km for long duration, seismic activity in Palghar district have been categorized as 'Earthquake Swarm'. However, some of the earthquakes have occurred at a depth of more than 5km, it is opined by some experts that these earthquakes may have been connected to tectonic activity but not the 'Earthquake Swarm'. Though scientists have different opinions, the major civil and housing structures needs to be strengthened and designed in the Palghar district as per earthquake resistant building codes such as Bureau of Indian Standard (BIS) and also earthquake resistant design parameters estimated by suitable methods. Though BIS codes are readily available for earthquake resistant design structures, it is also essential to estimate the future ground motion of the forthcoming earthquake events to mitigate the seismic risk. In the present study, the Maximum Credible Earthquake (MCE) and Design Basis Earthquake (DBE) level of ground motions are estimated using suitable Ground Motion Prediction Equation (GMPE).

The present study has an advantage of estimation of site specific seismic hazard at very close interval within the Palghar district. The Palghar district area is divided into 4413 grid points with an interval of 0.01° x 0.01° and assumed each corner of the grid as a site. Spectral amplitude values are computed at each grid point and thereby, seismic hazard contour maps are generated for Palghar district at selected periods by considering the bed rock site conditions.

2. SEISMOTECTONIC SETTING AND GEOLOGY

The major seismo-tectonic features in the region of Palghar district and its adjacent areas within 300 km radius from the Palghar district are shown in Figure1 which is based on the Seisat no: 18, 19, 20, 27, 28, 32 and 33 of Seismotectonic atlas of India by Geological Survey of India (GSI, 2000). The studied region includes features like faults, lineaments, folds, rifts. In the area covered by Deccan Traps, major faults and lineaments trend NW-SE, a trend that corresponds to the tectonic grains of the adjacent Precambrian basement rocks. Some of the faults and lineaments traversing the trap rocks are found to continue in the peripheral older rocks. Towards the North of the project site, faults trend E-W parallel to the Satpura trend. Juxtaposition of the two major structural trends of the Indian shield is believed to represent two separate blocks with different evolutionary history.

The major geofractures near the project sites are the West-Coast Fault (WCF), Neo Tectonic Fault (Ghod), Upper Godavari Faults (UGF), Panvel flexure and some other faults with basement and cover. The abrupt changes in the base level of Deccan Traps as well as its thickness indicate the presence of these transverse faults. The West-Coast Fault is postulated to be related to the breaking away of the Indian plate from the Gondwanaland, which could be continuous with the Eastern Marginal Fault of the Cambay Graben. The Cambay Basin is considered to have move westward due to right lateral movement along the Son Narmada Fault. The Chiplun and Warna Faults may be the secondary manifestation of the West Coast Fault. The linear disposition of the West Coast and the Western Ghat scarp is considered to be the geomorphic signature of this fault zone. Along this zone, abrupt termination as well as faulting of Deccan Trap flows is observed. Another important tectonic feature in the west coast zone is the Panvel Flexure, which is a monoclonal structure with its western limb dipping towards west. The axial trace of this flexure trends in NNW direction parallel to the West Coast Fault.

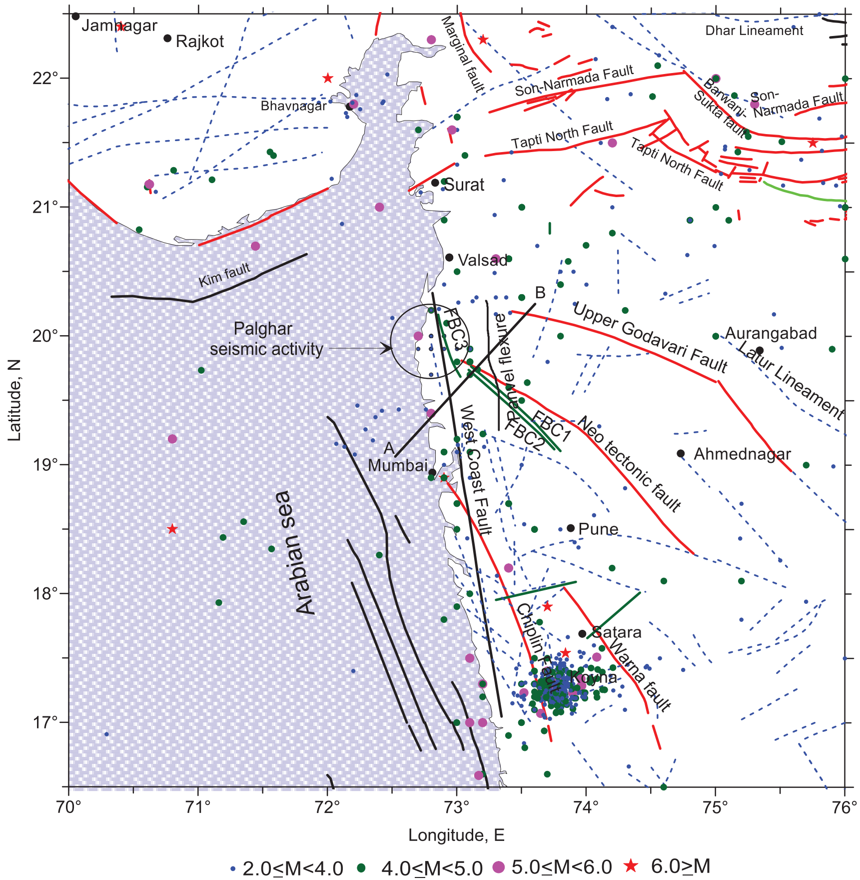

Figure 1 : Seismotectonic map of Palghar district and its surrounding area (modified after GSI, 2000) with past seismic events of different magnitudes during Nov, 2018- April 2019 (IMD catalogue).

The study area is part of peninsular India which also covers parts of Western Ghats. The rock spread across the study region is Basaltic rocks. The formations of basaltic rocks are due to the constant volcanic eruptions in age from Middle Proterozoic to Late Cretaceous and Early Tertiary. These volcanic eruptions resulted from fissures and cracks in the surface of earth from which lava erupted from time to time which resulted in thick sheet of basalt that covered much of previously existing topography of the region. The youngest of these is the Deccan Flood Basalt of Cretaceous to Eocene age. Most part of the selected region is covered by Deccan Traps, which almost entirely constitute the exposed rock unit of the terrain. It is generally accepted that the Western coast has been formed as a result of the faulting. Along this coast from Ratnagiri to Mumbai and further North in Thane district there exists a series of hot springs arranged almost in linear fashion which suggests that they are situated on a line of fracture. Further evidence regarding the formation of west coast by faulting is offered by the Western Ghats comprising Deccan trap lava flows, which are several hundred meters thick near the coast and which gradually thins out East wards. Near Panvel, the West Coast has the Deccan traps which show westerly slopes indicating designated as Panvel flexure.

A special feature of the tectonics of the west-coast region is the presence of a number of thermal hot springs, sparsely aligned with the major faults. The heat flow distribution over the western India region suggests elevated geo isotherms in the region of west coast thermal anomaly zone. A large number of thermal springs, with maximum temperature up to 70° C are found in the Konkan area of the west coast. All tectonic trends in the region and the line of hot springs oriented north-south, indicate crustal movements and up warping in the region. This suggests that nearly vertical faults have deeper connections to provide passage for upwelling of heat.

3. ANALYSIS FOR ESTIMATION OF GROUND MOTION PARAMETERS

3.1 Preparation of earthquake catalogue

A distance of 300 km on all sides of the Palghar district i.e., a rectangle consisting dimensions of 6° × 6° have been drawn around the Palghar district. Therefore, the region from 16.5°N – 22.5°N and 70°E – 76°E has been considered for the present seismic hazard assessment study. The first step of hazard assessment is to prepare an earthquake catalogue. Earthquake database which contains details of each earthquake event, such as time of occurrence in terms of year, month, day, hour and minute; location of occurrence in terms of longitude, latitude and depth; magnitude of earthquake in terms of M_L, M_s, M_b and M_w is known as Earthquake Catalogue. The earthquake catalogue for the present analysis has been prepared from the data available from ISC, USGS and IMD. The database has been updated up to 2019. The catalogue prepared for the present study contains a total of 618 earthquakes after the removal of dependent events (declustering).

3.2 Homogenization of earthquake catalogue

The updated earthquake catalogue contains magnitude in different scales, i.e., local magnitude M_L, surface wave magnitude M_s, body wave magnitude , M_b and moment magnitude , M_w for the events. Conversion of different magnitude scales into one type of magnitude (moment magnitude for hazard analysis) using suitable conversion relations is required to be carried out for Seismic Hazard Analysis because most of the attenuation relations are developed in terms of moment magnitude to avoid saturation effects. The process of conversion is termed as homogenization. The homogenization has been done using global empirical relations (Scordilis (2006), Sipkin (2003), Idriss (1985), Filiz et. al. (2016)). The Magnitude ranges from M_w 2.0 – M_w 6.5 for the present study.

3.3 Declustering of earthquake catalogue

The seismic events in the catalogue contain main shocks and triggered events (foreshocks and aftershocks). Main shocks are statistically independent and follow Poisson distribution. Triggered events are dependent on main shocks and tend to cluster in space and time. Seismic hazard analysis is generally based on the assumptions of Poissonian distribution of earthquakes. Therefore, it is necessary to identify and remove the foreshocks and aftershocks from the catalogue. The process is known as declustering. The Gardner and Knopoff (1974) window method gives a simple way out for identification of aftershocks and is widely used in practical seismic hazard analysis study. This approach states that aftershocks are dependent (a non-Poissonian process) on the size of the main shock and the dependent events need to be removed in accordance with defined distance and time windows. The time window T(M) in days and distance window L(M) in km after Gardner and Knopoff (1974) are as follows:

$$L(M) = 10^{0.3238\mathrm{M}+0.983}$$

$$\mathrm{T(M)} = \begin{cases} 10^{0.032\mathrm{M}+2.7389} \ ; \ \mathrm{M} \geq 6.5 \\ 10^{0.5409\mathrm{M}-0.547} \ ; \ \mathrm{M} < 6.5 \end{cases} \quad (1)$$

For any earthquake of magnitude M in the catalogue, the subsequent shocks are identified as aftershock if they occur within the time window T(M) and distance window L(M). It is more practical to put an upper limit on the magnitude of the aftershocks, say at least one magnitude units below the magnitude of the main shock (Bath, 1965). The method can also be applied to identify the foreshocks, if the time of occurrence is before the time of the shock under consideration and it has not been identified as aftershock of an earlier main shock. No upper limit is required to be put on the magnitude of the foreshock, except that it should be lower than that of the main shock. The declustered earthquake catalogue contains a total of 618 main shocks in Mw unit.

3.4 Catalogue Completeness

It is recognized that earthquake data in the catalogue are generally incomplete for smaller magnitude earthquakes in the olden times due to inadequate instrumentation. However, due to short return periods of smaller magnitude, their occurrence rates can be evaluated even from the most recent data for about 15-20 years. But, to get a reliable estimate for the occurrence rates of larger magnitude earthquakes with long return periods, the data for a much longer period should be considered. Failure to correct for the data incompleteness may lead to underestimation of the mean rates of occurrence of earthquakes. The correction can be made by identifying the time period of complete data for prescribed earthquake magnitude ranges. Reliable mean rates of occurrence of earthquake for the given magnitude ranges can then be computed from the complete data. Stepp (1973) proposed a statistical method to calculate the period of completeness and this method has been followed in the present study to determine the period of completeness. The data completeness and annual recurrence rate of earthquakes using Gutenberg-Richter (G-R) recurrence relation (Gutenberg and Richter,1944) are estimated for each zone.

4. IDENTIFICATION OF EARTHQUAKE SOURCE ZONES

A seismic source zone (SSZ) is defined as an individual fault, or an area of diffused seismicity with distinctly different seismogenic potential in terms of the maximum magnitude as well as the occurrence rate of earthquakes in different magnitude ranges. Considering the spatial distribution and correlation of seismic activity with the tectonic features in the region of Palghar district, four broad seismic sources have been identified.

All the above sources are shown in Figure 2 along with the epicenters of the available data on past earthquakes. The west coast fault off the west coast of India is a prominent seismotectonic feature associated with significant seismic activity, defined as a seismic source-I. The ongoing earthquake activity for more than five decades in the Koyna-Warna region is unique and significant with large number of seismic events, has been defined as Seismic source zone-II. The seismicity associated with two major Neo tectonic faults (Upper Godavari and Ghod fault) has been defined as Seismic source zone-III. A part of SONATA rift zone associated with significant seismicity activity is defined as a Seismic source zone -IV. These four sources have been taken into account in estimating the ground motion by the probabilistic approach. The epicenters due to seismic activities in the Arabian Sea and the epicenters of small magnitude earthquakes are seen to be dispersed widely in the remaining area out of these source zones, hence not considered.

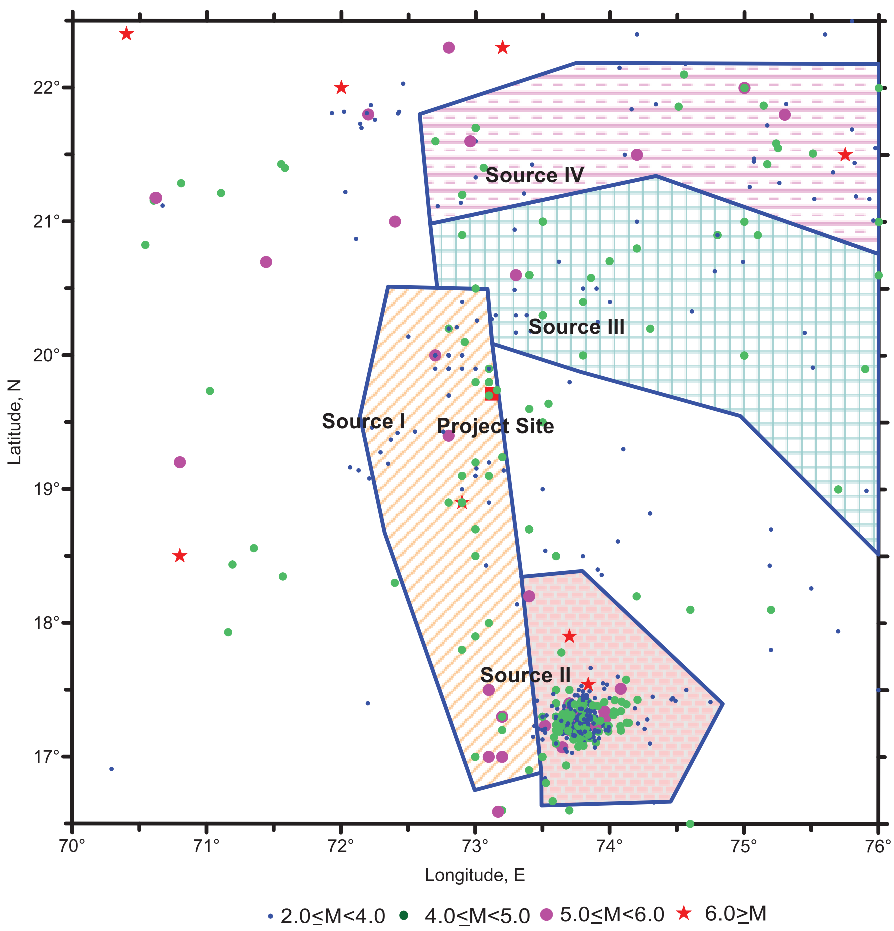

Figure 2 : Seismic source zones of Palghar district and its adjacent regions along with the epicenters of available data on past earthquakes.

5. PROBABILISTIC SEISMIC HAZARD ANALYSIS

The probabilistic seismic hazard analysis (PSHA) approach is used to get a reliable estimation of the seismic hazard by considering the effects of total expected seismicity with suitable spatial distribution of the site of interest. The PSHA approach provides the 5% damped target response spectra for a given area with a specified confidence level. This will not be exceeded due to any of the earthquakes expected to occur anywhere in the region during a specified exposure time.

The Maximum Credible Earthquake (MCE) level of ground motion is commonly specified with a 2% of exceedence during 50 years of exposure time for 2475 (~2500) years of return period (FEMA, 2004). The composite probability distribution of the spectral amplitude at a given natural period is expressed in the PSHA approach as given below.

$$P[SA(T)] = \exp\left\{-Y \sum_{i,j} q[SA(T)|M_j, R_i].\upsilon(M_j, R_i)\right\} \tag{2}$$

In the above equation, Y is the exposure period considered and υ(Mj, Ri)is the annual occurrence rate of earthquakes within a small magnitude range ($M_j - \delta M_j, M_j + \delta M_j$) and a small distance range ($R_i - \delta R_i, R_i + \delta R_i$) from the site of interest. Quantity q[SA(T)|M_j, Ri] represents the probability of exceeding the spectral amplitude SA(T) due to an earthquake of magnitude M_j at distance R_i. In the present study, the 5% damped probabilistic response spectra are obtained for both MCE and DBE levels of ground motion. This is estimated by the spectral amplitudes at all the natural periods with 96% and 81% probability of not exceeding in the exposure period of 100 years. The MCE and DBE levels of ground motion are estimated for the Jabalpur area using a suitable Ground Motion Prediction Equation (GMPEs).

6. GROUND MOTION PREDICTION EQUATIONS (GMPES)

There are several ground motion prediction equations developed by many authors (Ambrahamson and Silva, 2008; Boore and Atkinson, 2008; Campbell and Bozognia, 2008; Chiou and Youngs, 2008a; Idriss, 2008) as a part of Next Generation Attenuation (NGA) of ground motions for seismically active tectonic regions worldwide. In addition, there are several attenuation relations developed for Himalayan region by many authors (Anbazhagan et al, 2015). However, no attenuation model is developed for intra-plate regions based on recorded instrumental data as the strong motion data available for the region are sparse. Since Palghar area lies in intra-plate region and selecting the suitable ground motion prediction equation is difficult. In light of this problem, the attenuation models for seismically active regions based on only instrumental recordings are adopted to find out the suitable relation for the present study area.

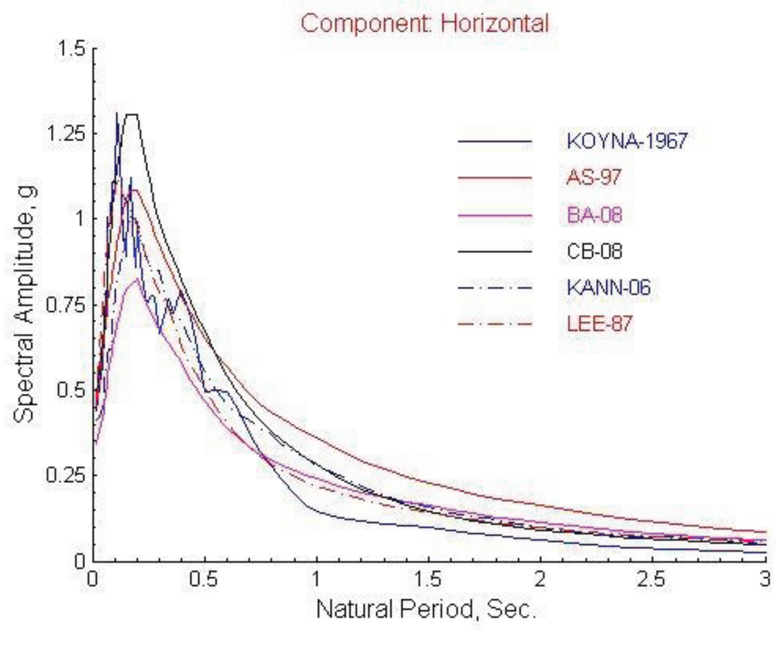

Figure 3 : Comparison of mean Response spectra of two horizontal components of the accelerograms recorded from Koyna earthquake of 10 Dec, 1967 with those predicted by five selected empirical attenuation relations at bedrock level.

Few attenuation relations are tested with recorded acceleration data of Koyna earthquake of 1967 with M6.3. However, response spectra due to three attenuation relations are found to be close to the response spectra of Koyna earthquake of 1967. Hence, three different GMPEs (Abrahamson and Silva, 1997 (AS97); Lee, 1987 (LEE87) and Campbell & Bozorgnia, 2008 (CB08) with weightage of 30%, 30% and 40% respectively are used to estimate the future ground motion for the study region.

In this study, the seismically active West Coast Fault (WCF) passing approximately in N-S direction and intersecting the western part of Palghar district. Since Palghar district is covered by only basalts as per seismotectonic atlas map of India published by Geological Survey of India (GSI, 2000), ground motion parameters area estimated only for rock site condition. Spectral amplitudes are calculated at 28 natural periods from 0.02 sec to 5 sec.

7. RESULTS AND DISCUSSION

The Palghar district is divided into smaller grid interval of 0.01° x 0.01° (approximately 1 km x 1km) and Seismic hazard contour maps have been prepared by performing the seismic hazard computations at 4413 grid points. The 5% damped spectral amplitudes are estimated at each corner of the grid for both MCE and DBE level of the ground motions. The Zero Period Acceleration (ZPA) of spectral amplitudes at each corner of the grid are assumed to be Peak ground acceleration values with 2% (MCE) and 10% (DBE) probability of excedance in 50 years exposure period and plotted in contours (Fig. 4).

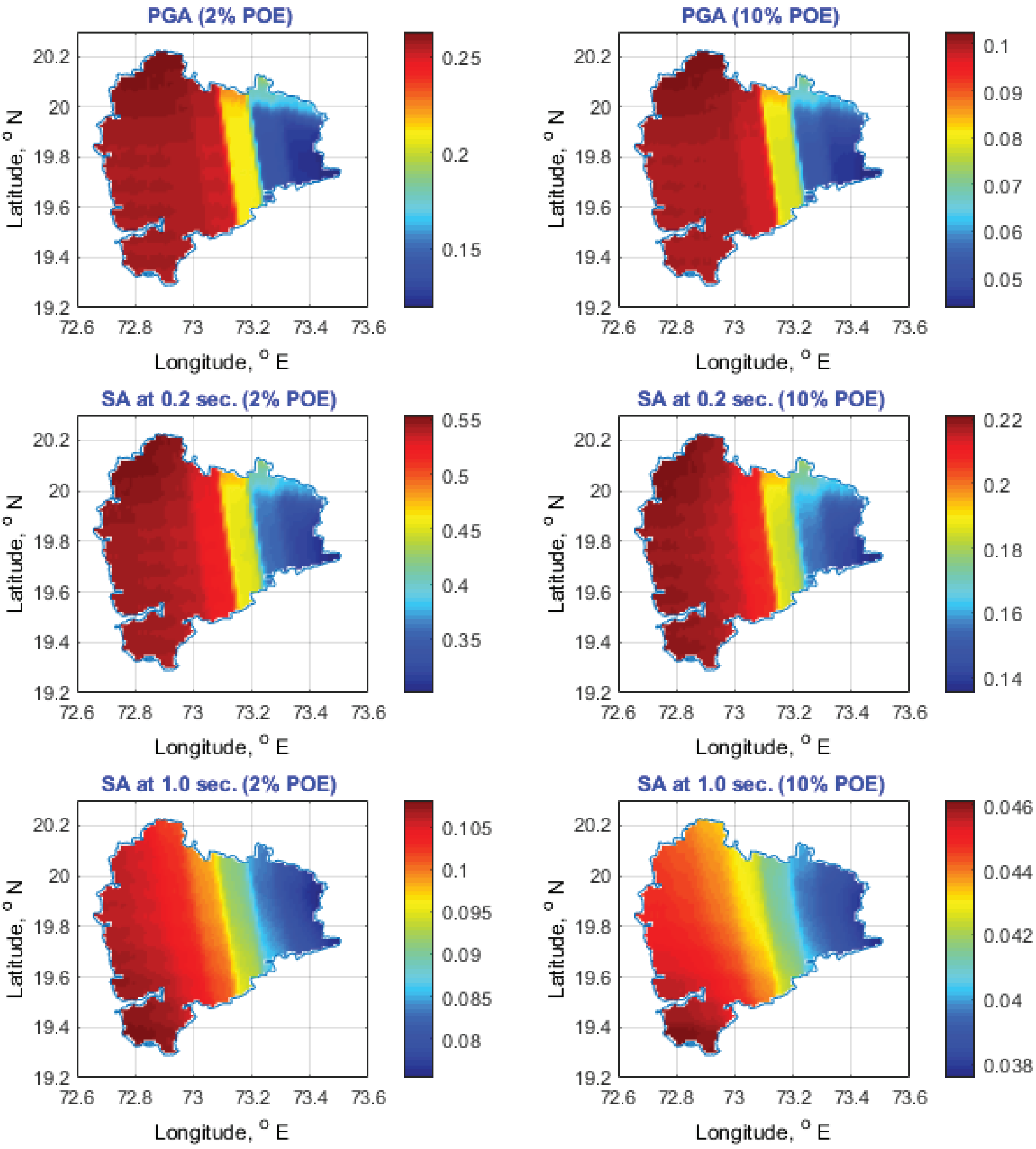

Figure 4 : Peak Ground Acceleration (PGA) contours for 2500 years (top left) and 500 years (top right) of return periods with an exposure period of 50 years. (b) Short period Spectral Acceleration (SA) values at 0.2 sec for return period of 2500 (middle left) and 500 (middle left) years with 5% damping for bed rock site conditions. (c) Long period Spectral Acceleration (SA) values at 1sec for return period of 2500 (bottom left) and 500 (bottom right) years with 5% damping for bed rock site conditions.

The PGA values are varying from 0.15g to 0.26g for MCE condition and 0.05g to 0.1g for DBE condition. In addition, Spectral amplitudes at selected natural periods of 0.2 sec and 1 sec are computed for the design response spectrum and presented in contours as shown in Figure 4. The spectral amplitude values at 0.2 sec are varying between 0.35g to 0.55g for MCE condition, whereas it is varying from 0.14g to 0.22g for DBE level of ground motion. The spectral amplitude values at 1sec for MCE condition are varying from 0.08g to 0.10g and for DBE condition; it is 0.03g to 0.04g. These maps are prepared for the return period of 2500 years and 500 years with an exposure period of 50 years. PSHA study carried out by National Disaster Management Authority (NDMA), Govt. of India (2010) and reported the Peak Ground Acceleration (PGA) value of 0.19g at bedrock level with 2500 years return period for Mumbai city, which is located to the south of Palghar district. However, the maximum value obtained for Palghar district is 0.26g for MCE condition. This value may be due to the active West Coast Fault (WCF) and also due to unusual seismic activity in the Palghar district.

8. CONCLUSION

Estimation of the site specific seismic design parameters is important for major civil engineering structures as it depends on several parameters such as local geology, distance from source to site and also thickness of the overburden and shear wave velocity of the underlying structures etc. Probabilistic seismic hazard analysis is carried out for the Palghar district to quantify the ground motion and thereby to estimate seismic hazard for the forthcoming earthquakes. An earthquake catalogue starting from 1846 to 2019 is compiled from several resources within a radius of 300km from the Palghar district. Data completeness is calculated and annual recurrence rate is estimated for available data set. Three ground motion prediction equations are found suitable for the study region i.e. AS97; LEE87 and CB08 is after comparing the predicted response spectra by five attenuation relations with the response spectra of recorded accelerogram of Koyna earthquake (10 Dec, 1967). Seismic hazard contour maps in terms of PGA and spectral amplitudes have been generated for 2475 (~2500) and 475 (~500) years of return periods, which is equal to 98% and 90% probability of not exceeding in 50 years. As per International building code IBC-2009, spectral acceleration values are also computed at 0.2 sec and 1sec for developing the design response spectrum for any major sensitive structures/buildings in Palghar district. It is observed that the seismic hazard in terms of PGA is varying from 0.15g o 0.26g for MCE and 0.05 to 0.1 for DBE levels of ground motion within the Palghar district.

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