

Geotechnical, Geological and Geophysical Investigations for Seismic Microzonation and Site-Specific Earthquake Hazard Analysis in Gujarat



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1 Introduction

Rapid development in India having moderate to great earthquakes warrants assessment of seismic hazard at the micro level. Most of Gujarat state in western India is prone to earthquakes of magnitude 5–8. It has experienced great earthquakes in the historical past, the last being the Bhuj earthquake (Mw 7.6, MMI + X) on 26 January 2001 which was the most destructive intraplate earthquake, causing catastrophic damage and killing about 14,000 people and injuring many more. The role of site effect was strongly realized due to this earthquake that caused damage to all types of buildings in the near distance and tall buildings up to 250 km in many cities. Dozens of multi-storeyed buildings collapsed in Ahmedabad at a distance of 225 km.

Several earthquakes like Mexico (1985) have shown that local site conditions have a significant role in the amplification of ground motion, especially on those areas that are located on unconsolidated young sedimentary materials. The softness of surface layer not only tends to amplify ground motion at certain frequencies but also extends the duration, which may cause further damage during earthquakes. The fundamental phenomenon responsible for the amplification of motion over soft sediments is trapping of seismic waves due to the impedance contrast between sedimentary deposits and the underlying bedrock.

It is also a well-known fact that the site amplification/shaking is stronger in low-shear-wave velocity areas. Mapping the seismic hazard at local scales to incorporate the effects of local ground conditions is the essence of seismic microzonation. Shallow shear-wave velocity structure to a depth of 30 m is a key parameter to

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evaluate the near-surface stiffness and for characterizing the given site. The classification of sites based on V_{s30} is given by the US-NEHRP (National Earthquake Hazard Reduction Program).

Natural frequency of each soil layer depends on the physical properties of soil and the depth to bedrock. The main aim of the site response study is to evaluate the amplification of ground motion and the determination of natural resonance frequency of the soil. Several Geotechnical, Geological and Geophysical investigations done for seismic microzonation and site-specific earthquake hazard analysis in Gujarat are outlined. Estimating depth of Engineering Bed Layer (EBL) and preparation of seismicity map are described. The required soil properties for site characterization are obtained from either geotechnical tests or geophysical tests. Assigning fault line and its maximum magnitude, estimation of strong motion time history at the EBL, amplification factor and strong ground motion at the surface are explained.

In the microzonation studies in Gujarat by the Institute of Seismological Research (Rastogi et al., 2007), the MASW test and PS-logging surveys have been carried out to estimate the shear-wave velocities. Shear-wave velocity profiles have been used to estimate the depth of EBL. Site amplification has been computed using the earthquake records besides using geotechnical data. We have used Broadband Seismographs (BBS) for recording earthquakes as well as microtremors at a sampling rate of 100 samples/s. Microtremors were recorded for 4 h at each site. ISR has done seismic microzonation and site-specific studies in the following areas of Gujarat.

Microzonation of various cities like Gandhinagar, Gift city (Mohan et al., 2018), Ahmedabad, Gandhidham–Kandla, Bhuj, Bharuch and Surat. Figure 1 shows some of these sites. Microzonation in Areas of Special Development: Ports of

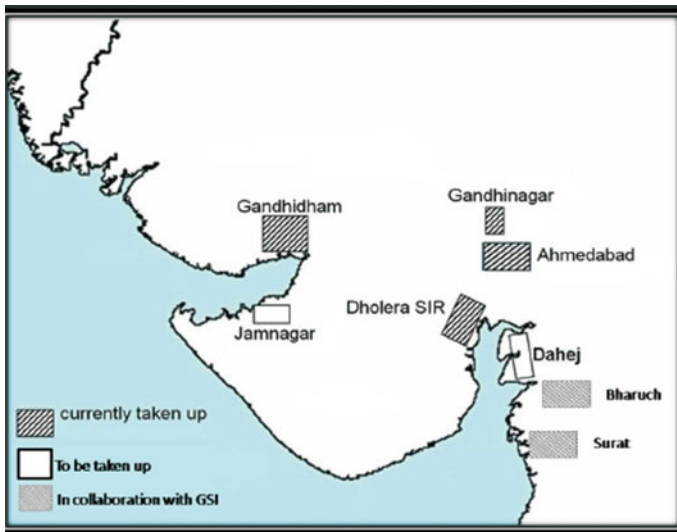


Fig. 1 Major sites of microzonation in Gujarat

Gujarat, Dholera Special Investment Region, Exhibition ground of Gandhinagar, and proposed sites of Devni Mori (Budha Statue in Shamlaji town in Sabarkantha District Nr. Mesow dam) and Sant Nagari (Nr. Dharoi dam).

Seismic Hazard Assessment of Specific Sites: Nuclear Power Plants of Kakrapar and Jaitapur, LNG Terminals of Mundra and Dahej, Statue of Unity, Multistorey VS Hospital, the Capital-Multistorey Commercial Complex, E-City (ISCON Circle, Ahmedabad).

2 Geological Investigations

Local geological conditions are assessed which affect ground motion at a given site. When subjected to the earthquake ground motions the response of different soil types differ. Usually, the younger softer soil amplifies ground motion relative to older, more compact soils or bedrock. Local amplification of the ground is often controlled by the soft surface layer, which leads to the trapping of the seismic energy, due to the impedance contrast between the soft surface soils and the underlying bedrock. Geological investigation involves the following steps to be followed:

- Determining the bedrock geology, including major structural features such as faults, surface geology in terms of soil types on a regional or if possible, local basis.
- Determining the climate conditions, which influence soil development, ground-water fluctuations, erosion, flooding, slope failures, etc.
- Determining associated geological hazards such as ground subsidence and collapse and slope failures.

2.1 *Site Characterization Based on Geomorphological Mapping*

Geomorphology map is prepared by 3D Digital mapping and ground check. Both site characteristics and geomorphology (e.g. valley, basin, ridge effects, etc.) play an important role in the observed response of surface ground motions. The selection of ground response analysis (e.g. 1D, 2D or 3D ground response analysis), depends upon mainly the topography (geomorphology) of the site.

2.2 Terrain Analysis

It is the most important part of the site investigation. Landforms and other surface characteristics are strong indices of geologic conditions and help to choose an appropriate ground response model. Characteristic terrain features reveal several useful information such as rock type, structural forms (where rock is shallow or deep) and weathering conditions, erosion, or representation of typical soil formations in terms of their origin, mode of deposition and thickness of the deposits. Engineering geology maps can be prepared from the terrain analysis that provides information about the geologic conditions over an entire study area.

3 Geotechnical Investigations

Geotechnical investigations are done for a variety of reasons like whether the soil strength can safely support a structure or which soil/rock layer is strong enough or whether soil is liquefiable or is there any other geologic hazard. Geotechnical investigations are performed by drilling and in situ tests. Small-diameter borings are used to allow retrieval of samples and to perform in-place soil tests. Soil samples are categorized as being either 'disturbed' or 'undisturbed'. A disturbed sample is one in which the structure of the soil has been changed sufficiently that tests of structural properties of the soil will not be representative of in situ conditions, and only properties of the soil grains (e.g. grain size distribution, Atterberg's limits and possibly the water content) can be accurately determined. An undisturbed sample is one where the condition of the soil in the sample is close enough to the conditions of the soil in situ to allow tests of structural properties.

Field investigations include drilling of boreholes, Standard Penetration Tests (SPTs), trial pits and load tests. Lab tests include grain size analysis (sieve and hydrometer), Atterberg's limit, specific gravity, density and water content, triaxial compression test, direct shear test and consolidation test. Geophysical surveys such as seismic surveys, electrical resistivity surveys, Ground Penetrating Radar (GPR) surveys and other geophysical methods for layer thickness and shear-wave velocity. Liquefaction susceptibility test is also done (Dwivedi et al., 2019).

4 The 2D and 3D Soil Modelling: Lithological Set-Up

2D and 3D soil profiles are prepared for all the study areas. Figure 2 shows soil profiles for Ahmedabad area constructed with 16 boreholes to 80 m depth and 208 boreholes to 30 m depth. There is more sand in the northern part, while clay and silt are in other parts.

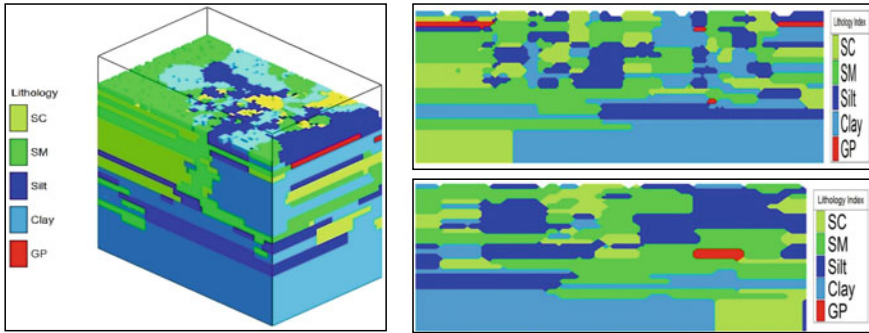


Fig. 2 The 3D (left), 2D N-S (upper right) and 2D E-W (lower right) soil profiles for all the boreholes up to 50 m depth in Ahmedabad. Sand (silty and clayey) shown by green colour is more, while clay and silt in blue colour are in small patches until 30 m depth

5 Estimation of Shear-Wave Velocity and Engineering Bed Layer

The shear-wave velocity, V_s with depth is estimated by various methods like PS-logging, shallow seismic (MASW) and microtremor surveys and contours are drawn for the areas of seismic microzonation. The N-values from standard penetration test are correlated with V_s in order to uniformly distribute the soil properties in grid pattern throughout the area of investigation. EBL is decided on the basis that this layer with $V_s > 500$ m/s and the same type of soil/rock exists throughout the area at known depths. These methodologies are described in the subsections below.

5.1 PS-Logging

Suspension PS-logging (Fig. 3) is used for the estimation of accurate vertical 1D V_p and V_s profile to a depth of 70 m or so. Suspension PS-logger is 8 m long and contains a weight, source driver, source (trigger), filter tube, lower and upper geophones connected by cables to a logger/recorder. The interval between upper and lower receivers is usually 1 m and distance from PS source to lower receiver is 4 m.

For measurement, the borehole is filled with water and the data is acquired by giving a trigger command in the acquisition software. Three to nine stacks of triggers are used as an energy source. The source generates a pressure wave in the borehole fluid. The pressure wave is converted to P and S waves and received by the geophones, which send the data to the recorder on the surface. Samples of P and S waves at one of the sites are shown in Fig. 3. Data is processed using the Glog-SUS processing software of OYO Inc, Japan. The elapsed time between arrivals of the waves at the

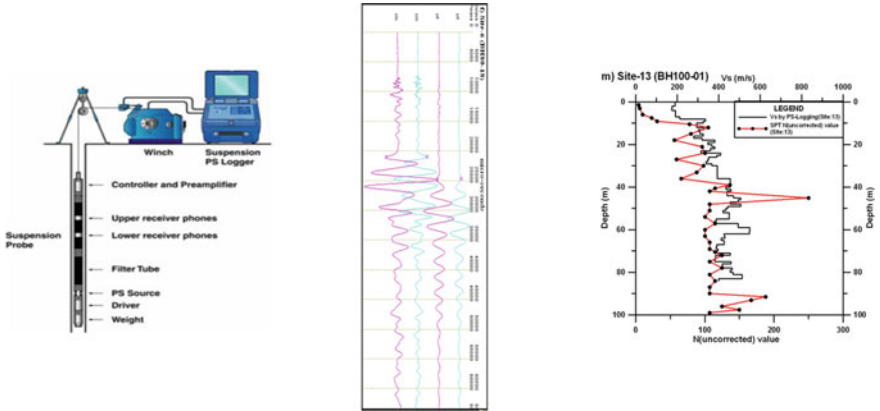


Fig. 3 From left to right, PS-logger set-up, a sample of waveforms as detected by PS-logger and a sample of Vs profile by PS-logging and SPT N-values for comparison

receivers is used to determine the average velocity of a 1-m-high column of soil around the borehole. Processing of the data involves the accurate picking of P-wave and S-wave phases.

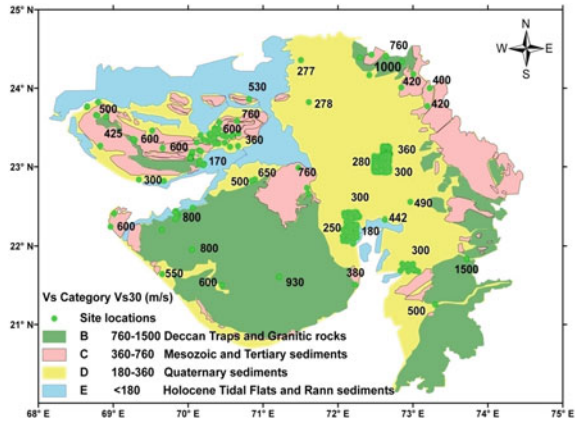
5.2 *Shallow Seismic Survey and Multichannel Analysis of Surface Waves (MASW)*

Multichannel Analysis of Surface Waves (MASW) is a non-invasive method developed to estimate shear-wave velocity profile from surface wave energy. Measurements of phase velocity of Rayleigh waves of different frequencies can be used to determine a velocity–depth profile.

5.3 *Shear-Wave Velocity Profiles Throughout Gujarat*

We have carried out MASW test (using Engineering Seismograph) and PS-logging surveys to measure shear-wave velocity profiles at over 1000 locations throughout Gujarat covering all geological units (Fig. 4). Thus, we have characterized the whole Gujarat based on Vs30 (average shear-wave velocity to a depth 30 m). This has helped generate site characterizing map and seismic hazard map of Gujarat at surface. S-wave velocity profiles were measured and PS-logging was done in Bhuj, Gandhinagar, Gift city, Anjar, Dholera, Ahmedabad, Mundra, Bharuch, coastal areas, industrial sites and sites of Strong Motion Accelerograph (SMA), BBS, etc. (Sairam et al., 2011, 2018, 2019) (Fig. 5).

Fig. 4 Vs30 map of Gujarat using Shallow seismic survey at 301 sites by MASW method and PS-logging



5.4 MASW Test to Identify Faults

We have used MASW and Refraction surveys for delineating the fault. We are able to identify shallow (30 m) faults as well as deeper (~100 m) faults. For shallow fault identification, we keep 5 m geophone interval, while 10 m geophone interval for deeper faults. MASW results at the Kodki fault near Bhuj are shown in Fig. 6a. Three MASW N–S Vs profiles of 25–75 m length were taken across the South Wagad Fault (the causative fault for the 2001 earthquake) to decipher the subsurface nature of the fault. The profile closest to the 2001 mainshock epicentre shows presence of fault.

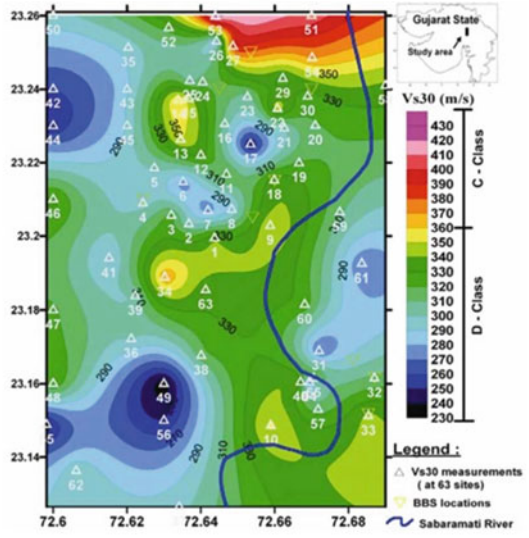
5.5 Determination of Relation Between Vs30 and SPT N Values

We have prepared a relationship between Vs30 and SPT N values for different areas. These are useful in assigning reasonable N-value in case measurement is missed or the value is an outlier.

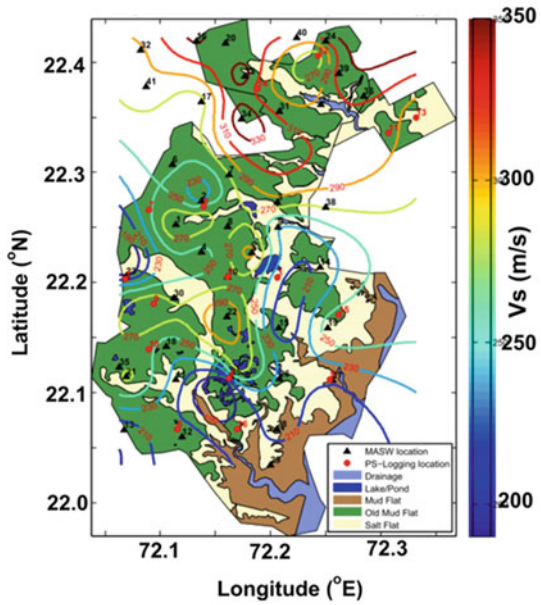
5.6 MASW Test at Anjar to Detect Possible Site Amplification Effects During Past Earthquakes

MASW tests have been carried out in Anjar area to study the possible side effects causing the damage during the past earthquake events (Rastogi et al., 2011) (Fig. 6b). MASW tests have been carried out at a) undamaged site, b) less-damaged site and c) severely damaged site, which show a remarkable difference in soil structure. The

Fig. 5 **a** Contour map of Vs30 in the Gandhinagar area. **b** Contour map of Vs30 in Dholera area. **c** Contour map of Vs30 in GIFT city area. **d** Sites of MASW tests carried out at SMA, SRR and Industrial locations in Gujarat

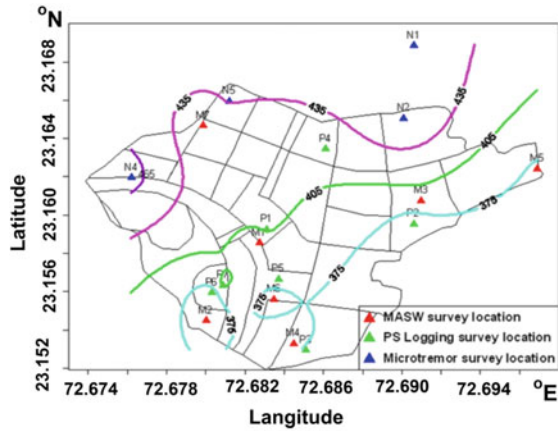


(a)

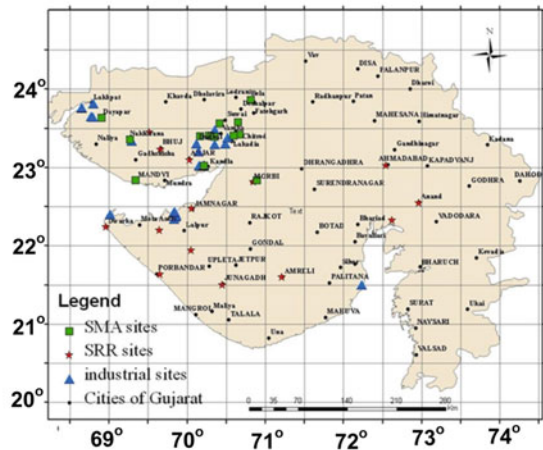


(b)

Fig. 5 (continued)



(c)



(d)

layers with high $V_s > 500$ m/s are at 4 m depth at undamaged sites but such high-velocity layers are at 15 m depth at the less-damaged site. Also at the severely damaged sites, the V_s is much lower, only 200–300 m/s to 20 m depth. Thus, the softer soil deposit is confirmed at severely damaged sites from shear-wave velocity profiles. From these results, it is inferred that possibly amplification is caused due to local geology resulting in damage at severely damaged area of Anjar. Traces of a filled-up pond were found in the severely damaged sites by MASW test.

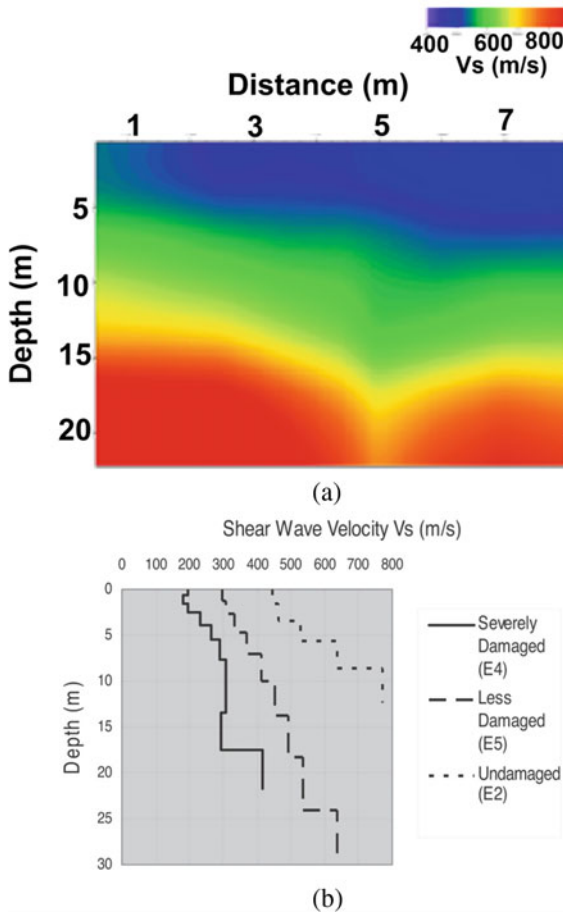


Fig. 6 **a** Delineating fault by MASW test at Kodki village near Bhuj city. **b** V_s versus Depth profiles in Anjar city

5.7 Refraction Survey at Mundra

In addition to MASW surveys, refraction surveys can also be conducted with engineering seismograph to identify the faults. Refraction surveys were conducted at Mundra for a kilometre-long profile (Table 1) with the objective of the study (i) to see whether hypothetical fault is there or not and (ii) to know the velocity and depth of shallow layers for tying up with 2D reflection survey. Results are correlating well with local geology.

Table 1 Velocity model of Mundra area by combined interpretation of Refraction and Reflection data

Depth of the layer, m	Vs, km/s
0–5	0.6
5–12	1.7
12–90	2.3
>90	2.5

6 Application of Microtremor Investigation for Subsurface Modelling

The term microtremor includes all ground vibrations, not due to events of short duration, such as earthquakes or explosions. Microtremor studies were originated in Japan and have gained broad recognition in the study of site effect on earthquake ground motion.

Several researchers have applied the Nakamura method (Nakamura, 1989) of microtremor H/V spectrum for site investigation and measuring the thickness of the topsoil cover over the bedrock in India and abroad (Al & Luzon, 2000; Bour et al., 1989; Hunter et al., 2002; Rodriguez & Midorikawa, 2003). The H/V spectral ratio of microtremor is used to map the thickness of different soil layers and bedrock depth in contrasting layered lithological formations, where frequencies of amplification are converted to the thickness of layers if Vs is known.

The instrument used for survey consists of a set of 7 number seismometers of 5 s natural period, digitizer, master remote control, GPS system and electronic distance measurement system. The data of individual recorders is used for estimating the fundamental frequency and amplification due to entire soil thickness, while, an array gives the 1D velocity section of the underlying strata. The array arrangement is circular with three recording stations on the circumference of inner circle, three on outer circle (radius 100 m) and one in the centre of circle. For each array measurement, two distances R, D were used for better resolution. R is the distance between the central and outer stations and D is the distance between two outer stations. Seven sets of Lennartz LE-3D-5 s seismometers with Lennartz Marslite digital recorders are deployed. The master remote control is used to trigger all seven stations at a time in order to avoid any phase shift. In order to establish geometry of the array, it is necessary to measure the distance as precisely as possible between stations in the field. The electronic Digital Meter (EDM) is used to estimate the distances of the different pairs of stations. The principle of EDM is based on the focusing laser beam to a target plate which gives the distance at cm accuracy. This array method uses low-frequency ambient vibrations generated due to ocean tides and vibration of trees due to winds while avoiding cultural vibrations. The observations are carried out for an hour with the sampling rate of 100 samples/s at each site. For reliable experimental conditions, we follow the guidelines proposed by Koller et al. (2004).

The array microtremor data is used for determining the 1D velocity structure using inversion tools. The dispersion curve is determined and then inversion tool is applied

to infer the ground structure, especially the seismic velocity V_s . The H/V (horizontal to vertical) ratio is calculated using at least 50–70 s time windows, overlapping one another by 5%. A FFT (Fast Fourier transform) is applied to the signal of the three components to obtain the three spectral amplitudes in microtremor analysis. The spectra are then smoothed. H/V is computed by merging the horizontal (North–South and East–West) components with a quadratic mean.

7 Estimating Depths to Different Layers

Resonant frequencies in H/V spectra of earthquakes recorded on BBSs and microtremor records give depths to different soil layers and basement using the relation.

$$f = V_s/4h$$

where f is the amplified frequency, h is the depth of the layer and V_s is the assigned shear-wave velocity based on our knowledge of the area. Kindly note that due to the low energy of microtremors only some period waves may reverberate with certain layers and not all. We have estimated the approximate depths of different layers in several areas of study in Gujarat (Singh & Navaneeth, 2013). Results of broadband earthquake records and microtremor records are compared with those by MASW and drilling for shallow layers. Results from Dholera area are shown in Fig. 7 and Table 2.

Fig. 7 Dholera area resonant frequencies in H/V spectra of earthquakes recorded on broadband seismographs give depths to different soil layers and basement ($f = V_s/4 h$). **b** the amplified frequency ~ 3 Hz in H/V spectra of microtremor records on broadband seismographs gives a layer at 20 m depth which is confirmed by MASW

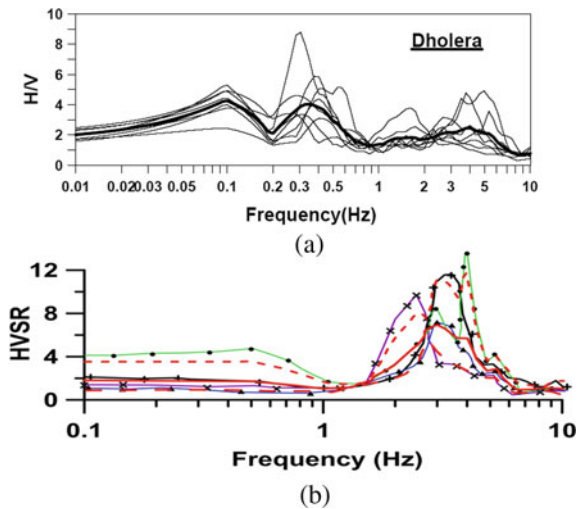


Table 2 Determining depths to different layers from Broadband Seismograms in Dholera area (refer to Fig. 7a)

Layer	f in Hz	H in m	Vs m/s
Basement	0.1	5000	2000
DT/Meso	0.35	350	1500
Q/T	1.5	100	500
Holocene I/II	4	15	250

8 Assessment of Strong Ground Motion

First, the EBL is worked out for the area and its depth at each borehole and at each grid point is estimated and contoured. The EBL in the area is usually decided at a shear-wave velocity of 450 m/s. Input ground motion is estimated at EBL by modelling. A ground model is constructed based on the results of geotechnical and geophysical investigations. The input ground motion is passed through ground model in 'SHAKE91' program to obtain the ground motion at surface.

8.1 Preparation of Ground Model for Response Analysis

To conduct the response analysis, the ground models are prepared for each borehole in the following format:

- A. Number of Layers and Depth of each layer (m)
- B. Damping Factor (%), Vs (m/s), Density (g/cm^3), Thickness (m), Non-linear Characteristic id (integer) for each layer

A sample ground model for Mundra area is shown in Fig. 8.

8.2 Input Motion at the Engineering Bed Layer

The input ground motion at a site can be generated by various methods like Empirical Green's Function (EGF), Stochastic Finite Fault Source Model (SFFSM) of Motazedian and Atkinson (Motazedian & Atkinson, 2005), Semi-Empirical or Composite Source model. ISR has installed BBSs at selected places on varied geomorphological units to record earthquakes from sources in Kachchh and Saurashtra. These BBS stations recorded earthquakes from these regions in the magnitude range 3.5–5.0. These earthquakes can be used as element earthquakes for EGF analysis. Quite often the signal-to-noise ratio is quite low and the records are noisier and not usable. The best method for generating strong ground motions is found to be the SFFSM and is used in most of our studies. An example is shown in Fig. 8.

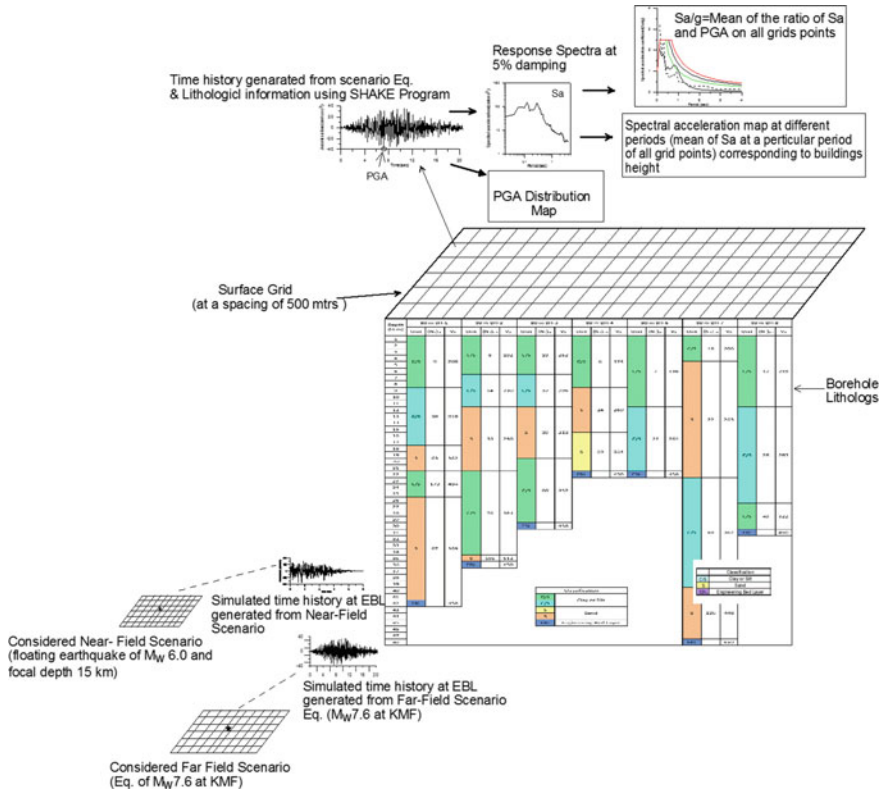


Fig. 8 The process of Response Analysis for Seismic Microzonation of Dholera Special Investment Region (Mohan & Rastogi, 2011)

8.3 Stochastic Finite Fault Source Modelling (SFFSM)

The basis of the stochastic method is that the high-frequency strong ground motion from earthquakes can be approximated by finite duration band-limited white Gaussian noise. The band limitation is defined by spectral corner frequency and the highest frequency passed by the accelerograph or the Earth’s attenuation. According to this method, a site-specific shape of the theoretical Fourier amplitude spectrum of the free field acceleration is estimated based on point source model. Next, a band-limited white noise is windowed with a shaping function of prescribed duration. The windowed time series is transformed into frequency domain and scaled to the square root of the mean-squared absolute spectra. The site-specific theoretical Fourier amplitude spectrum generated above is multiplied by the scaled spectrum of windowed time series. The Fourier transformation back into the time domain generates the simulated acceleration time series. This method was extended to large faults by subdividing the large fault into sub-faults each of which is then treated as a point

source. The ground motions at a site can be obtained by summing the contributions over all sub-faults. the concept of ‘dynamic corner frequency’ is used whereby the corner frequency reduces as the function of time accounting for the effect of an increase in fault length.

8.4 Ground Motion Parameters of Target Earthquakes

The result of the stochastic method depends on how well one knows the source, path and site characteristics of the given region where the ground motion is required. The researchers of ISR have determined the ground motion parameters for Gujarat region from the records of earthquakes in Kachchh, Saurashtra and the Mainland region separately. It is necessary that one should consider two target earthquakes, one far-field and another near-field for the generation of strong ground motions. The effects of local and regional earthquakes are different for different engineering structures. The far-field earthquake will affect the high-rise structures because of the dominance of low-frequency content and near-field will affect low-rise engineering structures. The probability of a large earthquake ($M_w > 7$) is very low for Saurashtra and the only region from where large earthquakes are expected is Kachchh where many faults are active. One far-field target earthquake will be generated like the 2001 Bhuj earthquake of $M_w 7.6$. Local active faults are also considered. The ground motion from these two scenario earthquakes will be used in the ground response analysis.

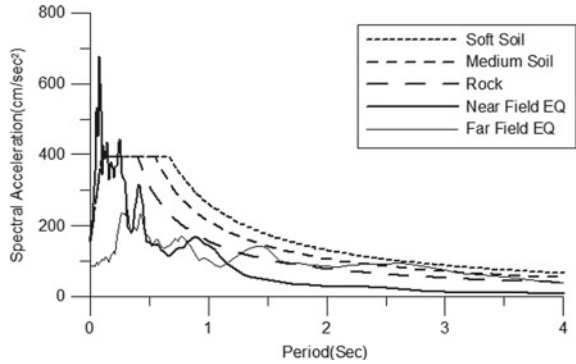
9 Measurement of Soil Amplification

Soil amplification is measured by several methods. In India and abroad, the Nakamura (1989) method of H/V spectral ratio is widely used. However, it has been found to give unreliable results due to weak ambient vibrations or earthquake data considered (Bard, 1998). The resonance frequencies obtained with this method are reliable. We have used the geotechnical data as input in the SHAKE program to get amplification, and compared the results with the following additional methods using:

- i. Average frequency-dependent amplification for the strongest few earthquakes recorded in the area.
- ii. Empirical amplification given by Boore (2006) method (developed using world-wide data whereby frequency-dependent amplification is given for generic soils with V_s of 760 or 520 or 450 m/s, etc., for EBL and 350 m/s at surface).
- iii. The relationship developed by Midorikawa et al. (1994) between shear-wave velocity and amplification factor of PGA, which is as follows.

$$\log ARA = 1.35 - 0.47 \log AVS30.$$

Fig. 9 Spectral Acceleration for near-field and far-field earthquakes compared with BIS curves for Gandhinagar in Seismic Zone III



Here, ARA is the amplification factor of PGA at shear-wave velocity AV_{s30} . From the formula, the amplification factor difference of PGA may be calculated, say between V_s 450 m/s and 520 m/s, i.e. $(ARA (450) - ARA (520))$.

10 Response Analysis

In the response analysis, a complete accelerogram (acceleration values with respect to time), PGA (maximum amplitude of the accelerogram), response spectra (spectral acceleration of single degree of freedom system vs. time) at 5% damping at the ground surface for hundreds or thousands of grid points distributed uniformly in the entire area with a spacing of 500 m or so are calculated. The spectral acceleration distribution maps are prepared at all grid points for different periods (0.1, 0.2, 0.4, 0.55, 0.67, 0.75, 1 and 1.25 s) from the computed response spectra. The spectral acceleration coefficient (Sa/g) values at all the grid points are also calculated by taking the ratio of the spectral acceleration and PGA at all the grid points. Mean Sa/g is also estimated for an area.

The spectral accelerations estimated for different periods in different areas of study in Gujarat indicate 50–70% more value in the period range 0.2–0.3 s than that is recommended in the BIS code (Fig. 9). The distance of higher damage potential increases to 20 km for faults with expected magnitude 6–7 and 40 km for faults with expected magnitude 8.

11 Liquefaction Potential

Investigations done for estimation of liquefaction potential are water depth (> 50 m may not liquefy), PGA, type of soil (sand, silt and gravel are liquefied), soil properties, N-value (layers at >30 m may not liquefy, tri-axial cyclic test of failure

of soil samples under simulation of repeated seismic waves). The methods given by Japan Road Association Method (Specifications for Highway Bridges & Part V Earthquake Resistant Design., 1980) and Seed and Idriss (Seed & Idriss, 1971) were adopted for liquefaction analysis.

12 Conclusions

The Institute of Seismological Research has conducted microzonation in Gujarat state of western India since 2007. Seismic microzonation has been done at Dholera Special Investment Region (SIR) along the Mumbai–Delhi corridor and Gandhidham–Anjar–Kandla area in collaboration with Oyo International Corporation, Japan. Seismic microzonation has been carried out for the cities of Bhuj, Gandhinagar and Ahmedabad. Microzonation studies in 250–500 m grid including measurements of V_{s30} , resistivity and geotechnical investigations through numerous boreholes were carried out in these areas. Earthquake hazard assessment was done for Kakrapar and Jaitapur Nuclear Power Plants, Mundra and Dahej LNG Terminals, Gujarat Infrastructure and Finance Tech (GIFT) city which is the first smart city in the country, several high-rise buildings, Dwarka, Deoni Mori and Santnagari religious sites, Gandhinagar Exhibition ground, etc.

The majority of microzonation studies in the country are not standardized as far as procedure, type of surveys and interpretation of data are concerned. ISR has done wide research on the development of methodology of seismic microzonation (geotechnical investigations, strong motion simulation techniques, Shear-wave velocity (V_s) estimation, V_s & SPT-N-value (V_s –N) relationship using data from MASW, Microtremor and PS Logging, establishment of EBL, estimation of liquefaction potential and response analysis. Therefore, now, we have a very well-tested and established technique of seismic microzonation.

Outcomes of these studies are peak ground acceleration, spectral acceleration at different periods (site-specific response spectra) corresponding to different heights of the buildings at a particular site of interest considering tectonic setting, shear-wave velocity structure, and subsurface soil/geotechnical properties. The liquefaction potential assessment is also an important outcome of the microzonation.

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