Detailed Ground Response Analysis at Park Hotel in Kolkata City, India

by

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SUMMARY:
It is the most discerned fact that earthquake ground motion alters as it propagates through the soil from bedrock to the surface. The parameters that need to be defined in order to estimate the ground response during an earthquake are mainly dependent on the earthquake magnitude, local geology, surface topography, fault mechanism, the length of the propagation path between the source and site, and dynamic properties of the soil through which the seismic waves travel from the focus (Abrahamson & Shedlock 1997). The ground motion analysis is one of the pivotal tasks of a geotechnical engineer in seismically active areas. In this paper, a study on ground response analysis at the Park hotel located in Kolkata city, India is carried out detailed which lies in seismic zone III (IS: 1893, 2002) of the zonation map of India. It has several active faults in the vicinity. The Peak Ground Acceleration (PGA) of the city ranges from 0.1g to 0.34g. Amplification has always been a significant parameter for civil engineering structures. The site amplification factors for the city are found out using the shear wave velocities with which the ground response can be analyzed.

Keywords: Vulnerability, Amplification factor, Ground Response, Seismic Hazard

1.INTRODUCTION:

Influence of near surface geological conditions in the form of sediment amplification or site response is apparent from the damage distribution of many destructive earthquakes (Edward H., 1996).Earthquake damage is a function of the magnitude or the energy released, which is termed as the source, path and site. Magnitude of earthquake, degree of shaking, and destruction caused is dependent on numerous factors. Magnitude of an earthquake is proportional to the energy released and it might attenuate or amplify as it travels away and when spread over larger province. The degree of shaking of ground relies on the matching of the fundamental frequency of ground and the building and the degree of damage of structure is in turn influenced by the properties and type of rock, soil deposits, tectonic and geomorphologic features. Susceptibility of subsoil to liquefaction, a complex behavior of soil due to the decrease in effective stress, is also regulated by the degree of shaking. Hence, it is essential to carry out the ground response analysis to find out the ground motion parameters.

About 56% of Indian subcontinent is prone to different levels of seismic hazard. Indian landmass can be divided into three major tectonic provinces known as the Himalayan, Indo-Gangetic and Peninsular India.

All of these areas are characterized by distinctive stratigraphic, tectonic and deep crustal features (Pande P., 2005). The complex landmass with varied rheology behaves differently in response to far-field stress to generate intraplate earthquakes (Dasgupta et al., 2000). More than 650 earthquakes with M> 5 have been recorded in India in the last one century (Pande P., 2005). Indian seismic zonation map (IS 1893:2002) divides the country into four major zones based on the peak ground acceleration and about 28% of the area of India falls in zones IV and V.

In the present paper, the park hotel site in the city of Kolkata, capital of West Bengal has been considered for the study, to perform the ground response analysis. Kolkata, formerly known as Calcutta, is one of the nation's largest agglomerations. More than 80% of the city has built-up area with different types of buildings that were constructed with improper town planning and are primitive kind. Due to high density of population and improper planning, the city might suffer great damage due to near and far field earthquakes.

2. DETAILS OF THE STUDY AREA:

Kolkata city has the geographical coordinates 22º 32' N and 88º 20' E .The city is spread over an area of approximately 1851 sq. km. and comprises a population of about 15.7 million people including the suburban as per recent census.

The role of geological and geotechnical data is very important in the urban planning of city infrastructure, which can recognize, control and prevent geological hazards (Bell et al., 1987; Legget, 1987; Hake, 1987; Rau, 1994; Dai et al, 1994, 2001; Van Rooy and Stiff, 2001). Kolkata was originally covered with marshy wet lands but due to human habitation it has been converted to fishing canters, while the eastern part of the city is still covered by marshy wetlands. The city has three major soil types i.e., silty clay / clayey silt, alluvial deposits with top most layer as sand and silty soil. The clay layer extends from 10-25m which is succeeded by sand bed of 30-35m and the lower depths consists of dark brown clay from 60-100m and coarse, medium and fine sand mixture from 120-180m below ground level. Below this sand zone gravel bed occurs. The thickness of acquifer of the city ranges from 10-20m on an average.

Kolkata city falls under the seismic zone III as per the seismic zoning map of India. The earthquake database in India is yet to be completed and hence the zoning offers preliminary guide to earthquake hazard for a particular region. The city is less than 300 km to the principal faults of the Indo-Asian plate boundaries in Burma and the Himalayan area and has experienced major earthquakes namely, Kolkata earthquake (1737), Shillong earthquake (1897), Assam earthquake (1950), Kolkata earthquake (1964), Sikkim earthquake (2006), Sikkim earthquake (2011), Indonesia earthquake (2012). The 1737 Kolkata earthquake was also accompanied by hurricane and floods. The number of deaths was quite a speculation which was about 3, 00,000. This is one of the historical earthquakes of Kolkata region. The 1964 earthquake that occurred in the Sagar Island was of magnitude M 5.2 recorded to be V on Mercalli scale in Kolkata. Due to the mushrooming of a number of structures, improper and poor quality construction practice, and irregular and heavy traffic conditions the vulnerability to earthquake damage in the city is high. This justifies the need to conduct necessary experiments to understand the behavior of soil under seismic loading.

3. DATA ACQUISITION:

Seismic site classification and response studies require a complete geotechnical site characterization. Site characterization procedure should include an evaluation of subsurface features, sub surface material types and their properties. In the present study, geotechnical bore hole data has been collected in the Park hotel site. The hotel location is at a distance of around 5 km from Salt Lake area of Kolkata. From the borehole data it has been observed that the predominant soil was observed to be silty clay .The topmost layer was that of silty clay and the subsequent layers were of clayey silt and sandy silt. Standard penetration test (SPT), core cutter, dynamic cone penetration test (CPT) etc were conducted to find out the different soil properties. In the crosshole seismic test, from the recorded P (compression) and S (Shear) wave velocities dynamic shear modulus, dynamic young modulus, dynamic bulk modulus and poisson ratio are determined. Seismic (P-Wave) velocity of materials relates to the strength properties and the degree of weathering and joint sets available in-situ in rocks and compactness and saturation in soil. The variation in velocity can be correlated to the local geology by using standard table of seismic wave velocities in different geologic medium in dry and wet conditions or with a prior information of rock/soil types (local geology) or based on laboratory investigations of the core samples.

Form the geotechnical tests conducted, the average unit weight of soil layers was found to vary from 18 to 21 kN/m^3 and shear wave velocity from 100 to 700 m/sec. The ground water levels were shallow and within the range of for 0.1 m to 2.2 m below the ground surface. The cross-hole seismic test recordings were recorded at 3 m depth interval starting from 1 m to 58.5 m depth. The equipment consists of seismograph, a 3-component downhole sensor with Pneumatic clamping and high pressure motorized pump and the energy source used is borehole hammer. Polarized shear waves are generated for clear identification of shear wave. Interactive seismic software Pickwin module of SeisImager (GEOMETRICS) was used for identification and first arrival picking of P and S waves. Figure 1 shows the polarized S wave for the identification of shear wave. Figure 2 gives the S and P wave profiles at different depths for the area of study. The recorded data is analyzed using SeisImager Analysis Software.

To calculate elastic moduli of the strata, bulk density values were noted from the samples collected from the boreholes. V_p, V_s and corresponding dynamic elastic moduli values recorded in crosshole locations 1 and 2 are shown in Table 1(a) and 1(b) and the corresponding velocities and parameters are shown in Fig 3. The velocities of P and S waves are found to vary from 400 - 1480 m/sec and 100 - 700 m/sec respectively. The value of Poisson ratio varies from 0.24 to 0.48; Shear modulus (G) and Young's Modulus (E) vary from 160 Kg/cm^2 to 9996 Kg/cm^2 and 475 Kg/cm^2 to 24832 Kg/cm^2 respectively. Usually, seismic velocities and the corresponding parameters increases with depth and shear wave velocity of sandy strata is higher.

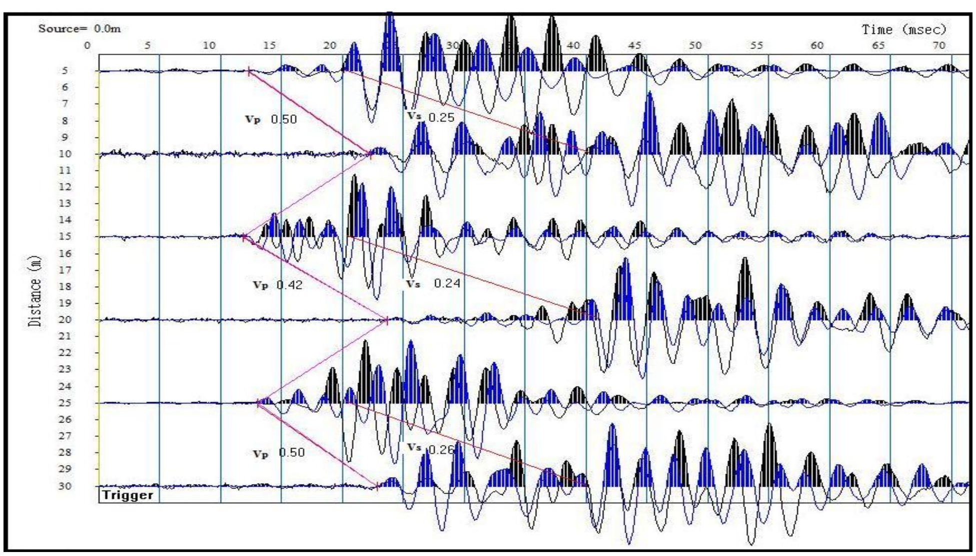
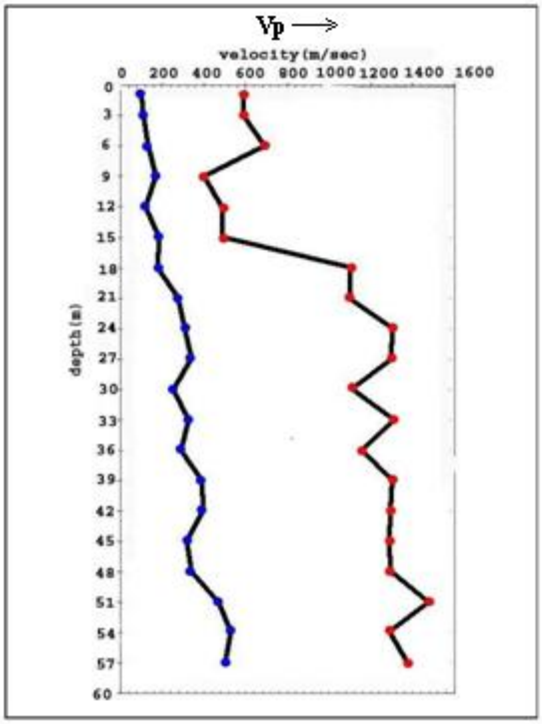
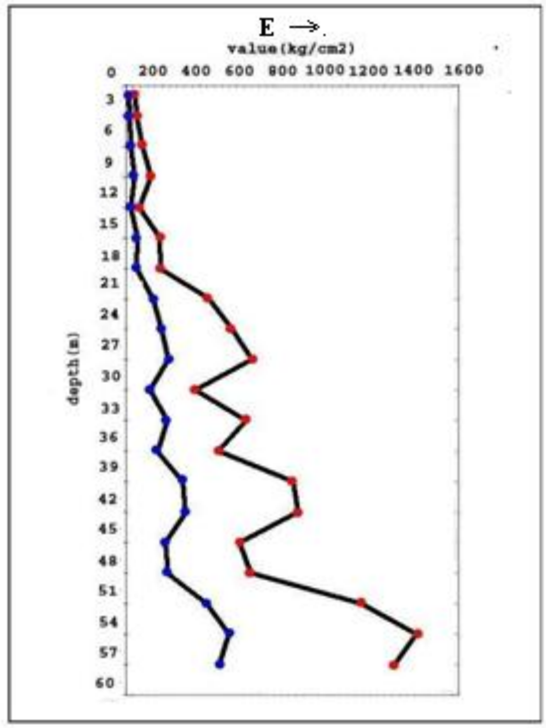


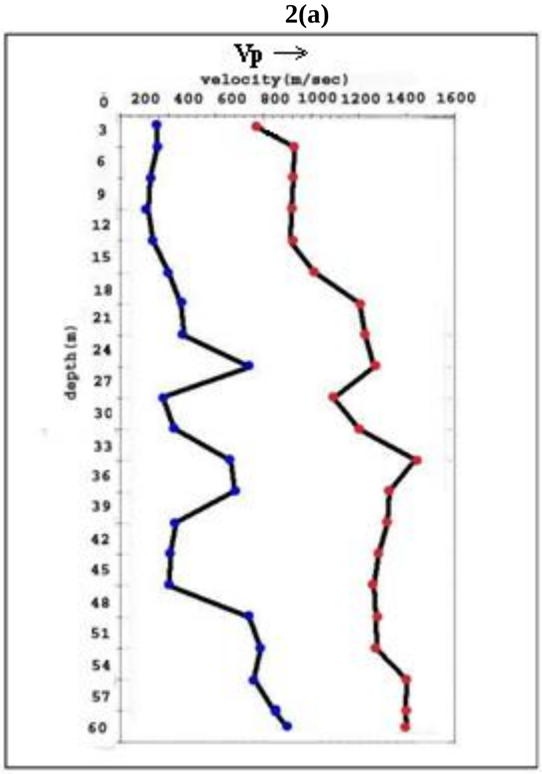
Figure 1. Polarized Shear Wave for identification of S-wave



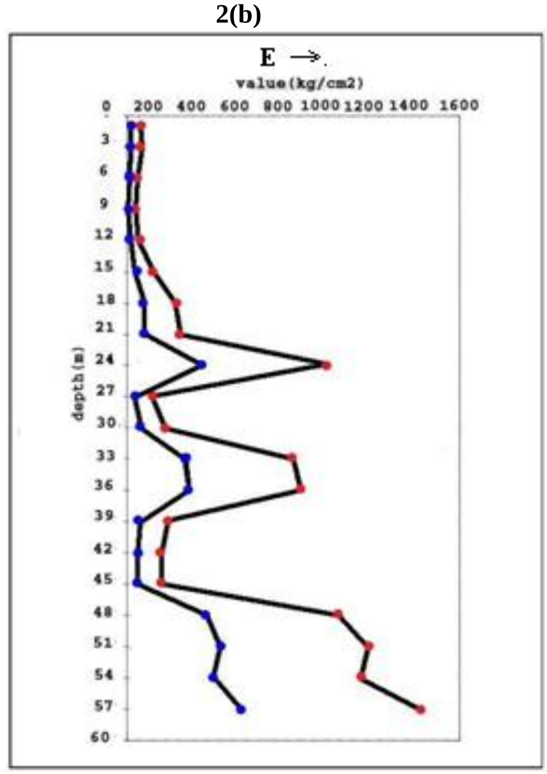
2(a)



2(b)



2(c)



2(d)

Figure 2. (a), (b), (c), (d) P wave profiles and elastic modulus profiles at different depths at two different locations

4. ANALYSIS:

Different methods can be employed to estimate the ground response. Theoretical approaches require performing necessary sensitivity tests for different locations and uncertainty analysis is usually impractical. The most widely used method for the analysis is one-dimensional wave propagation analysis because of its simplicity, availability and its conservative results (Schnabel et al. 1972). To estimate the free-field response of the area of study, linear analysis using DEEPSOIL (Youssef M.A.H, 2009) has been carried out. For the response analysis, the input parameters required are input ground motion, shear wave velocity profile and dynamic soil characteristics (strain dependent modulus reduction and damping behavior and cyclic strength curves). Sikkim earthquake (2011) ground motion of moment magnitude 6.9 has been used and the shear wave velocity obtained from CPT test is used. Parameters like dry density, layer thicknesses etc are obtained from borehole explorations. Figure 4 shows the soil profiles of boreholes of 60m deep. Later Fast Fourier transform is applied and analysis is done for 5% damping. Finally, PGA at surface and that at bedrock is obtained from the analysis. The peak ground acceleration values at surface are observed to be in the range of 0.40g to as high as 0.73g and that of the bedrock were observed to vary from 0.1g to 0.3g. The impedance in the acceleration values can be observed. Such, a sudden rise within few meters can cause considerable damage to the sub and super structure resulting in huge loss.

Site amplification factors at sub surface layers are often used as one of the parameters for estimation of ground response. The factor is the ratio of peak ground acceleration at surface to that of the acceleration at hard rock. Hence, the amplification factors have also been computed and it has been identified that similar to the peak ground acceleration values, the variation is within 1.6 to 5.4. Table 2 gives the water table depth, latitude, longitude and the peak ground acceleration and amplification factors at different borehole locations.

Table 1(a). Seismic Velocities and Dynamic Elastic Moduli at Crosshole location1

Depth (m)	Density (Kg/m^3)	Seismic Velocity		Soil Parameters		
		V_p (m/sec)	V_s (m/sec)	Poisson's Ratio	Shear Modulus G (Kg/cm^2)	Young's Modulus E (Kg/cm^2)
1.0	1600	590	100	0.485	160	475
3.0	1600	590	110	0.482	194	574
6.0	1803	690	132	0.481	314	931
9.0	1750	400	170	0.390	506	1406
12.0	1750	490	120	0.468	252	740
15.0	1870	490	186	0.416	647	1832
18.0	1870	1100	185	0.485	640	1901
21.0	2020	1100	275	0.467	1528	4481
24.0	2020	1300	312	0.469	1966	5779
27.0	2020	1300	340	0.463	2335	6834
30.0	2040	1110	250	0.473	1275	3757
33.0	2040	1311	330	0.466	2222	6514
36.0	2040	1155	290	0.466	1716	5031
39.0	2040	1300	390	0.451	3103	9002
42.0	2040	1290	396	0.448	3199	9264
45.0	2040	1290	320	0.467	2089	6130
48.0	2000	1290	340	0.463	2312	6763
51.0	2000	1480	470	0.444	4418	12758
54.0	2000	1290	530	0.398	5618	15713
57.0	2000	1379	506	0.422	5121	14565

Table 1(b). Seismic Velocities and Dynamic Elastic Moduli Crosshole location 2

Depth (m)	Density (Kg/m^3)	Seismic Velocity		Soil Parameters		
		V_p (m/sec)	V_s (m/sec)	Poison's Ratio	Shear Modulus G (Kg/cm^2)	Young's Modulus E (Kg/cm^2)
1.0	1600	571	155	0.460	384	1123
3.0	1600	727	155	0.476	384	1135
6.0	1600	727	130	0.483	270	802
9.0	1820	720	110	0.488	220	655
12.0	1736	720	140	0.480	340	1007
15.0	1736	817	200	0.468	694	2039
18.0	1965	1000	255	0.465	1278	3744
21.0	1965	1025	265	0.464	1380	4041
24.0	1900	1064	547	0.320	5685	15013
27.0	2030	893	182	0.478	672	1988
30.0	2030	1000	220	0.475	983	2898
33.0	2030	1240	466	0.418	4408	12500
36.0	2030	1130	480	0.390	4677	13002
39.0	2030	1120	230	0.478	1074	3174
42.0	2030	1080	210	0.480	895	2651
45.0	2030	1060	210	0.480	895	2649
48.0	2040	1074	540	0.331	5949	15833
51.0	2040	1075	588	0.287	7053	18148
54.0	2040	1200	563	0.359	6466	17573
57.0	2040	1200	645	0.297	8487	22013
58.5	2040	1200	700	0.242	9996	24832

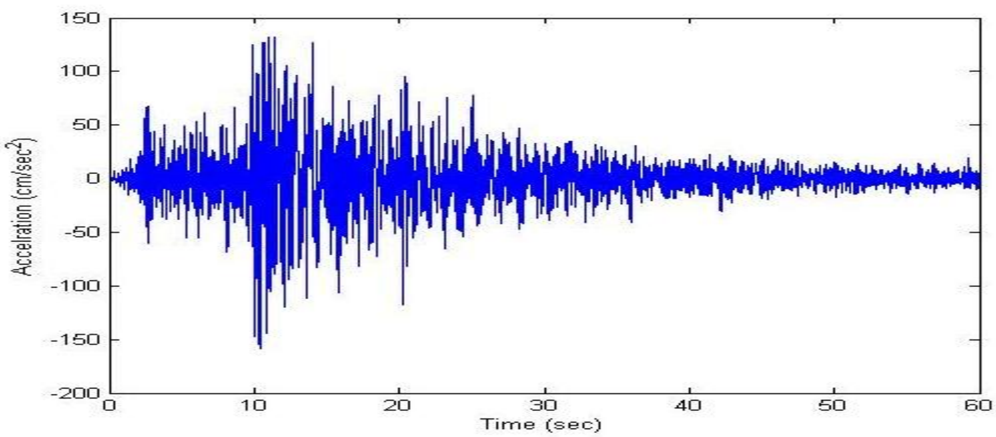


Figure 3. Input ground motion, Sikkim Earthquake (M_w=6.9)

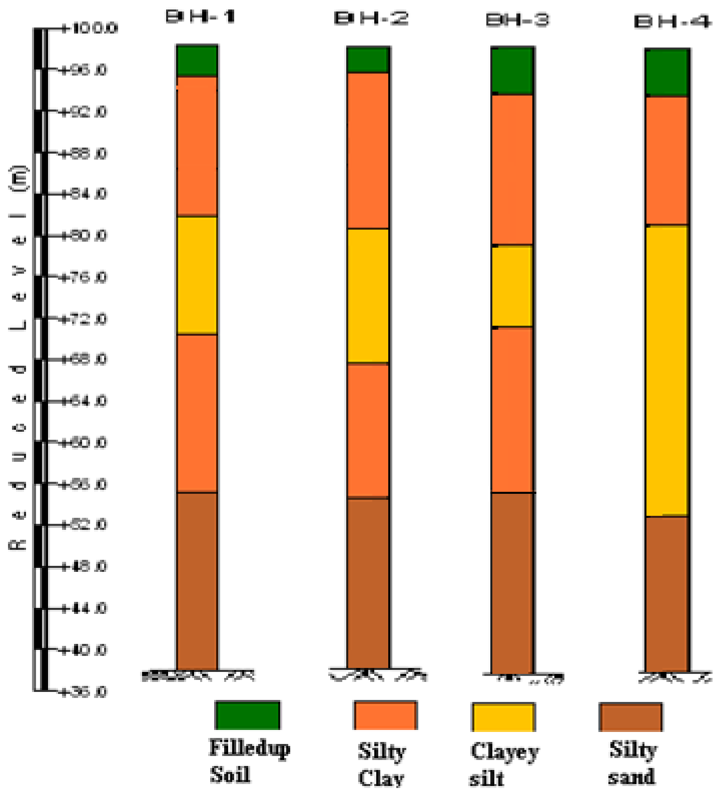


Figure 4. Borehole profiles at the Park hotel site

Table 2. Estimated Peak ground acceleration and spectral amplification factors at different locations

S.No	Water table (m)	Location		PGA values		Spectral Amplification Factor (SAF)
		Latitude (N)	Longitude (E)	At Surface (g)	At Bedrock (g)	
1	2.2	24°94'690"	64°40'83"	0.453	0.141	3.216
2	2.1	24°94'677"	64°41'11"	0.513	0.133	3.857
3	1.9	24°94'664"	64°41'38"	0.517	0.132	3.931
4	0.75	24°94'649"	64°41'64"	0.654	0.120	5.447
5	0.25	24°94'645"	64°41'94"	0.609	0.381	1.596
6	0.4	24°94'626"	64°41'86"	0.454	0.123	3.684
7	0.18	24°94'632"	64°42'22"	0.453	0.139	3.245
8	0.3	24°94'612"	64°42'13"	0.497	0.115	4.306
9	0.4	24°94'619"	64°42'49"	0.485	0.120	4.042
10	0.28	24°94'598"	64°42'39"	0.605	0.129	4.697
11	1.25	24°94'606"	64°42'76"	0.730	0.129	5.644
12	0.5	24°94'584"	64°42'66"	0.458	0.109	4.196
13	-	24°94'593"	64°43'03"	0.407	0.118	3.442
14	0.1	24°94'570"	64°42'92"	0.446	0.131	3.412
15	0.8	24°94'575"	64°43'37"	0.524	0.129	4.054
16	0.1	24°94'553"	64°43'20"	0.654	0.134	4.880
17	-	24°94'574"	64°43'11"	0.734	0.144	5.108
18	0.8	24°94'588"	64°42'54"	0.481	0.150	3.196
19	0.32	24°94'601"	64°42'57"	0.560	0.140	3.996

5.CONCLUSIONS:

Kolkata is one of the largest agglomerations of the world located on the banks of Hoogly River. Larger area of the city has closely packed residential buildings, business districts, hospitals and schools with bad construction practice. Several active faults are present in this region. In the past, the city had suffered damage to structures by both far and near earthquake sources mainly due to those associated with Himalayan tectonics. Calcutta is characterized by flat terrain with marshy lands and alluvial deposits. For better understanding of the ground response and parameters needed for estimating earthquake risk and hazard assessments, Park hotel site in Kolkata has been selected.

For the site specific ground response analysis at the hotel site, borehole logs have been collected at different test locations. The shear wave velocity and other soil characteristics are found out using SPT and dynamic CPT tests.CPT data has been analyzed using SeisImager software. S-wave and P- wave velocity profiles were generated. The shear wave velocity, damping, dry density, soil layer depth etc have been used in DEEPSOIL and the peak ground acceleration at surface level has been estimated. From the surface and bedrock predominant acceleration, amplification factors have been calculated. The peak ground acceleration values are varying from 0.30g to 0.73g and the amplification factors from 1.5-3.8. Almost all the test sites had amplification factors of nearly 1.5 except for one location. There was not sudden change of subsoil or other features observed that would have result in sudden increase of the factor. Eventually, this sudden increase for a specific location within few meters has motivated this study and demonstrates the need for site specific ground response analysis of an area to be considered at design stage.

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