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SITE RESPONSE ANALYSIS: GUWAHATI CITY AND CMP 2025

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ABSTRACT

In this study an attempt has been made to study the ground response as a preliminary hazard assessment for an additional area of western part of Guwahati city on the south bank of River Brahmaputra, which is mostly consisted of alluvial deposits. It has been attempted to estimate the amplification parameters of the region under study based on SPT Borehole investigation, Litho log and 1-Dimensional Equivalent Linear Method. Further, spectral ratio analysis of earthquake records of single station in the form of Horizontal to Vertical Spectral Ratio (HVSR) was carried out. A general comparison of both the analyses showed fairly agreeable results of amplification in the predominant frequency range obtained from HVSR analysis. Both analyses clearly indicated that the presence of soft alluvium in the region greatly influences the free field ground motion in the low frequency range (less than 4Hz).

INTRODUCTION

In many past and recent earthquakes it has been observed that the local site conditions - soil and topographic effects - have a great influence on the damage distribution. The potentially severe consequences of this phenomenon were recently demonstrated in the damage patterns of the 1985 Michoacan, Mexico earthquake (Singh et al., 1988), the 1988 Armenian earthquake (Borcherdt et al., 1989), the 1989 Loma Prieta earthquake (Hough et al., 1990; Borcherdt and Glassmoyer, 1992) and the Northridge earthquake in Los Angeles, California (EERI, 1994). Numerous other studies have also demonstrated the ability of surface geologic conditions to alter seismic motions (Borcherdt, 1970; Tucker and King, 1984; Aki, 1988; Field et al., 1992).It is therefore very important to take into account and predict these possible local site effects when assessing the earthquake hazard at regional and local scale. Soft soil deposits significantly amplify an earthquake ground motion, which is often referred to as site effects. Site effects play a very important role in characterizing seismic ground motions because they may strongly amplify (or de-amplify) seismic motions at the last moment just before reaching the surface of the ground or the basement of man-made structures (DST, 2008).

In the present study an attempt has been made to carry out one dimensional equivalent site response analysis of an area on the western fringe of Guwahati city using numerical code DEEPSOIL, SHAKE2000 and Seismosignal. The input motions used in the analyses were obtained from PESMOS, IIT Roorkee. Besides, the results of equivalent linear method of analysis were compared with the results of Horizontal to Vertical Spectral Ratio (HVSR) technique (Lermo and Chavez-Garcia, 1993). HVSR technique, a single station, non-reference site technique of analysis was applied to the recorded earthquake waves near the area of study to have an assessment of the amplification of the recorded waves.

AREA OF STUDY

The whole of northeast India falls in zone V of the seismic hazard zonation map (BIS, 2002) of India, the highest vulnerable zone in the country. This can be substantiated by the fact that devastating earthquake of Mw 8.1 in 1897 and Mw 8.6 in 1950 has occurred in this region which resulted in the change of topography of the area.

The Guwahati city being located almost at the center of the region, acts as the gateway and transit point for communication and transportation for the seven sister states of northeastern region of India. Shifting of the capital of Assam from Shillong to Guwahati in the year 1972 has increased its importance manifold. People from all over Assam and from the neighboring states have been migrating to Guwahati for job, business and education. This has resulted in very fast and unplanned growth of the city. In early 70’s, only a few multistoried buildings existed in the city except in the downtown area. Most of the houses were kutcha-pucca Assam type with corrugated (G.I.) sheet or thatched roofs. But during the recent past many multistoried buildings have come up which are juxtaposed to each other in the main commercial and business hubs and markets, perhaps due to acute shortage of space.

Many natural water bodies have been filled up for construction of houses making them more vulnerable to earthquake hazard. In some cases steep slope of the hillocks has been occupied making life and property vulnerable to landslides, especially during earthquake and heavy rains. Keeping in view the unplanned growth of Guwahati city, a Comprehensive Master Plan-2025 (CMP-2025) has been drawn up to facilitate planned growth an decongestion of Guwahati city which encompasses an addition of 66 sq. km to the existing 262 sq. km . New Town III (as defined in CMP-2025) is situated towards the south western part of Guwahati Metropolitan Area. It is worth mentioning that Lokapriya Gopinath Bordoloi International Airport (LGBI) is located nearby besides many residential schools, important public organizations etc. Also the area under consideration has many new housing and infrastructure projects. It has been observed that no previous study of the concerned area has been undertaken. It is also known that earthquake shaking affects nearby areas differently. Severity of shaking is closely related to local site conditions. Hence, this study targets Western Guwahati as the area of interest and tries to give a preliminary insight to the effects of local site conditions.

SOIL PROFILE

For definition of soil profiles, bore Logs and soil properties , Lithologs were collected from various agencies the Bore logs were available up to a depth of 15 meters while the litholog gave the various layering of the soil up to bedrock of the study area.

Table 1: Bore Log

Depth	Description	Field N-Value
0.0 to 1.50	Silty Clay up to 9.00m (Water table = 0.75 m)	2
1.50 – 3.00		3
3.00 – 4.50		5
4.50 – 6.00		7
6.00 – 7.50		7
7.50 – 9.00		17
9.00 – 11.50	Silty sand up to 12.50	28
11.50 – 12.00		37
12.00 – 13.50	Fine sand / silt up to explored depth	42
13.50 – 15.00		46

Table 1 depicts the general soil profile as encountered in the study area, the Litholog is shown in Table 2, while Table 3 provides the generalized soil profile used in the one dimensional equivalent linear analysis which was derived from the layering of the subsoil from bore hole data as well as litholog. As is evident from table 3, some amount of simplification is carried out in obtaining the generalized soil profile used in the analysis.

Table 2: Litho log (source: CGWB)

Lithology	Depth Range (below ground level) (m)	Thickness (m)
Clay , sticky, brown	0.0 – 6.60	6.60
Clay, brown, non sticky	6.60 -9.60	3.00
Silt, Grey	9.60 - 12.75	3.15
Sand, fine, Grey	12.75-28.05	15.30
Sand ,fine to medium, Grey	28.05-46.00	18.45
Sand , medium to coarse, Grey	46.50-71.10	24.60
Sand ,fine to medium, Grey	71.10-77.25	6.15
Sand , medium to coarse, Grey	77.25-83.40	6.15
Clayey sand, clay , Grey, Sand ,medium to coarse	83.40-89.55	6.15
Clay, Grey , sticky	89.55-92.70	3.15
Sand , medium to coarse, Grey	92.70-95.70	3.00
Clayey sand, brown	95.70-98.85	3.10
Clay mixed with Konkar, Grey	98.85-135.75	36.90
Gravel mixed with clay	135.75-148.05	12.30
Sand , coarse to very coarse, Grey with little gravel	148.05-154.20	6.15
Sand ,fine to medium, brownish	154.20-160.35	6.15
Sand , medium to coarse, Grey	160.35-170.65	10.30
Sand , coarse to very coarse, Grey	170.65-186.95	16.30
Clay mixed with gravel, clay sticky, black.	186.95-194.10	7.15
Gravel, composed of Feldspar & Quartz.	194.10-200.25	6.15
Bedrock (Granite)		

Table 3: Generalized Soil Profile

Description	Depth Range (m)	Thickness(m)
Clay	0.0. to 9.60	9.60
Silt	9.60 to 12.75	22.35
Fine sand	12.75 to 28.05	15.30
Fine/Medium sand	28.05 to 83.40	55.35
Coarse sand from	83.40 to 89.55	6.15
Clay from	89.55 to 92.70	3.15
Sand/Clay / Gravel	92.70 to 194.10	101.40
Gravel	194.10 to 200.25.	6.15
Competent Bedrock (Granitic)		

SHEAR WAVE VELOCITY (Vs)

Shear wave velocity was obtained from the uncorrected field N value. Maheswari et. al., (2010), Mhaske and Choudhury (2011) had reported that the corrected and uncorrected N-Values predicted Vs with reasonable good efficiency.

$$Vs = 74.639 \times N^{0.3876} \quad (1)$$

The relation proposed by Sharma et. al., (2013) as given by Eq. (1) was used to determine the shear wave velocity up to the depth to which N-Values were available. Beyond that the shear wave velocity was assumed to be increasing linearly up to the engineering bedrock level. A shear wave velocity of 760 m/sec was assumed for the engineering bedrock level (Anbazhagan and Sitharam ,2009), upto which soil/rock profile was available. The competent bedrock was assigned a shear wave velocity of 1500 m/sec.

DYNAMIC MATERIAL PROPERTIES

Dynamic material properties were defined in the form of Shear Modulus reduction (G/Gmax) and Damping Ratio Vs shear strain plots as available in the database of SHAKE 2000. Due to absence of site specific dynamic material properties previously published material curves by Schnabel (1973), Seed and Idriss (1970), Seed et. al. (1986), Vucetic and Dobry (1991) were used. Published dynamic material curves have been used in the absence of site specific dynamic material properties by many authors (Roy and Sahu, 2012; Kumar and Dey, 2015) for site amplification studies.

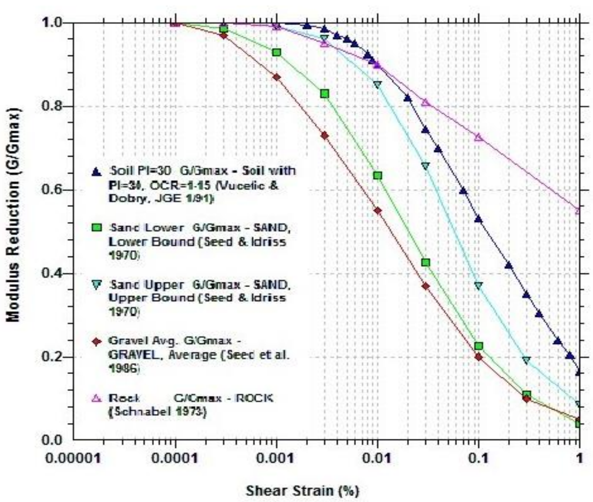

Fig. 1: Shear Modulus Reduction curves

Besides, Hashash et. al. (2011) had reported that in the absence of site specific dynamic material properties standard curves proposed by published literature can be considered as a better alternative for analysis. Figure 1 & 2 depicts the curves used for analyses in this study

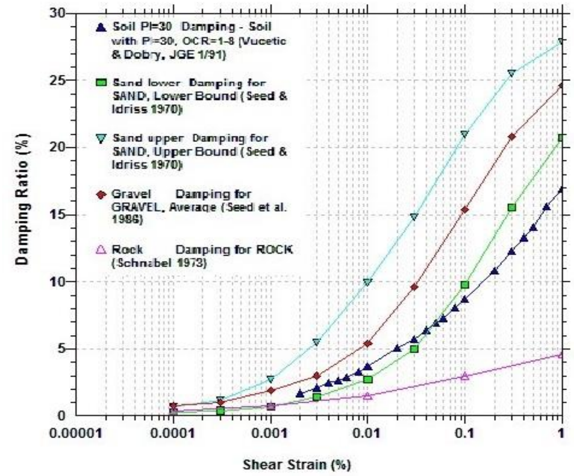

Fig. 2: Damping Ratio curves.

INPUT MOTIONS

Three earthquakes recorded at Nongstoin, obtained from PESMOS were used as input motion for the analysis. Nongstoin is located at a distance of approximately 100km from the study area and is classified as site class A (Mittal et. al., 2012) having shear wave velocities within the range of 700m/sec to 1400m/sec. The records were used as outcrop motions which were applied to the bedrock of the study area to obtain the free field ground motions. The basic properties of the three input motions are provided in Table 4 & 5.

Table 4: Input motions properties

Earthquake	Epicenter	Magnitude (Mw)	Focal Depth (km)	Epicentral Distance (km)
11Aug 2009	24.4N 94.8E	5.6	22	378
03 Sep 2009	24.3N 94.6E	5.9	100	363
21 Sep 2009	27.3N 91.5E	6.2	8	197

Table 5: Input motions properties

Earthquake	Maximum Acceleration (g)	Predominant Period (sec)
11Aug 2009	0.015	0.20
03 Sep 2009	0.009	0.20
21 Sep 2009	0.028	0.22

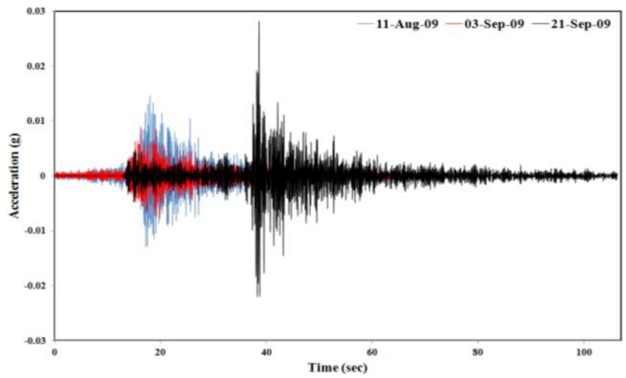

Fig.3: Acceleration time history of input motions

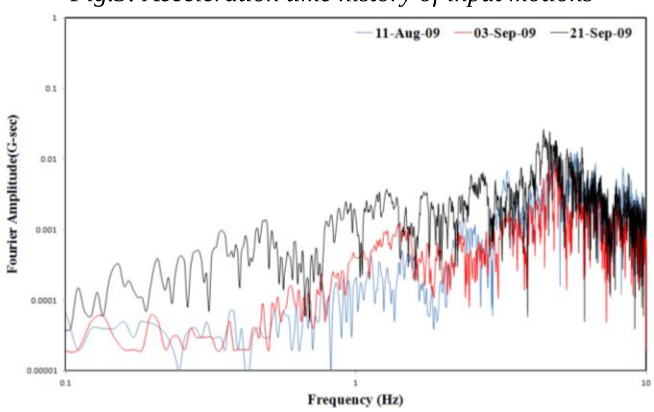

Fig. 4: Fourier Amplitude Spectrum (FAS) of input motions

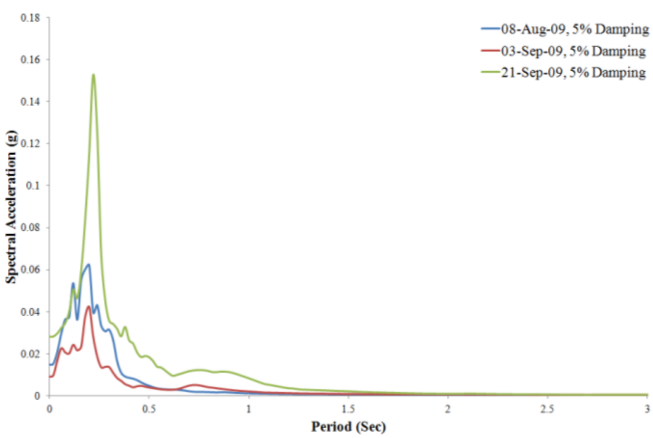

Fig. 5: Response Spectrum at 5 % damping of input motions

It can be seen from the Figure 4 that Fourier amplitude of the 21-Sep-209 earthquake had comparatively higher amplitude throughout the entire frequency band; the reason might be attributed to the epicentral distance and focal depth, which were less as compared to the 08-Aug-2009 and 09-Sep-2009 earthquake. Spectral acceleration as can be seen from Figure 5 was maximum at a predominant period range of approximately 0.20 – 0.25 sec and ranged from 0.04g to 0.15g for the three events. The time history plot of the input motions is given in Figure 3.

RESULTS AND DISCUSSIONS

Equivalent Linear Method of Analysis

One dimensional equivalent linear site response analysis was performed by using the generalized soil profile as described in table 3 and the dynamic material properties as shown in Figure 2. It was observed that the maximum acceleration of the free field ground increased from 0.015g to 0.046g for the 08-Aug-2009; 0.009g to 0.024g for the 03-Sep-2009 and 0.028g to 0.085g for the 21-Sep-2009 earthquakes. Increase in the maximum acceleration indicated amplification of earthquake motions. The increase in maximum acceleration can be visually interpreted for the three cases from Figure 6, 7 & 8 respectively. There was no change of predominant period of the free field ground motions obtained from the analysis as can be compared from Table 5 & 6.

Table 6: Free field ground motion properties

Earthquake	Maximum Acceleration (g)	Predominant Period (sec)
11Aug 2009	0.046	0.20
03 Sep 2009	0.024	0.20
21 Sep 2009	0.085	0.22

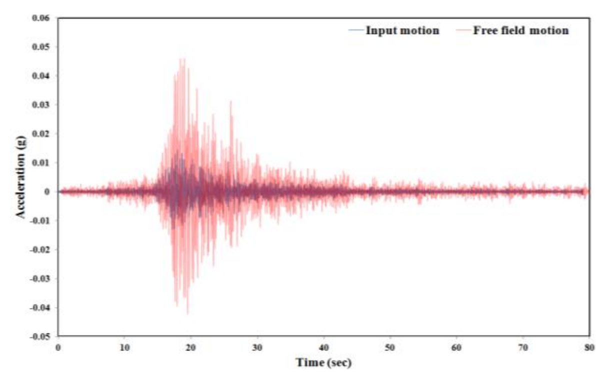

Fig. 6: Acceleration time history of input vs. free field ground motion of 08-Aug-09 Earthquake

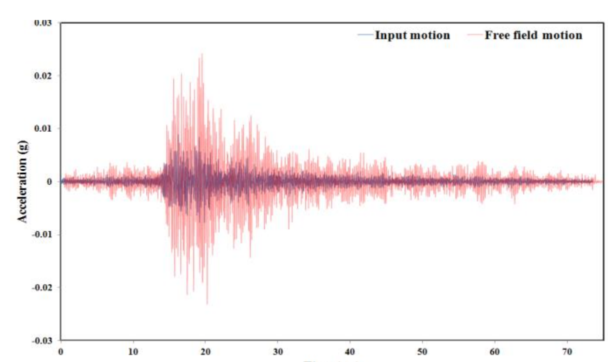

Fig. 7: Acceleration time history of input vs. free field ground motion of 09-Sep-09 Earthquake

Amplification of seismic waves at the free field can be observed from the Figure 9, 10 & 11 which shows how the frequency amplitude changes while Figure 12, 13 & 14 depicts the change in spectral acceleration at 5% damping. It is evident from Figure 9, 10 & 11 that within the frequency range of 0.8 – 4.0 Hz, the seismic wave has amplified. Amplification of the waves can also be seen in the Spectral acceleration Vs time period plots from Figure 12, 13 & 14.

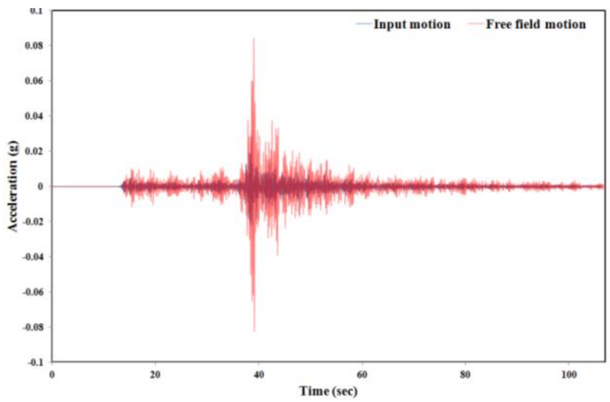

Fig. 8: Acceleration time history of input vs. free field ground motion of 21-Sep-09 Earthquake

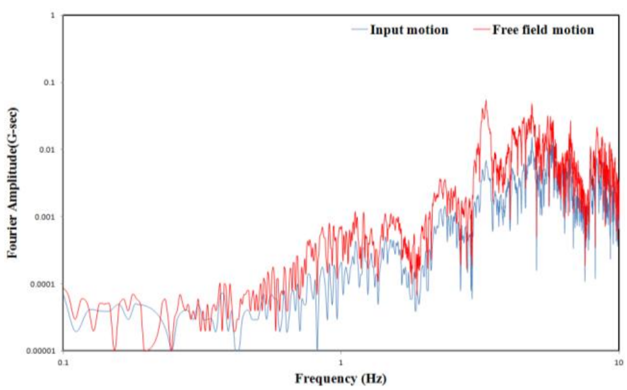

Fig. 9: FAS of input vs. free field ground motion of 08-Aug-09 Earthquake

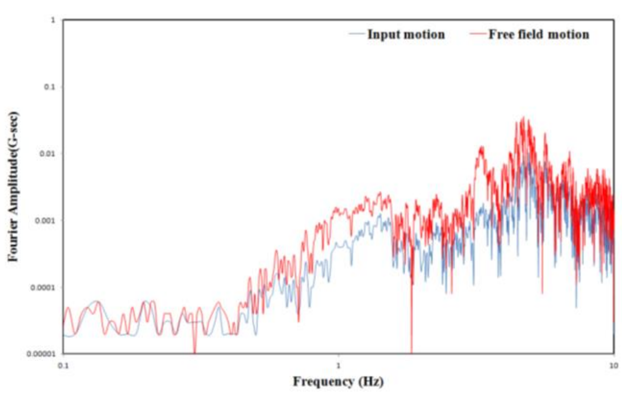

Fig. 10: FAS of input vs. free field ground motion of 09-Sep-09 Earthquake.

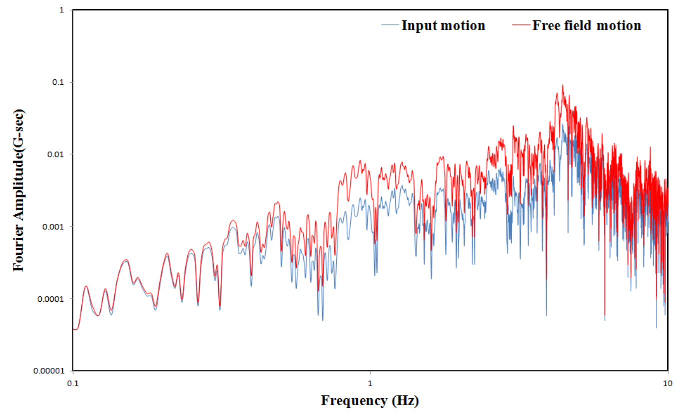

Fig. 11: FAS of input vs. free field ground motion of 21-Sep-09 Earthquake

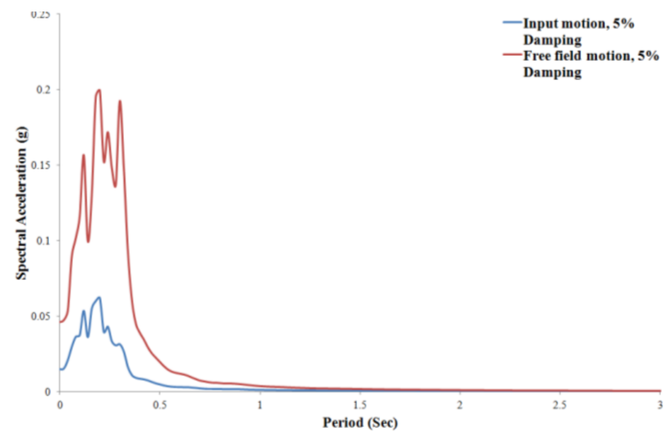

Fig. 12: Response Spectrum of input vs. free field ground motion of 08-Aug-09 Earthquake

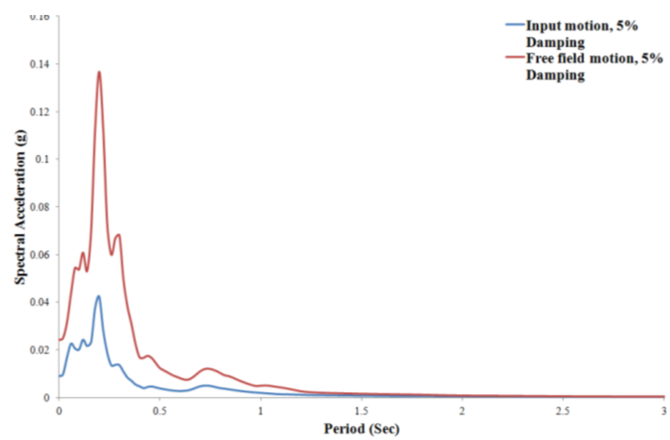

Fig. 13: Response Spectrum of input vs. free field ground motion of 09-Sep-09 Earthquake

Spectral acceleration plot as shown in Figure 12, 13 & 14 shows that there is a substantial change in spectral amplification from the range of 0.04 – 0.15g to 0.14 – 0.50g indicating substantial spectral amplification in the predominant period range of 0.20 – 0.25 sec.

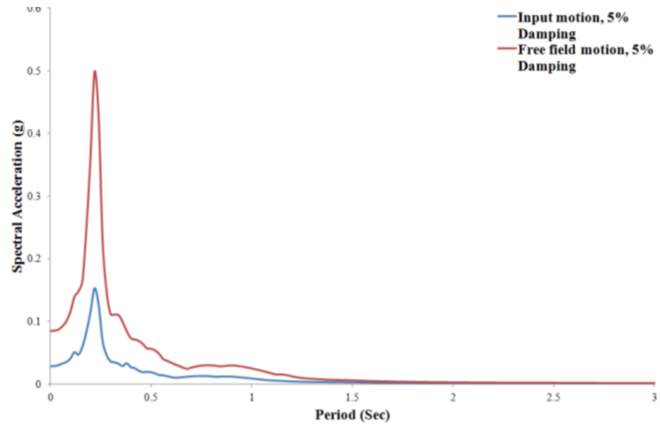

Fig. 14: Response Spectrum of input vs. free field ground motion of 21-Sep-09 Earthquake

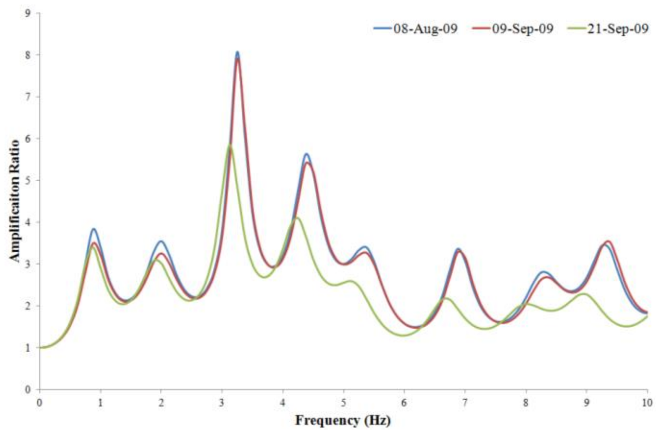

Fig. 15: Amplification Spectrum

Amplification Spectrum of the three one dimensional equivalent linear analyses can be seen in Figure 15. It is observed that amplification of the 21-Sep-2009(Mw 6.2, Focal Depth-8km) earthquake is less as compared to the 08-Aug-2009 (Mw 5.6, Focal depth-22km) and 03-Sep-2009(Mw 5.9, Focal Depth-100km) in the peak amplification frequency range of 3-4Hz.

HVSR Analysis

HVSR analysis (Lermo & Chavez-Garcia, 1993) of the earthquake waves have been conducted for the three cases. Although, there is sufficient debate (Bard, 1998; Bour et. al., 1998; Mucciarelli, 1998; Al-Yuncha & Luzon, 2000) on the applicability of HVSR method to define site amplification yet many authors (Lermo & Chavez-Garcia, 1993 etc.) have defined site amplification from HVSR method. However, there is a general agreement among many authors (eg. Lermo and Chavez, 1993; Gitterman et. al., 1996; Seekins et. al. 1996; Fah, 1997) that predominant resonance frequency of a site can be accurately determined for all practical purposes from the HVSR analysis. It was found that the predominant frequency for the site was in the range 0.5 – 2.0 Hz. Peak amplification within the range of 3.5 – 5.0 was observed in the predominant frequency range identified.

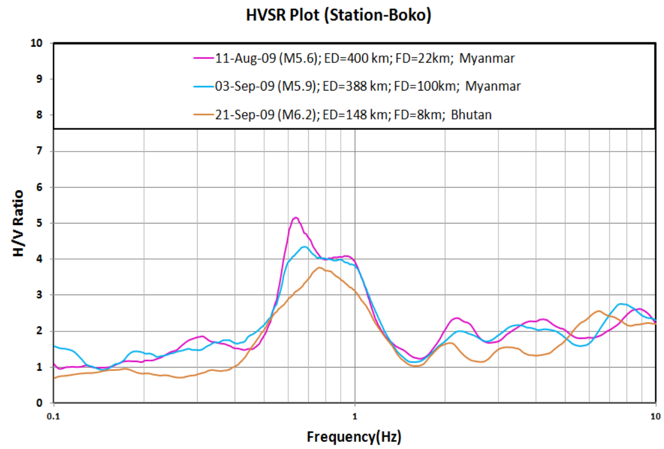

Fig. 15: HVSR plot

SUMMARY AND CONCLUSIONS

The study attempted to analyze a soil profile generalized from both bore hole data and Litholog to determine the effects on the earthquake waves when it travels from the bedrock to the surface. A comparison of the same parameter was done with HVSR analysis. It was found during the study that one dimensional equivalent linear method provided an substantial amplification of around 6.0 – 8.5 in the frequency range of 3.0 – 4.0 Hz, which might govern the design of the buildings in the 2 – 4 storey height range. Further, the amplification provided by both methods was found to be matching in the predominant frequency range of 0.5 – 2.0 Hz. It was observed that within this frequency range the amplification provided by both the methods was around 3.0 – 5.0 indicating a general agreement of the results. However, from the study in can be clearly stated that while extending the Guwahati city in line of CMP 2025 due importance has to be given to the proper assessment of site amplification and other allied seismic related parameters like liquefaction etc., for sustainable development by appropriate risk management.

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REFERENCES

1. Aki, K. (1988), "*Local site effects on strong ground motion*", Earthquake Engineering and Soil Dynamics II –

Recent Advances in Ground Motion Evaluation, June 27-30, Park City, Utah.

2. Al-Yuncha, Z. & Luzon, F., (2000), "*On the horizontal-to-vertical spectral ratio in sedimentary basins"*, Bull. Seism. Soc. Am., **90,** 1101–1106.

3. Anbazhagan, P. and Sitharam, T.G. (2009), "*Seismic Microzonation of Bangalore*", India, Journal of Earth Syst. Sci, 117, S2, November 2008, 883-852.

4. Bard, P.-Y. (1998), *" Microtremor measurements: a tool for site effect estimation?*", Proceeding of the Second International Symposium on the Effects of Surface Geology on Seismic Motion, Yokohama, Japan, **3,** 1251–1279

5. BIS (2002), "*IS: 1893-2002: Criteria for Earthquake Resistant Design of Structure*", Bureau of Indian Standards, New Delhi.

6. Borcherdt, R.D. (1970), "*Effects of local geology on ground motion near San Francisco Bay*", Bull. Seism. Soc. Am., 60, 29-61.

7. Borcherdt, R.D., G. Glassmoyer, A. Der Kiureghian, and E. Cranswick (1989), "*Results and data from seismologic and geologic studies following earthquakes of December 7, 1988 near Spitak, Armenia, S.S.R"*, US Geol. Surv. Open-File Rept., 89-163.

8. Borcherdt, R.D., and G. Glassmoyer (1992), "*On the characteristics of local geology and their influence on ground motions generated by the Loma Prieta earthquake in the San Francisco Bay region, California*", Bull. Seism. Soc. Am., 82, 603-641.

9. Bour, M., Fouissac, D., Dominique, P. & Martin, C., (1998), "*On the use of microtremor recordings in seismic microzonation",* Soil Dyn. and Earthq.Eng., 17, 465–474.

10. CMP-2025, "*Master Plan for Guwahati Metropolitan Area – 2025*", www.gmda.co.in

11. DST (2008),"*Microzonation of Guwahati City*", www.amtron.in

12. EERI (1994), "*Northridge earthquake, January 17, 1994, Preliminary reconnaissance report*", Earthquake Engineering Research Institute, Oakland, Calif.

13. Field, E.H., K.H. Jacob, and S.E. Hough (1992), *"Earthquake Site Response Estimation: A weak motion case study*", Bull. Seism. Soc. Am., 82, 2283-2307.

14. Gitterman, Y., Zaslavsky, Y., Shapira, A. & Shtivelman, V. (1996), *"Empirical site response evaluations: case studies in Israel",* Soil Dyn. and Earthq. Eng., 15**,** 447–463.

15. Fah, D. (1997), *"Microzonation of the city of Basel*", J. Seism., **1,** 87–102.

16. Hashash, Y.M.A., Groholski, D.R., Phillips, C.A., Park, D. and Musgrove, M. (2011), "*DEEPSOIL version 4.0, Tutorial and user Manual*", 98p

17. Hough, S.E., R.D, Borcherdt, P.A. Friberg, R. Busby, E. Filed, and K.H. Jacob (1990), "*The role of sediment-induced amplification in the collapse of the Nimitz freeway during the October 17, 1989 Loma Prieta earthquake*", Nature, 344, 853-855.

18. Kumar, S.S. and Dey, A. (2015), "*1D Ground Response Analysis to Identify Liquefiable Substrata: Case Study from Guwahati city*", UKIERI Workshop Workshop on Seismic Requalification of Pile Supported Structures (SRPSS)7-9 January 2015, Guwahati

19. Lermo, J. and E J. Chavez-Garcia (1993), *"Site effect evaluation using spectral ratios with only one station*", Bull. Seism. Soc. Am. 83, 1574-1594.

20. Mhaske, S.Y. and Choudhury, D. (2011), "*Geospatial contour mapping of shear wave velocity for Mumbai City*", Springer, 12 March, Nat Hazards (2011) 59:317–327.

21. Maheswari, U. R., Boominathan, A. and Dodagoudar, G.R. (2010), "*Use of Surface Waves in Statistical Correlations of Shear Wave Velocity and Penetration Resistance of Chennai soils",* Geotechnical and Geology Engineering, 28(2), 119-137.

22. Mittal, H.; Kumar, A.; Ramhmachuani, R. (2012), "*Indian National Strong Motion Instrumentation Network and Site Characterization of Its Stations",* International Journal of Geosciences, 2012, 3, 1151-1167.

23. Mucciarelli, M. (1998), "*Reliability and applicability of Nakamura's technique using microtremors: an experimental approach",* J. Earthq. Eng., **2,** 625– 638.

24. Roy, N. and Sahu, R.B. (2012), *"Site specific groundmotio simulation and seismic response analysis for microzonation of Kolkata",* Geomechanics and Engineering. Vol. 4, No. 1(2012), 1-18.

25. Schnabel, P.B. (1973), "*Effects of Local Geology and Distance from Source on Earthquake Ground Motion",* Ph.D. Thesis, University of California, Berkeley, California.

26. Seed, H.B., and Idriss", I.M. (1970), "*Soil Moduli and Damping Factors for Dynamic Response Analyses"*, Rep. No. EERC-70/10, Earthquake Engineering Research Center, University of California, Berkeley, California

27. Seed, H.B., and I.M. Idriss (1970), "*Soil Moduli and Damping Factors for DynamicResponse Analyses"*, Rep. No. EERC-70/10, Earthquake Engineering Research Center, University of California, Berkeley, California

28. Seekins, L.C., Wennerberg, L., Marghereti, L. & Liu, H.-P. (1996), "*Site amplification at five locations in San Fransico, California: a comparison of S waves, codas, and microtremors",* Bull. seism. Soc. Am., **86,** 627–635.

29. Sharma, B; Rahman, S.K. and Saikia, B.D. (2013), "*Use of contour maps for preliminary assessment of subsoil of Guwahati City*", Proceedings of Indian Geotechnical Conference, December 22-24, IIT, Roorkee.

30. Singh, S.K., E. Mena, and R. Castro (1988), "*Some aspects of source characteristics of the 19 September 1985 Michoacan earthquake and ground motion amplification in and near Mexico City from strong motion data"*, Bull. Seism. Soc. Am., 78, 451-477.

31. Tucker, B. E. and J. L. King (1984), "*Dependence of sediment-filled valley response on input amplitude and valley properties"*, Bull. Seism. Soc. Am. 74, 153-165.

32. Vucetic, M and Dobry, R.(1991), "*Effect of Soil Plasticity on Cyclic Response"*, Journal of Geotechncial Engineering, Vol. 117, No. 1, January 1991, ASCE. Pp. 89-107.