Shear Wave Velocity Profiling for Lucknow Urban centre using Seismic Refraction Survey

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ABSTRACT: The character of ground motion during any event changes completely when it reaches to the site due to local soil condition. This is the reason why the local geology is being studied in details while assessing the seismic safety for any important structure or a region. Since, the geology in any region can vary uniform to very complex, its study using the common methods like Standard Penetration Test (SPT) makes the effort very limited in terms of depth of exploration, costing, time for testing and setup problems. Under such condition, geophysical methods based on seismic refraction techniques like Multichannel Analysis of surface waves (MASW) can be used effectively being less time consuming, greater depth of exploration, accurate, non-destructive and parallely the other properties like Poisson's ratio can be easily evaluated in this method. Lucknow subsoil has been explored for soil classification using MASW at 50 locations. 14 locations were common where both MASW and SPT tests were carried out. Knowing the SPT N value and Vs in these locations at various depths, a correlation between N value and Vs has been proposed for the area under study and compared with the available relation in the literature showing good performance.

INTRODUCTION

Earthquakes like 2001 Bhuj, 1999 Chamoli has highlighted the role of local geology to change the ground motion features during an earthquake and caused large damages to the buildings in the region where loose sediments are predominant. The variation in the local geology usually follows complex nature. In order to capture this complexity accurately, large number of boring tests have to be carried out. Since, expensive, time consuming and the depth of boring also depend upon the testing method and soil type. Conventional SPT test is limited in depth due to many reasons. For microzonation studies, SPT data till 30 m depth should be effectively used. However, in case of any hard strata like rock, it's almost difficult to carry out the SPT test. Also, it requires large amount of money, labor and time to carry out such tests. Bypassing these difficulties in regular testing, geophysical techniques are alternative. Geophysical techniques have advantages including rapid testing, accurate results, can explore deeper depths, non-destructiveness and can be done in any type of soil except very loose. Using geophysical technique for site characterization and microzonation studies may enhance the degree of accuracy for such works. The limitations of geophysical techniques are requirement of open and long stretch ground, skilled labor and initial investment for the instrument. Present work consists of carrying out Subsoil exploration at Lucknow urban centre using one dimensional seismic refraction technique of MASW (Multichannel Analysis of Surface Waves). Method consists of using an active source for generating low frequency surface waves which will be recorded at known distance by 4.5 Hz geophone on a 24 channel geode. About 50 tests has been carried out in city of Lucknow urban center covering important locations of the city and evaluated Shear wave velocity (V_s) profiles at these locations. These Vs values are used to estimate average 30 m Vs values and these Site Classification considering conventional site classification system. Even though direct applicability of 30m concept for India is limited (Anbazhagan et al 2010a and b), in this study it is followed as there is no site classification system for deeper basins. SPT tests were also carried out at 14 locations close to MASW locations and N value variations with respect to depth have been obtained. Comparison between V_s and N value at each location has been done. These values are further used to develop correlation between SPT N and Vs values.

Study area details

Lucknow, capital of Uttar Pradesh is located in the historical region of awadh covers the central part of Indo-Gangetic plain The central part is located at 26.85° N,

80.92°E co-ordinates, covers an area of 2528 sq km at district level with a population of 28 lakhs. Its average elevation is 128m above sea level. However, there is a difference of 29m in the elevation from its highest elevation of 129m in the area of Sarda canal to its lowest elevation of 100m on the southeastern boundary. River Gomati flows from the mid of Lucknow along north-south direction.

Soil in the region is mainly comprises older and younger alluvium of Ganga-Ghagra interfluves. The older alluvium spreads over the vast area between elevations 115m and 129m, covering the areas like Chowk, Aminabad, Charbagh, kakori and Kakori. The alluvium comprises of weathered sediments of silty clay and sand with layers of Kankar in between. Sand mounds with height 4-5m from the ground level have been observed on Malihabad and Gosainganj.

Multichannel Analysis of Surface waves (MASW)

MASW is wisely used in India for site classification, to measure the dynamic properties of subsurface materials and microzonation (Anbazhagan and Sitharam, 2008 and 2010; Anbazhagan et al., 2009). In this study 24 channels geode in combination with 24 geophones of 4.5 Hz frequency has been used. Active source consists of a sledge hammer of 15 pounds for generating surface waves and these will be recorded by geophones at known distance from the source. The profiling procedure is divided into three steps namely 1) Recording of field data, 2) generation of dispersion curve (phase velocity vs. frequency), 3) Inversion from the dispersion curve (Anbazhagan and Sitharam, 2008). The outcome of the analysis will be the Vs variation with depth along with calculated signal to noise ratio (S/N) throughout the analysis. This method has been used in number of studies throughout world for site classification and site response studies (Anbazhagan et al., 2009; Maheshwari et. al 2010; Dikmen 2009).

In the present work, geophone interval of 1m with a short distance varies from 5 m to 25 m (Xu *et al.* 2006) have been carried out to assess the depth of penetration with 10 stacks. While generating dispersion curve, trials were made to fit the experimental curve with the theoretical curve for high S/N ratio. Dispersion curve is furthur used for inversion analysis with iterative procedure. After inversion, Vs profiles were obtained with initial and final Vs variation with depth along with final S/N ratio through the depth. Similar test and processing were repeated for the 50 locations. Figure 1 show MASW test locations in Lucknow. This study shows that a source distance of 15 m yield optimum penetration depth of 30m or more with minimum S/N ratio of more than 60%.

Seismic site characterization:

For Site classification 30 m average Vs (Vs^{30}) has been evaluated using the following formula;

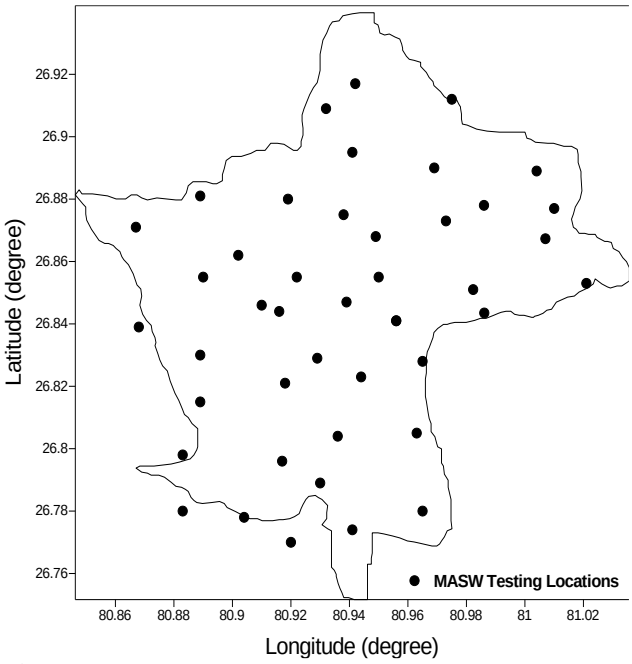

Figure1: MASW testing Locations

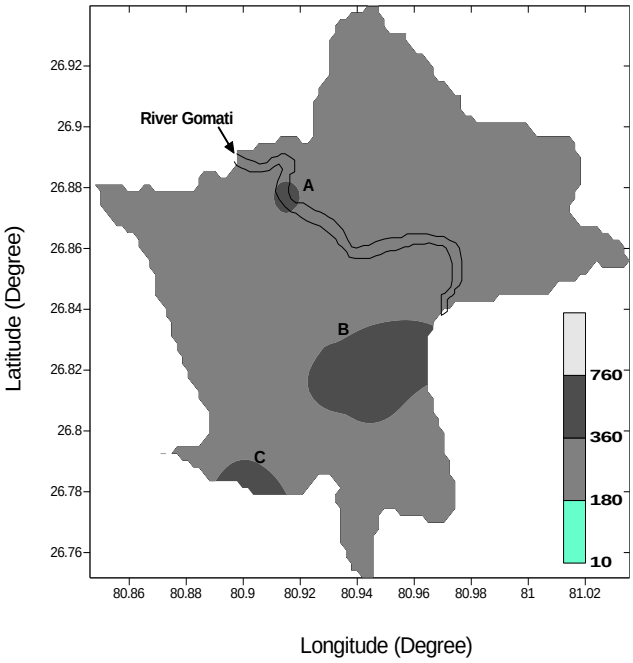

Figure 2: 30 m $V_{s\ average}$ contours along with River Gomati alignment

$$Vs^{30} = \frac{30}{\sum_{i}^{n} \frac{d_i}{Vs_i}} \quad (1)$$

Where; d_i=thickness of i^{th} layer
V_i =shear wave velocity of i^{th} layer

The estimated Vs^{30} at 50 locations are used to map Vs^{30} by considering Kriging technique for interpolated at intermediate locations. Figure 2 shows Vs^{30} distribution in Lucknow. It can be seen from the Figure 2 that most part of the city belongs to site class D having shear wave velocity ranging from 180 to 360m/s. Only some locations in Figure 2 (A, B and C) belongs to site class C. Field observation at these locations revealed that, point A belongs to the only area having some construction along the Gomati river, one wharf called as Kudiya Ghat along with some monuments. This historic construction activity might compacted the soil and became stiffer when compared to other area near by. Similarly, point B covers areas like Parade ground, Telibagh, Badi Lal kurti,Shai lines and Alambagh along with Charbagh railway station. These areas are developed in earlier time hence the soil has undergone immense settlement, also bore holes at these locations resembles soil with bulk density of 2.04g/cc and SPT N values in the range of 47-50. Again location C comprises areas consisting areas near Amausi Airport and nearby locations. Bore hole testing done adjacently to the airport at NH25 (Lucknow-Malihabad road) indicates purely clayey soil with a bulk density of 2.03 g/cc and SPT N value of 48.

Comparison between Vs and Uncorrected SPT N value

Data from 14 locations with both MASW and SPT tests have been collected to develop the correlation. Some typical data used for the statistical analysis is shown in figure 3. In total, 200 pair of data has been used for regression analysis. Since, the area under study has mixed type for soil and due to limited number of data available for each type of soil, the relation developed is applicable to all types of soil. Figure 4 shows a regression relation obtained with data. Equation 2 shows obtained regression relation with R^2 value of 0.74.

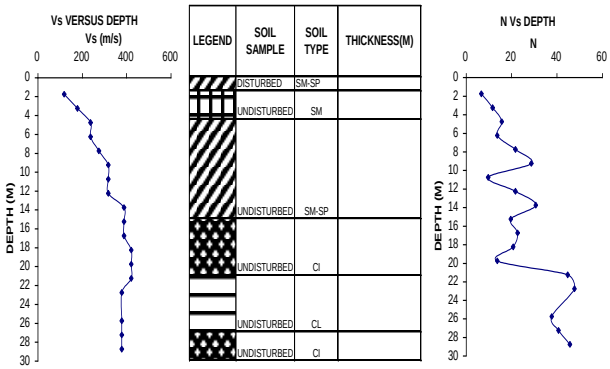

Figure 3: Typical V_s and SPT N variation used for the regression analysis

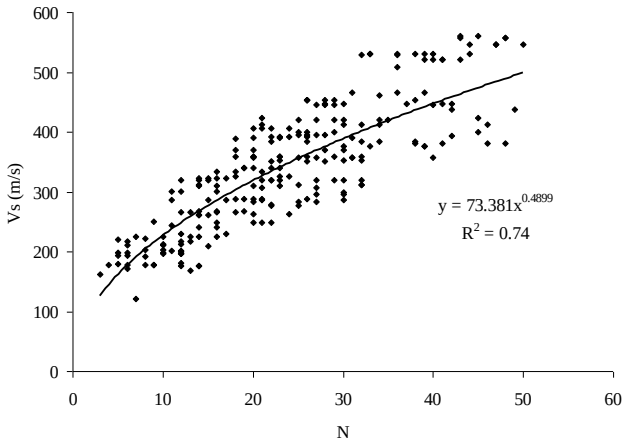

Figure 4: Correlation between N and V_s developed for all type of soils of Lucknow urban centre

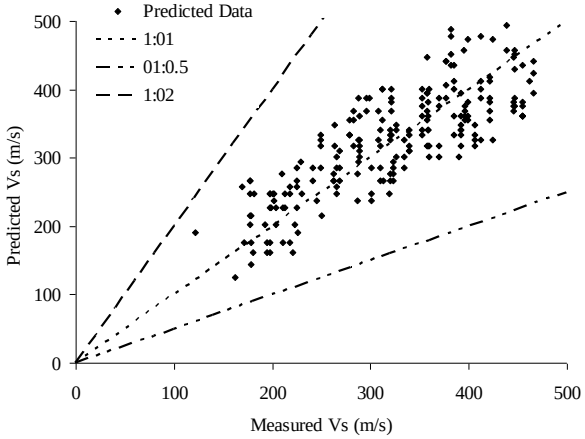

Figure 5: Comparison between measured and predicted shear wave velocities

$$Vs = 73.381N^{0.4899} \quad (2)$$

Comparison between measured and predicted Vs from the above relation are scattered between the lines of slope 1:0.5 and 1:2 as shown in Figure 5.
The newly developed correlation has been compared with the existing correlation for Indian Soil (Hanumantharao and Ramana, 2008) and also with Japan Road Association (JPA). Figure 6 shows that the new relation matches well with the other relation. The study area is mainly consists of loose sandy and clayey with a thickness of more than 300 m (as per Central ground water board (CGWB).

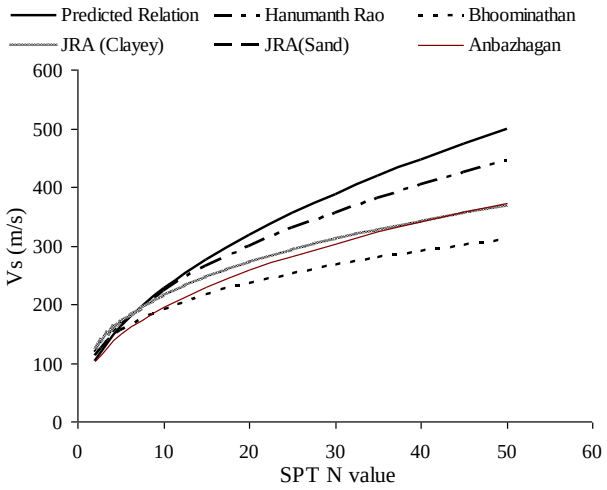

Figure 6: Comparison between predicted relations with other relations for Indian region

Conclusion

This paper presented seismic site characterization of Lucknow urban centre. This work will be continued future for microzonation. The seismic refraction survey of MASW has been carried out at 50 locations in the study area. Vs has been measured and used to estimate Vs^{30} for site classification. Vs^{30} shows that most of the city area belongs to site class D and some locations to class C as per NEHRP site classification system. Similar classification also obtained from borehole with SPT N values. Out of these 50 locations, 14 locations were close borehole with SPT N values and other laboratory tests. In these locations Vs and N values are comparable, which were used to develop correlation between uncorrected SPT-N and Vs. The newly developed relation was compared with the relations available in the literature shows good agreement. The developed relation is applicable upto the SPT N value of 50, since the regression analysis is limited to maximum N value of 50.

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References:

Anbazhagan, P., Abhishek Kumar and Sitharam, T.G. (2010) "Site Response Deep Sites in Indo-Gangetic Plain for Different Historic Earthquakes" Proceedings of Fifth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, San Diego, California, Paper No. 3.21b: P-12.

Anbazhagan, P, Neaz Sheikh and Hing-Ho Tsang (2010b), "Seismic Site Classification Practice In Australia, China And India: Suitability" proceedings of International Conference on Materials, Mechanics and Management (IMMM2010), Kerala, India, Vol,1, pp 189-197.

Anbazhagan, P., and Sitharam, T. G., (2008), Mapping of Average Shear Wave Velocity for Bangalore Region: A Case Study, Journal of Environmental & Engineering Geophysics Vol. 13, (2), pp. 69-84.

Anbazhagan, P. and Sitharam, T. G. (2010) "Relationship between Low Strain Shear Modulus and Standard Penetration Test 'N' Values" ASTM Geotechnical Testing Journal, 33 (2); 150-164.

Anbazhagan. P., Sitharam T.G., and Vipin, K. S (2009) Site Classification and Estimation of Surface Level Seismic Hazard Using Geophysical Data and Probabilistic Approach, Journal of Applied Geophysics, 68 (2), 219-230.

Dikmen Unal 2009 Statistical Correlations of shear wave velocity and penetration resistance for soils *J. Geophys. Eng.* 6 61-72.

Hanumantho Rao C and G V Ramana 2008 Dynamic Soil properties for microzonation of Delhi, India. *J. Earth. Syst. Sci.* 117 (S2). 719-730.

Maheshwari R Uma, Boominathan A and Dodagoudar G R 2004 Seismic site characterization for nuclear structures and power plants; *Curr. Sci.* 87 1384–1397.

Japan Road Association (JRA) (1980) Specification for highway bridges. Part V, *Earthquake resistant design*.

Xu, Y., Xia, J. & Miller, R.D. 2006. Quantitative estimation of minimum offset for multichannel surface-wave survey with actively exciting source. *Journal of Applied Geophysics* 59(No. 2):117–125.