PREDICTION OF SHEAR WAVE VELOCITY USING SPT – N VALUE

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Abstract

Shear wave velocity is an important parameter with respect to geophysical investigation, site classification and microzonation studies. For site characterization, it is important to determine shear wave velocity directly using an empirical correlation when it is difficult to conduct the test at all location because of lack of equipment's availability, unavailability of open space to perform the test and initial investments for instrument. The objectives are focused on studying the shear wave velocity profile for subsurface soil using Multichannel Analysis of Surface Wave (MASW) technique used in geophysical investigation, to determine the correlation between shear wave velocity (V_s) and SPT value (N) using regression analysis and to determine the average shear wave velocity (Vs_{30}) for the top 30 m depth of soil for site classification as per National Earthquake Hazard Reduction program (NEHRP). Subsurface soil profile and other engineering properties can be evaluated by drilling bore holes and conducting standard penetration test (SPT). Using SPT results, a prediction of shear wave velocity is done by non-linear regression analysis as it is very difficult to see the actual behavior of shear wave velocity with the subsurface soil strata beneath the ground surface and also standard penetration test is laborious and highly time consuming.

Index Terms - MASW, NEHRP, SPT value (N), Vs, Vs_{30}.

I.INTRODUCTION

The hazardous effects of earthquake are generally affected by the behavior of soil under dynamic loading; such behavior under dynamic loading is determined by the dynamic soil properties such as shear wave velocity, shear modulus, poisson's ratio and damping characteristics. Many earthquakes (Kashmir (2005), Bhuj (2001), Chamoli (1999), Jabalpur (1997), Uttarkashi (1991), Assam (1950) and Shillong (1897)) indicate that topography changes due to change in ground motion features during an earthquake and caused large damages to those regions where loose deposits are predominant. This deviation in topography shows a complex nature. To see such a complexity accurately, geophysical and geotechnical investigations are carried out. Under geotechnical investigation, Standard Penetration Test (SPT) is conducted. Since depth of exploration depends on method of boring, soil type and many other factors hence SPT is limited in depth. For 30m depth SPT data can be effectively used for microzonation studies but in case of rocky strata, it is difficult to conduct SPT. Also, it takes large amount of time to carry out the test. Geophysical investigation is alternative including, accurate results, quick testing, can be conducted in any type of soil and deeper depth exploration. Geophysical investigation is limited because it requires skilled labour, open ground and initial investment for the instrument. Under geophysical investigation, shear wave velocity can be measured using MASW technique. This technique is used to determine the shear wave velocity profile for subsurface soil with respect to depth. It includes preparation of multichannel record (also called shot gather or a field fill) using 24 channel geode seismograph with 24 geophones of 4.5 Hz capacity, Dispersion curve analysis and Inversion curve analysis. First waves are captured in signal form then waves are analyzed for Dispersion curve, which is a function of phase velocity and frequency. Then inversion curve analysis is done to obtain shear wave velocity profile with respect to depth.

II.RELATED WORKS

To evaluate the shear wave velocity profile near surface Multi Channel Analysis of Surface Waves (MASW) is a fast method because of its multichannel recording and it also covers the depth in the entire range of investigation. Because of its high accuracy, fast speed and investigation of elastic property near surface material MASW is efficient as compare to Spectral Analysis of Surface Waves (SASW) [15]. It needs a proper shear wave velocity profile to evaluate seismic site dependent parameters. In these days seismic refraction technique is largely used to determine the dynamic properties of underlying layers [8].Shear wave velocity is used to evaluate dynamic behavior of soil, which is an important parameter to determine shear modulus and seismic site characterization [1]. Shear wave velocity is an important parameter to represent the stiffness of soil at low strain level [20]. It is considered as an advantage to evaluate a reliable correlation between Vs and standard penetration blow count (SPT-N) when it is unfeasible to perform the test at all locations [12]. Due to presence of loose sediments the propagation of seismic waves near surface strongly affected and it results in variation of ground motion characteristics [11]. Unit weight, stiffness and material damping are soil properties used for dynamic ground analysis. To control site response characteristics shear wave velocity near surface and deeper sediments is one major factor. Use of shear wave velocity is an alternative method to describe dynamic properties of soil. In seismic hazard analysis, site-specific shear wave velocity is an indication of the expected ground shaking, in response. However, the determination of shear wave velocity at field is not often economically feasible in urban areas for microzonation studies. This is also due to non-availability of necessary free space as per technical requirement for such field tests to an earthquake [4]. Shear wave velocity can be used for various applications, including foundation stiffness assessment, liquefaction potential, earthquake site response, soil compaction [17]. Presence of soil deposits predominantly responsible for earthquake motion at a site [10]. Many researchers developed their own correlations between shear wave velocity (Vs) and standard penetration value (N) for different types of soil, including clay, sand, silt and all type of soil by conducting both seismic refraction and standard penetration test at different locations. It has been observed that the differences exist in the correlations given by various researchers because of change in geological condition and also due to errors in the measurement of SPT value and shear wave velocity (Vs). The existing correlations given by other researchers are shown in Table I.

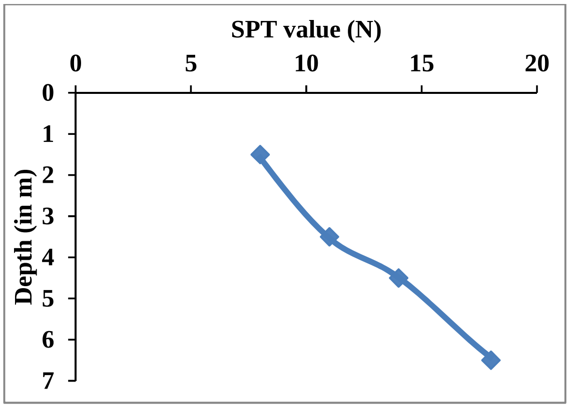
Table I Correlations given by other researchers

S. No.	Authors & Year	Type of Soil	Predicted Correlations
1	Anbazhagan and Sitharam (2006)	All soil	Vs = 50 $N_{60}^{0.41}$
2	Hanumantharao and Ramana (2008)	Sand	Vs = 79.0 $N^{0.434}$
		Silty sand	Vs = 86 $N^{0.42}$
		All soils	Vs = 82.6 $N^{0.43}$
3	Unal Dikmen (2009)	All soil	Vs = 58 $N^{0.39}$
		Sand	Vs = 73 $N^{0.33}$
		Silt	Vs = 60 $N^{0.36}$
		Clay	Vs = 44 $N^{0.48}$
4	Maheswari, Boominathan and Dodagoudar (2010)	All soil	Vs = 95.64 $N^{0.301}$

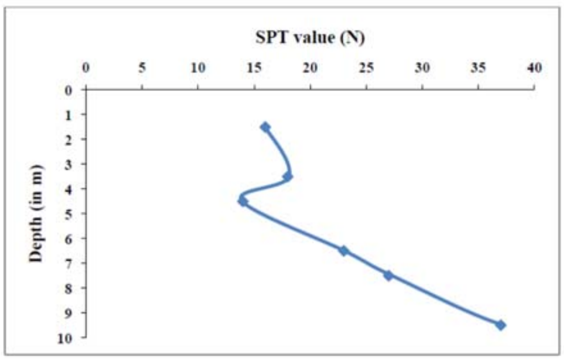
S. No.	Authors & Year	Type of Soil	Predicted Correlations
5	Kumar, Anbazhagan and Sitharam (2010)	Sand	$Vs = 100.53 N^{0.265}$
		Clay	$Vs = 89.31 N^{0.358}$
		All soil	$Vs = 73.381 N^{0.489}$
6	Tsiambaos and Sabatakakis (2011)	All soils	$Vs = 136.6 N^{0.274}$
		Clay	$Vs = 140.1 N^{0.290}$
		Silt	$Vs = 99.45 N^{0.364}$
		Sand	$Vs = 92 N^{0.341}$
7	Chaterjee and Chaudhury (2013)	All soils	$Vs = 78.21 N^{0.3769}$
		Clay	$Vs = 77.11 N^{0.3925}$
		Sand	$Vs = 54.82 N^{0.5255}$
		Silt	$Vs = 58.02 N^{0.455}$
8	Fauji, Irsyam, and Fauzi, U. J (2014)	All soil	$Vs = 105.03 N^{0.286}$
9	Kirar, Maheshwari, and Muley (2016)	Sand	$Vs = 100.3 N^{0.348}$
		Clay	$Vs = 94.4 N^{0.379}$
		All soils	$Vs = 99.5 N^{0.345}$

III.GEOTECHNICAL INVESTIGATION

The test site falls in Sehore district near Budni block. The district is generally covered with black cotton soils covering almost three fourths of the area. The rest part has red yellow mixed soils derived from sandstone, shale, gneiss. The alluvial soils are found along the river courses. A major portion of Budni block falling in the south eastern part of the district is covered with Vindhyan formations comprising sandstones, shales, quartzite and breccias. Geotechnical investigation is done by drilling bore holes. Bore holes are drilled at 24 locations, out of which observed standard penetration value is available only at 7 locations. In these 7 locations maximum depth of penetration is done up to 10 meter from the ground level. The type of soil found in such locations is silty clay. At the remaining 16 locations rock drilling is done due to presence of moderately weathered to highly weathered rock. The coring was done by using impregnated NX size diamond drill bitsand double tube core barrel, which produces a nominal core and hole diameter of 52mm and 76 mm respectively. For boring Boreholes of 150 mm diameter were sunk with the help of auger and cable operated shell using engine driven mechanical winch. The auger is connected with adequate length of pipes and rotated thereby at the bottom of the hole. The soil cuttings are held in the auger and are drawn to the surface by pulling the auger out of the hole each time the auger is filled. In continuation to auger boring shell is used which is a 127mm diameter steel cylinder with a cutting edge at the bottom and is fitted with a hinged one-way flap valve at the bottom. The bore hole is advanced by raising the shell up to a height and allowing it to fall and this is repeated several times till sufficient amount of soil enters the shell. When the shell gets nearly filled with soil, it is lifted out of the bore hole and emptied. Seamless flush jointed steel casing of 150mm size is used to prevent any caving and water loss from bore holes and those are inserted simultaneously with the advancement of boring operation. Depth wise measured SPT value for some location is shown in Fig. 1 (a) and (b)



(a)

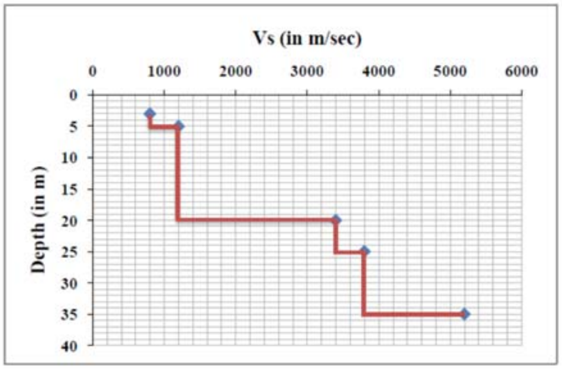


(b)

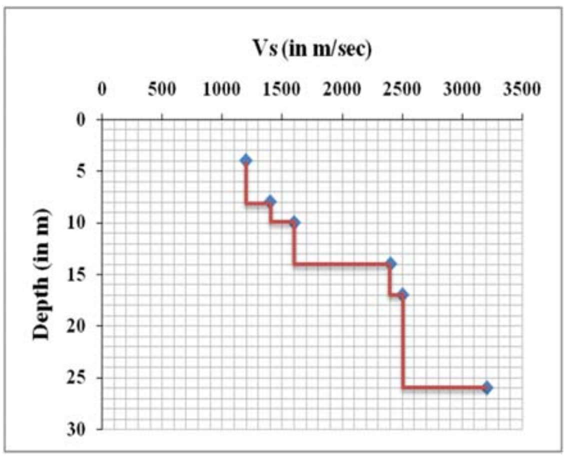
Fig. 1 (a) Measured SPT with depth at chainage 1+200 Km.
(b) Measured SPT with depth at chainage 2+800 Km.

IV.GEOPHYSICAL INVESTIGATION

Determination of Dynamic soil properties including, shear modulus, elastic modulus, poisson's ratio and damping characteristics can be done by both laboratory and field tests but determination of shear wave velocity through the soil or on the response of soil structure systems to dynamic excitation generally depends on field methods. The seismic refraction method, due to its versatility, is one of the most commonly used geophysical methods in various engineering applications, including mining, ground water exploration and environmental site investigations. This method is based on the measurement of the travel time of seismic waves refracted at the interfaces between subsurface layer of different velocity. Seismic energy is provided by a source (shot) located on the surface. Seismic energy is provided by impacting hammer on a plate. Energy radiates out from the shot point, either travelling directly through upper layer (direct arrivals), or travelling down to and then laterally along higher velocity layers (refracted arrivals) before returning to the surface. This energy is detected on surface using linear array (or spread) of geophones spaced at regular intervals. Beyond a certain distance from the shot points, known as the cross-over distance, the refracted signal is observed as a first arrival signal at the geophones, arriving before the direct arrival. Observation of the travel times of the direct and refracted signals provides information on the depth profile of the refractor. Shots are deployed at and beyond both the ends of the geophone spread in order to acquire refracted energy as first arrivals at each geophone position. Travel time versus distance graph is then constructed and velocities calculated for the overburden and refract or layers through analysis. Depth profiles for each refractor are produced by an analytic procedure based on consideration of shot and receiver geometry and the measured travel times and calculated velocities. The final output comprises velocity profile with respect to depth for subsurface soil. The equipments used for seismic refraction test are, a 24 channel seismograph with 16 bit resolution, automatic pre-trigger in connection with 24 electromagnetic geophones having frequency 10 Hz and Two connection cable of 60 meter length to connect the geophones. The cables have fixed connections with the geophones at every 5 meter interval in order to facilitate the positioning of geophones, thus sensors position is tied. Therefore array of all 24 geophones has a theoretical length of 115 m. This length is considered as theoretical length because due to site specific issue and undulating morphological / ground surface. The energy source is provided by impacting a hammer of weight 9 Kg on a metal plate. Referring to the geological conditions and the distance between geophones, the current survey leads to a maximum depth of investigation varying between 20 m to 35 m. For each test the shot sequence is composed of seven shots: two external to the array at 30m distance from geophone no. 1 and geophone no. 24, one each in position of geophone no. 1 and geophone no. 24, one between geophone no. 6 and geophone no. 7, one between geophone no. 12 and geophone no. 13 and one between geophone no. 18 and geophone no. 19. Due to site specific situation, at some locations the distance of the external shot from the end geophones has been reduced or in extreme cases the external shot has not been carried out. Depth wise measured shear wave velocity for location SR-1 and SR-5 is shown in Fig. 2 (a) and (b).



(a)



(b)

Fig. 2 (a) Measured shear wave velocity for SR-1 location
(b) Measured shear wave velocity for SR-5 location

V.RESULTS AND DISCUSSIONS

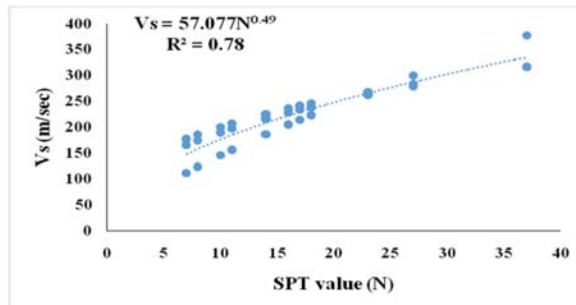
For site characterization, it is important to determine shear wave velocity directly using an empirical correlation when it is difficult to conduct the test at all location because of lack of equipment's availability, laborious, unavailability of open space to perform the test and initial investments for instrument. At no any nearby location both SPT and seismic refraction test are carried out. So it is difficult to predict the true correlation. To overcome such difficulty correlations given by other researchers is used to determine another variable. Hence the correlation is established for two locations.

i) For such location where only SPT value is available.
ii) For such location where only shear wave velocity is available.

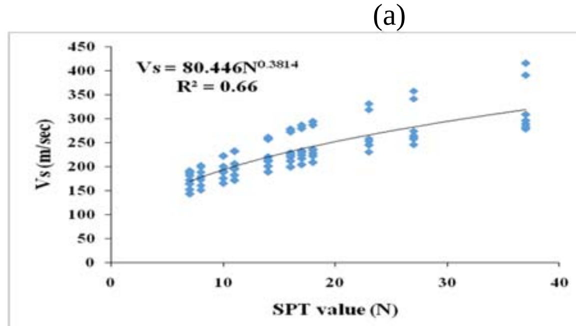
Using non-linear regression analysis Shear wave velocity is predicted as a function of SPT (N) value for different types of soil (clay, all soil and sand). The predicted correlation is in the form of power function refer (1).

$$Vs = aN^b \quad (1)$$

The predicted correlations for different types of soil including clay, all soil and sand are shown in fig. 3 (a), (b) and (c) for such locations where only SPT value is available.



(a)



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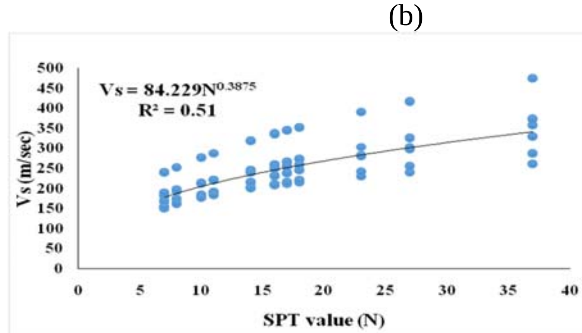
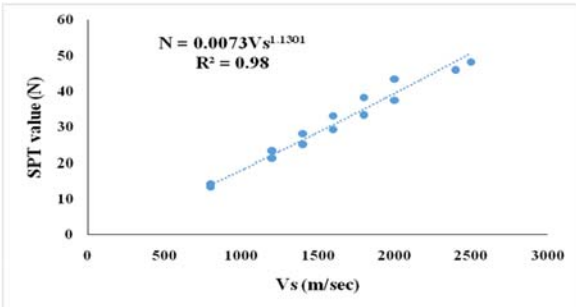


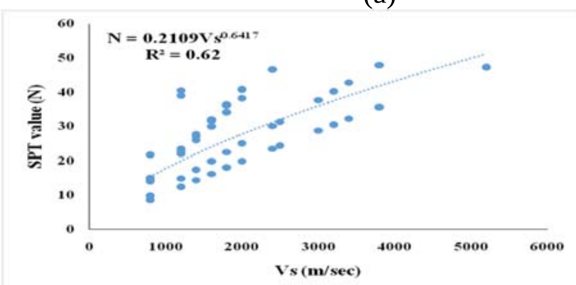
(c)

Fig. 3 (a) Correlation between shear wave velocity (Vs) and SPT (N) for clay. (b) Correlation between shear wave velocity (Vs) and SPT (N) for all soil. (c) Correlation between shear wave velocity (Vs) and SPT (N) for sand.

Similarly the correlation is established between SPT value and shear wave velocity for such locations where only shear wave velocity data is available. By using existing correlations given by other researchers shear wave velocity parameter is determined and a new correlation is established. The predicted correlations are shown in Fig. 4 (a), (b) and (c).



(a)



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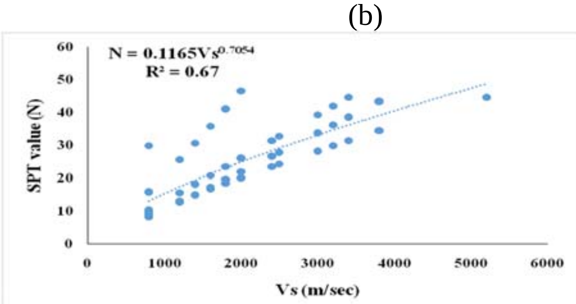
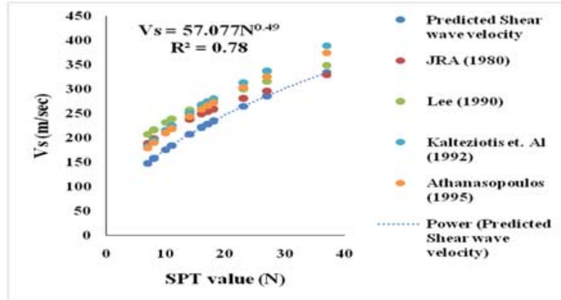


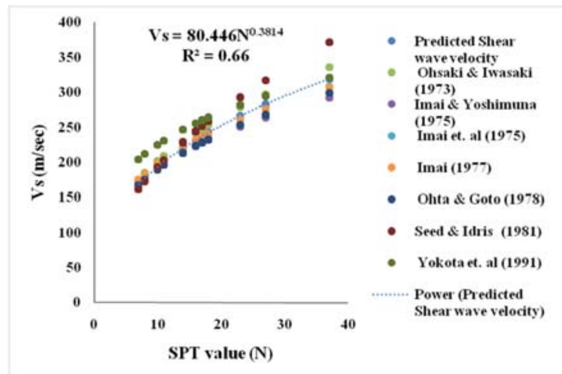
(c)

Fig. 4 (a) Correlation between SPT and shear wave velocity for clay. (b) Correlation between SPT and shear wave velocity for all soil. (c) Correlation between SPT and shear wave velocity for sand.

To validate the results the predicted correlations between shear wave velocity and SPT value for clay, sand and all soil are compared with the existing correlations given by other researchers. The comparison is shown in Fig. 5 (a), (b) and (c). It shows a similar pattern followed by existing correlations given by other researchers.



(a)



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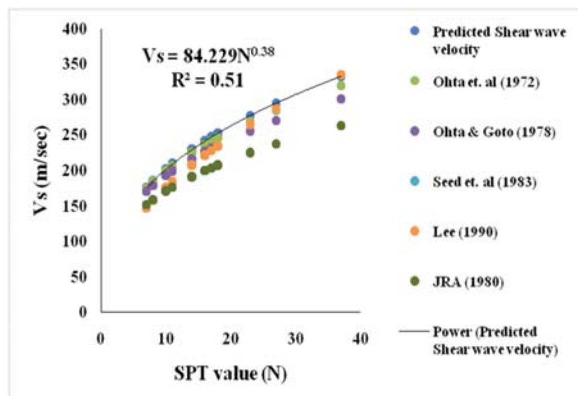
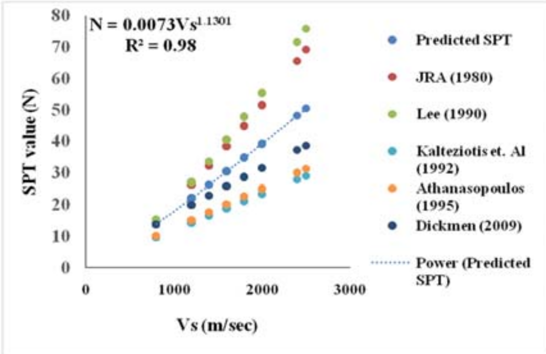


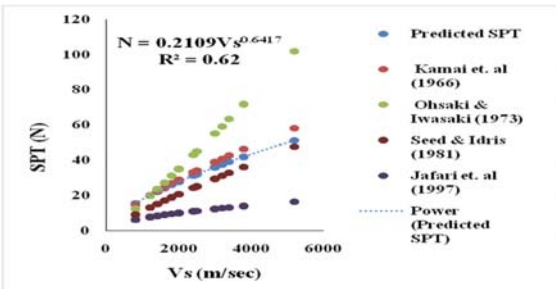
(c)

Fig. 5 (a) Comparison of predicted shear wave velocity for clay. (b) Comparison of predicted shear wave velocity for all soil. (c) Comparison of predicted shear wave velocity for sand.

Similarly the predicted correlations between SPT value and shear wave velocity for clay, sand and all soil are compared with the existing correlations given by other researchers. The comparison is shown in Fig. 6 (a), (b) and (c). It shows a similar pattern followed by existing correlations given by other researchers.



(a)



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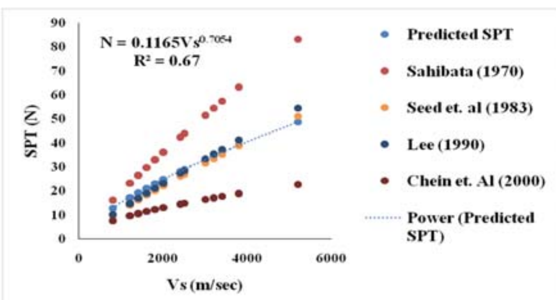

(c)

Figure 6 (a) Comparison of predicted SPT for clay. (b) Comparison of predicted SPT for all soil. (c) Comparison of predicted SPT for sand.

VI.SITE CLASSIFICATION

Site classification is done by evaluating average shear wave velocity (Vs_{30}) for top 30 m subsurface soil. For site classification type of soil and class of soil can be defined as per National Earthquake Hazard Reduction Program (NEHRP). To evaluate the average shear wave velocity following expression can be used refer (2).

$$Vs_{30} = \frac{\sum_{i=1}^{n} hi}{\sum_{i=1}^{n} hi/_{Vsi}} \quad (2)$$

Where h_i and Vs_i denote the thickness in meter and shear wave velocity of the i^{th} layer in meter per sec respectively, in a total of n, exiting in the top 30m. The Vs_{30} was accepted for site classification in the USA (NEHRP) by the UBC (Uniform Building Code) in 1997. To characterize the site the Vs_{30} has been calculated.

Table II Site classification scheme defined in NEHRP Provision (1998) and Uniform Building Code (UBC) (1997)

S. No.	Class	Vs_{30} (m/sec) Average shear wave velocity for top 30 m subsurface soil	Type of soil
1	A	>1500	Hard rock
2	B	760-1500	Rock
3	C	360-760	Very dense soil
S. No.	**Class**	**Vs_{30} (m/sec) Average shear wave velocity for top 30 m subsurface soil**	**Type of soil**
4	D	180-360	Stiff soil
5	E	<180	Soft clay soil

Average shear wave velocity (Vs_{30}) is calculated for proposed site at Budni where seismic refraction test is conducted at five locations named as SR-1, SR-2, SR-3, SR-4 and SR-5. From the calculated average shear wave velocity it has been observed that at four locations, SR-1, SR-3, SR-4 and SR-5 site falls under class A and the average shear wave velocity range is found in between 2286 m/sec to 3586 m/sec and the type of soil is hard rock. At SR-2 location the average shear wave velocity is found 1480 m/sec. it shows that the velocity is less than 1500 m/sec and it falls under class B and the type of soil is rock. The calculated average shear wave velocity for different location is shown in Table III.

Table III Calculated average shear wave velocity (Vs_{30}) for Budni site

S. No.	Location	Vs_{30} (m/sec)	Class	Type of Soil
1	SR-1	2295	A	Hard rock
2	SR-2	1480	B	Rock
3	SR-3	3586	A	Hard rock
4	SR-4	3494		
5	SR-5	2286		

VII.CONCLUSION

For predicted shear wave velocity the best correlation is found for clay having coefficient of regression (R^2) value 0.78 which shows a quite strong correlation. Except clay the coefficient of regression value for other type of soil (all type, sand) is found in between 0.50 to 0.70 which shows a moderate correlation. The predicted shear wave velocity is limited up to SPT (N) value 50. Similarly for predicted SPT (N) value the best correlation is found for clay having coefficient of regression (R^2) value 0.98 which shows a quite strong correlation. The coefficient of regression for all soil and for sand is found in between 0.60 to 0.70 which again shows a moderate correlation. The predicted SPT (N) value is limited up to shear wave velocity 6000 m/sec. The differences exist in all the predicted correlations because of field measurement error and change in geology or soil strata. Empirical correlations are limited up to a certain value but for actual measurement of investigation field and laboratory tests are more effective.

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