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DEVELOPMENT OF NEW MODIFIED EMPIRICAL CORRELATION OF SHEAR WAVE VELOCITIES WITH STANDARD PENETRATION RESISTANCE IN GUWAHATI REGION

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Abstract
Information on shear wave velocities (VS) of soil deposits is required for solution of design earthquake motions, soil-structure interaction and wave amplification. Dynamic elastic moduli computed using shear wave velocities are used as input parameter in finite element programs for dynamic analysis of structures, for soil structure interaction and for assessing liquefaction potential of soil. There are several wave propagation tests namely; seismic cross-hole, down-hole,
up-hole and Multi-channel Analysis of Surface Waves (MASW) which yield shear wave velocity but all most of them are expensive. This paper attempt to propose a general correlation between shear wave velocity and standard penetration resistance based on empirical research equations which had been established worldwide. It first reviews earlier development and current advancement of previous related studies. Short reviews had revealed that previous investigations are all site dependent studies which tend to be independent from other researchers. Most of the researchers attempted to quantify the relation between shear wave velocity and standard penetration resistance at local scale for various countries in past few decades, others tried to correlate in terms of various soil indexes including depth, geological epoxy etc. Although numerous researchers had studied the correlation regression through empirical data, there is no concrete evidence to plot the range boundary of the regression correlations. Most researchers are in consensus to use a power-law form in describing the relationship between shear wave velocity and standard penetration resistance. This study propose new empirical correlation of VS and SPT-N values that has been generated based on statistical analysis of earlier published correlations which is applicable to all soil type.

Introduction
Shear wave velocity (V_S) of near ground surface is one of the important fundamental soil characteristics for both earthquake and geotechnical engineering. The most devastating damages and casualties are usually caused by ground shaking and enlarged by the site effect. Hence, shear wave have become key controller in ground response, soil-structure interaction and wave amplification. Shear wave for the top 30m also serve as key indicator in classifying site class for both building codes and design standard. Considering impotency of this issue, the necessity to describe subsurface characteristics and geology stratifications through shear wave velocity is essential.
Most of the researchers attempted to quantify the relation between shear wave velocity and standard penetration resistance at local scale for various countries in past few decades, others tried to correlate in terms of various soil indexes including depth, geological epoxy etc. Although these empirical correlations are convincing with notable worldwide agreement, it is region specific and not applicable to other site. The aim of this study is to review the existing empirical correlations and to generate universal correlation by using statistical simulation.

Literature study
Numerous relations between SPT blow count (N) and shear wave velocity (V_S) exist in the literature. Early efforts utilized laboratory results to develop correlations, and the correlations were subsequently refined as field measurement of V_S became more common and data became available. The early correlations based on field data often involved blow counts that were not corrected for energy, rod length, or sampler inside diameter. Hence, it is impossible to know whether bias is introduced by hammer efficiency, non-standard samplers, etc. Furthermore, various methods of measuring V_S were utilized in the correlations, including cross-hole, seismic CPT, spectral analysis of surface waves (SASW), and suspension logging. These different methods provide very different resolutions for V_S measurements at different depths. For example, SASW uses low frequencies to measure deep shear wave velocities, and the resulting measurement is averaged over a large mass of soil, but provides fairly high-resolution measurements near the surface whether other methods are often less accurate. Spatial resolution with depth suffers as a result, and it is unclear how a point estimate of N should correlate with a vertically averaged estimate of V_S. Cross-hole methods and suspension logging methods use higher frequency waves that average the properties of a much smaller mass of soil, and therefore provide a higher resolution point estimate similar in spatial scale to an SPT blow count.

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There are numerous, but similar definitions to limit their investigation boundaries within the context of V_S and SPT-N given by experts. There are diverse opinions as to include some additional dependent variables in describing the relationship. Although different researchers tried to correlate V_S in terms of various soil indexes including depth, geological epoxy and so on, soil type and SPT-N value are the most favorable parameters. The following subsections will further discuss on considerable influences of each variable towards shear wave velocity.

The most common functional form for the relations proposed in the literature is $V_S=A \cdot N^B$, where the constants A and B are determined by statistical regression of data set. A controls the amplitude and B controls the degree of curvature. The N-values are typically not corrected for overburden, but sometimes are corrected for hammer energy, rod length, and sampler inside diameter, in which case N would be replaced by N_{60}. The V_S values are typically not corrected for overburden. A significant number of correlations have been published on various soil types.

Imai and Yoshimura (1975) studied the relationship between seismic velocities and some index properties over 192 samples and developed empirical relationships for all soils.

Ohta Y, Goto N (1978) have developed fifteen empirical relations for shear wave velocity estimation using soil indices like SPT, depth, geological age and soil grain size from the data of about 300 soil samples collected in Japan.

Sykora and Stokoe (1983) pointed out that geological age and type of soil are not predictive of V_S while the uncorrected SPT-*N* value is most important.

Sykora and Koester (1988) found strong statistical correlations between dynamic shear resistance and standard penetration resistance in soils.

Iyisan (1996) examined the influence of the soil type on SPT-*N* versus V_S correlation using data collected from an earthquake-prone area in the eastern part of Turkey. The results showed that, except for gravels, the correlation equations developed for all soils, sand and clay yield approximately similar V_S values.

Jafari et al (2002) presented a detailed historical review on the statistical correlation between SPT-N versus V_S.

Hasancebi and Ulusay (2006) studied similar statistical correlations using 97 data pairs collected from an area in the north-western part of Turkey and developed empirical relationships for sands, clays, and for all soils irrespective of soil type.

Ulugergerli and Uyanık (2007) investigated statistical correlations using 327 samples collected from different areas of turkey and defined the empirical relationship as upper and lower bounds instead of a single average curve for estimating seismic velocities and relative density.

Ünal Dikmen(2009) suggested New empirical formulae to correlate SPT-N and V_S, based on a dataset collected in a part of Eskişehir settlement in the western central Anatolia region of Turkey. The results suggest that better correlations in estimation of V_S are acquired when the uncorrected blow counts are used.

Uma Maheswari et al.(2010), have developed a relation between V_S and SPT 'N' from the 200 data pairs (V_S and SPT-N) collected at 50 sites in Chennai city, India which predominantly consist of very soft to very stiff clay and very loose to dense sand as: $V_S= 95.64\ N^{0.301}$

Iyengar and Ghosh using only depth as the parameter has proposed a relation for the Delhi region as: $V_S = K\ D^n$ + error (Depth of soil).

There are total 60 established correlations which are developed globally within past 50 years have been selected and summarized in Table 1

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Year	Researcher	All soil	Cohesionless soil	Cohesive soil
1966	Kanai	$V_s = 19N^{0.6}$	-	-
1970	Ohba and Toriumi	$V_s = 84N^{0.31}$	-	-
	Shibata		$V_s = 32N^{0.5}$	-
	Imai and Yahimura	$V_s = 76N^{0.33}$		-
1972	Ohta et al		$V_s = 87N^{0.36}$	-
	Fujimara	$V_s = 92.1N^{0.337}$		-
1973	Ohsaki and Iwasaki	$V_s = 81.4N^{0.39}$	$V_s = 59.4N^{0.47}$	-
1975	Imai and Yoshimura	$V_s = 92N^{0.329}$	-	-
	Imai et al	$V_s = 89.9N^{0.341}$	-	-
1977	Imai	$V_s = 91N^{0.337}$	$V_s = 80.6N^{0.331}$	$V_s = 102N^{0.292}$
1978	Ohta and Goto	$V_s = 85.35N^{0.348}$	$V_s = 88N^{0.34}$	
1980	JRA		$V_s = 80N^{0.33}$	$V_s = 100N^{0.33}$
1981	Seed and Idriss	$V_s = 61.4N^{0.5}$	-	-
1982	Imai and Tonouchi	$V_s = 97N^{0.314}$	-	-
1983	Seed et al	-	$V_s = 56.4N^{0.5}$	-
	Sykora and Stokoe	-	$V_s = 100.5N^{0.29}$	-
1989	Okamoto et al	-	$V_s = 125N^{0.3}$	-
1990	Lee	-	$V_s = 57.4N^{0.49}$	$V_s = 114.43N^{0.31}$
	Imai and Yoshimura	$V_s = 76N^{0.33}$	-	-
1991	Yokota et al	$V_s = 121N^{0.27}$	-	-
1992	Kalteziotis et al	$V_s = 76.2N^{0.24}$	$V_s = 49.1N^{0.50}$	$V_s = 76.6N^{0.45}$
1995	Raptakis et al		$V_s = 100N^{0.24}$	$V_s = 184.2N^{0.17}$
	Athanasopoulos	$V_s = 107.6N^{0.36}$	-	-
	Sisman	$V_s = 32.8N^{0.51}$	-	-
1996	Iyisan	$V_s = 51.5N^{0.516}$	-	-
1997	Jafari et al	$V_s = 22N^{0.85}$	-	-
2000	Chien et al	-	$V_s = 22N^{0.76}$	-
2001	Kiku et al.	$V_s = 68.3N^{0.292}$	-	-
2002	Jafari et al	$V_s = 22N^{0.85}$	$V_s = 19N^{0.85}$	$V_s = 27N^{0.73}$
2007	Hasancebi and Ulusay	$V_s = 90N^{0.309}$	$V_s = 90.82N^{0.319}$	$V_s = 97.89N^{0.269}$
2008	Hanumantharao and Ramana	$V_s = 82.6N^{0.43}$	$V_s = 79N^{0.434}$	
2008	Lee and Tsai	$V_s = 137.153N^{0.229}$	$V_s = 98.07N^{0.305}$	$V_s = 163.15N^{0.192}$
2009	Dikmen	$V_s = 58N^{0.39}$	$V_s = 73N^{0.33}$	$V_s = 44N^{0.48}$
2010	Brandenberg et al			
	Uma Maheswari et al.	$V_s = 95.64N^{0.301}$	$V_s = 100.53N^{0.265}$	$V_s = 89.31N^{0.358}$
2011	Tsiambaos and Sabatakakis	$V_s = 105.7N^{0.327}$	$V_s = 79.7N^{0.365}$	$V_s = 88.8N^{0.370}$
2012	Anbazhagan et al	$V_s = 68.96N^{0.31}$	$V_s = 60.17N^{0.56}$	$V_s = 106.63N^{0.39}$

Table 1: Existing correlations between V_S and SPT-N

Objective

The main objective of the study is to see how shear wave velocity and geotechnical properties of soil are related to each other. Among various properties of soil, SPT-N value is the most important parameter that can be correlated with shear wave velocity more precisely. In this study, particular attention is given to the functional form used to relate VS to Nobs, Ncr and (N1)60 and to developed a new modified empirical correlation of shear wave velocities (VS) and Standard penetration resistance.

Project work and observation

A bore log test data have been collected from the site of LGBI Airport, Guwahati, where a field test have been carried out for the construction of hangers in the LGBI Airport site in the year of 2012. The variation of SPT-N value with increase in depth is shown in figure1.

Project name:
Construction of Hangers at LGBI Airport, Guwahati Authority of India.

- Depth of water table: 4.20 m below E.G.L.
- Method of drilling : Augur and Wash boring
- Bore hole no : 5

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- Bore hole started on : 19/01/2012
- Bore hole completed on : 22/01/2012
- Bore hole diameter : 150 mm

Courtesy:

- Airport Authority of India (AAI), Guwahati
- Vishal Infrastructure Limited
- Cadmetric Consulting
- Experto Geotechnical Consultants And Research Pvt. Ltd

SL NO	DEPTH (m)	N_{obs}
1	1.5	3
2	3	5
3	4.5	6
4	6	8
5	7.5	9
6	9	12
7	10.5	14
8	12	15
9	13.5	16
10	15	17
11	16.5	18
12	18	19
13	19.5	19
14	21	19
15	22.5	20
16	24	20
17	25.5	21
18	27	21
19	28.5	22
20	30	22

Table 2: Field test data for hangers construction in

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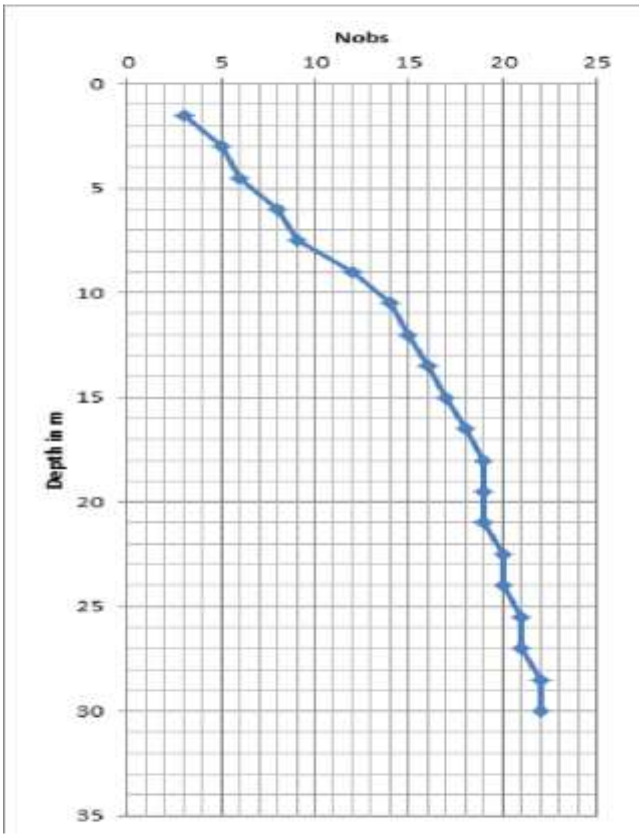

Fig 1: Depth vs. observed N-value in the LGBI airport, Guwahati.

SPT-N Value Correction

Overburden Correction

The observed SPT-N values are first corrected for overburden pressure considering equation of correction proposed by Peck, Hanson and Thornburn (1974).

Correction for Dilatancy

Next dilatancy correction is to be applied when corrected SPT-N value after overburden correction, exceeds 15 in saturated fine sands and silts as recommended by Terzaghi and Peck as per IS: 2131-1981. Now utilizing all the existing correlations modified empirical correlations are developed for both observed and corrected SPT-N values and analyzed. Next utilizing statistical means an attempt has been made to develop new modified correlations applicable to all soil type and analyzed.

Correction for field testing procedure

Observed SPT-N values are corrected for field testing procedures at 60% hammer efficiency and normalized to effective overburden pressure of 1 atmosphere to evaluate N_{60} and $(N_1)_{60}$. Other correction factor that incorporated is bore-hole diameter correction, sampler correction and rod-length correction adopted from Skempton (1986).

Correlation of V_S as per correlation of various research workers

Correlation of Shear Wave Velocity with respect to N_{60} and $(N_1)_{60}$ have been evaluated and Mean value of shear wave velocities is evaluated.

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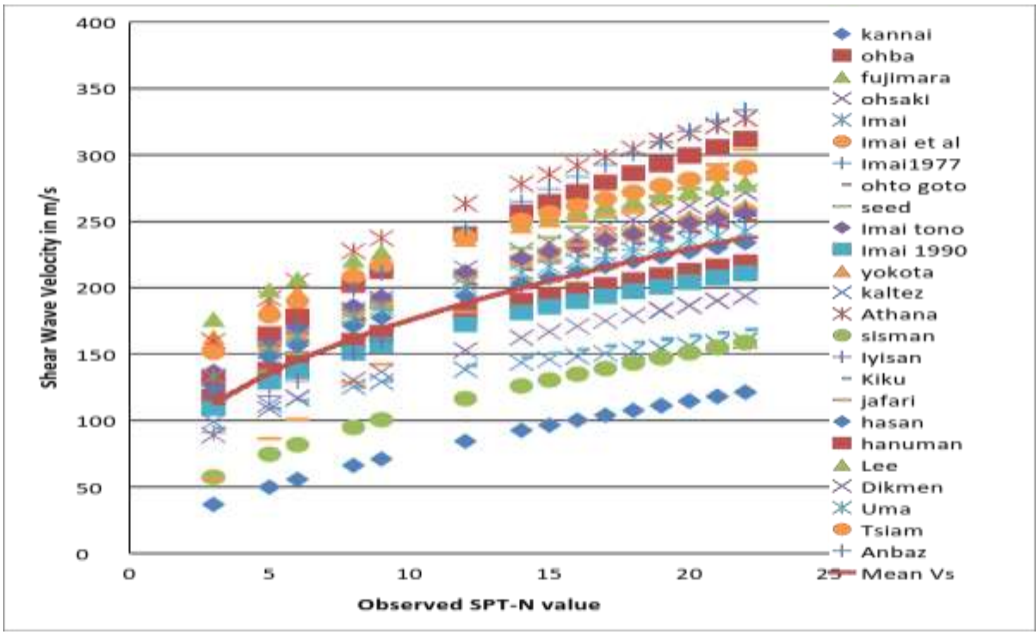

Fig 2: Correlation of V_S and N_{obs} and Mean V_S for all soil types

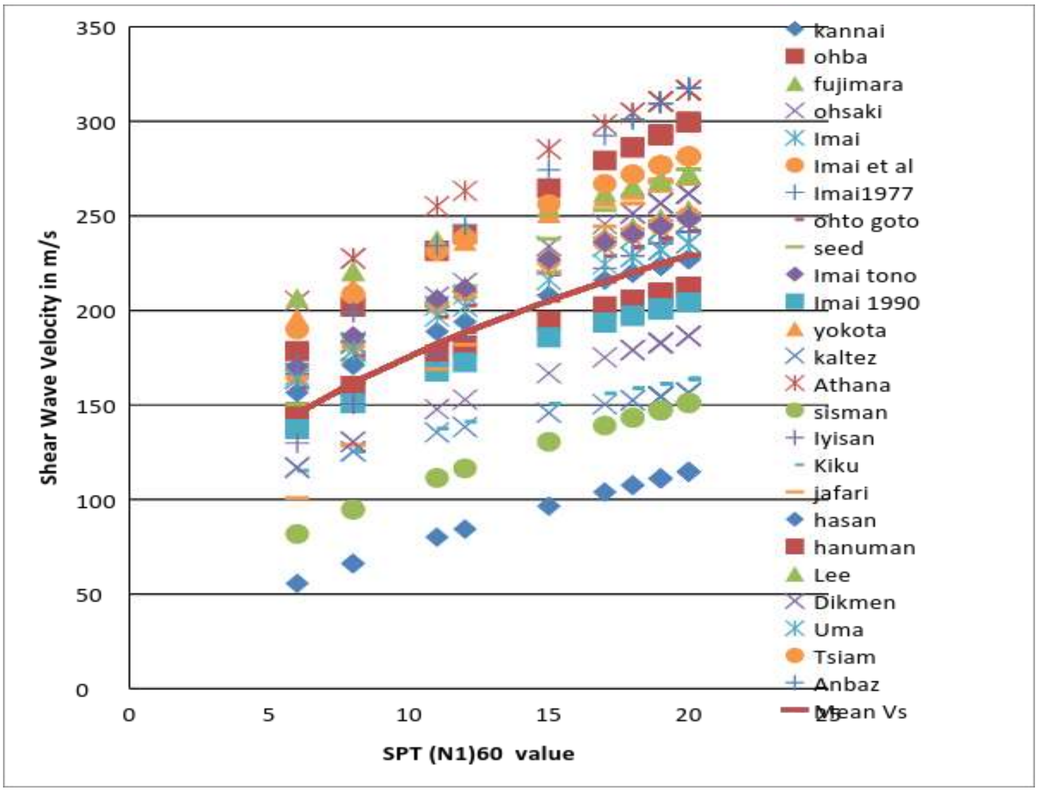

Fig 3: Correlation of V_S and $(N_1)_{60}$ and MeanV_S

Prediction of empirical correlation of shear wave velocity

Based on field test data of the present site, two empirical expressions are generated among which one equations is generated from correlation of V_S with N_{obs} and other one is developed from correlation of V_S with $(N_1)_{60}$. By analyzing these empirical correlations, the best fitted correlation of shear wave velocity and standard penetration resistance having high correlation coefficient is considered as the new modified empirical correlation of V_S that can be applicable in that site.

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Correlation of V_s With	Empirical Correlation	R^2 value
N_{obs}	$V_S = 74.24\ N_{obs}^{0.376}$	0.9
$(N_1)_{60}$	$V_S = 73.50\ (N_1)_{60}^{0.379}$	1

Table 3: Result summary

Observing new empirical correlations, it is found that new correlation of shear wave velocity with N_{obs} & $(N_1)_{60}$ gives nearly same correlation coefficient but empirical expression of shear wave velocity with SPT-$(N_1)_{60}$ shows higher value of B, where B is a constant that controls the curvature of curve.

Conclusion

This study shows an advancement to incorporate all earlier research findings to generate new modified correlations which are applicable to all soil types globally. On the basis of previous research findings, this study tries to generate modified empirical correlations of V_S with N_{obs} and $(N_1)_{60}$ utilizing about 25 existing empirical correlation of V_S and SPT-N values applicable to all soil type for a single bore hole in Guwahati region. From the observation it can be concluded that correlation of shear wave velocity with $(N_1)_{60}$ gives slightly higher correlation coefficient (R^2) than that given by the correlation with N_{obs}. Although both the modified correlation can be used for the prediction of shear wave velocity in any region of any soil composition. For further research, shear wave velocity can be computed for the same region using any direct method and that can be compared with the same found by using modified correlation of V_S and N values.

Reference

1. Akin, Muge K., Kramer, Steven L., Topal, Tamer (2011) “Empirical correlations of shear wave velocity Vs and penetration resistance SPT-N for different soils in an earthquake-prone area Erbaa, Turkey”, Engineering Geology 119.1-2.
2. Aminaton Marto, Choy Soon Tan and Tiong Kung Leong (2013) “Universal Correlation of Shear Wave Velocity and Standard Penetration Resistance”, University of Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia.
3. Anbazhagan P, Sitharam T.G. (2008), “Mapping of average shear wave velocity for Bangalore region: a case study”, J Environ Eng Geophys 13(2):69–84.
4. Andrus, R. D., Piratheepan, P., Ellis, B.S., Zhang, J., and Juang, C. H. (2004), “Comparing Liquefaction Evaluation Methods using Penetration-V_S relationships”, Soil Dynamics and Earthquake Engineering, 24, 713-721.
5. Campbell, K.W. and Duke, C.M. (1976), “Correlations among seismic velocity, depth and geology in the Los Angeles area”, Report ENG-7662, University of California at Los Angeles School of Engineering and Applied Science.
6. Ch.Subba Rao (2013), “Estimation of shear wave velocity from soil indices” published in Indian Geotechnical Society.
7. David W Sykora, “Examination of Existing Shear wave Velocity and Shear Modulus Correlations in Soil”
8. Dikmen, U (2009), “Statistical correlations of shear wave velocity and penetration resistance for soils”, Journal of Geophysics and Engineering, 6, 61-72.
9. Imai, T (1977), “P-and S-wave velocities of the ground in Japan”, Proc.9th Int. Conf. on Soil Mechanics and Foundation Engineering, vol 2, 127–32
10. Imai, T. and Tonouchi, K (1982), “Correlation of N-value with S-wave velocity and shear modulus”, Proc. 2nd European Symp. of Penetration Testing (Amsterdam), 57–72.
11. Iyisan (1996), “Correlation between Shear Wave Velocity and In-situ Standard Penetration results”, Teknik Dergi, vol 7, no 2, April, pp. 1187-1199.
12. IS:2131-1981, “Method for Standard Penetration Test for soil”
13. Jianfeng Zhang, Ronald D. Andrus and C. Hsein Juang(2005), “Normalized Shear Modulus and Material DampingRatio Relationships” Journal of Geotechnical and Geoenvironmental Engineering, Vol. 131, No. 4.
14. Kamil kayabah (1996), “Soil liquefaction evaluation using shear wave velocity”, University of Ankara, Turkey.

INTERNATIONAL JOURNAL OF RESEARCH SCIENCE & MANAGEMENT

15. Kanai, K.(1966), "Conf. on Cone Penetrometer the Ministry of Public Works and Settlement (Ankara, Turkey)", presented by Y Sakai 1968.
16. Naresh Bellana (2009), "Shear Wave Velocity as Function of SPT Penetration Resistance and Vertical Effective Stress at California Bridge Sites", University of California, Los Angeles.
17. Ohba, S. and Toriuma, I. (1970), "Dynamic response characteristics of Osaka Plain", Proc. Ann. Meeting AIJ (in Japanese).
18. Prof. Ramana G. V. and Gupta Sorabh (2003), "Dynamic properties of Delhi silt from field investigation", Department of civil engineering, IIT Delhi.
19. Uma Maheswari R, Boominathan A, Dodagoudar GR (2008), ''Development of empirical correlation between shear wave velocity and standard penetration resistance in soils of Chennai city'', The 14th World Conference on Earthquake Engineering, Beijing.
20. Unal Dikmen (2009), "Statistical correlations of shear wave velocity and penetration resistance for soils", Journal of geophysics and engineering volume 6 no 1.
21. Ohta Y, Goto N (1978), "Empirical shear wave velocity equations in terms of characteristic soil indexes", Earthquake Eng Struct Dynam 6:167–187.
22. P Anbazhagan and T G Sitharam (2008), "Seismic microzonation of Bangalore, India", Civil Engineering Department, Indian Institute of Science, Bangalore.
23. Shibata, T (1970), "Analysis of liquefaction of saturated sand during cyclic loading", Disaster Prevention Res. Inst. Bull., 13, 563–70.
24. Seed, H. B. and Idriss, I. M. (1970), "Soil Moduli and Damping Factors for Dynamic Response Analyses", Earthquake Engineering Research Center, University of California, Berkeley, California, Rep. No. EERC-70/10.
25. Sykora, D. E. and Stokoe, K. H. (1983), "Correlations of in-situ measurements in sands of shear wave velocity", Soil Dyn. Earthq. Eng., 20, 125–36.

"Seismic Microzonation Atlas of Guwahati region"(2007), Department of Science and Technology, Government of India, www.amtron.in/microzonation.