Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)
© 2016 Australian Geomechanics Society, Sydney, Australia, ISBN 978-0-9946261-1-0

Correlation of p-wave velocity and SPT-N on volcanic soils in Costa Rica

Ibanez, S.J., Ortiz-Palacio, S., Lopez-Ausin, V. & Porres-Benito, J.A.
INGITER S.L.-University of Burgos, Burgos, Spain

ABSTRACT: The prediction of the Standard Penetration Test (SPT-N) blow count using p-wave velocities (V_p) has been barely studied. Traditionally, the field s-wave velocities (V_s) have been the aim of the most of the efforts to correlate seismic behavior and penetration resistance properties of soils. Nevertheless, this new approach will expand the correlation to the field of primary waves. The potential use of this correlation will be useful in the search for new easy, non-invasive and non-expensive methods to probe soil properties in underdeveloped and developing countries, in which deep-boring machinery is hard to find or too expensive to use. After a large soil testing program in Costa Rica, in volcanic soils, p-waves were used to develop a correlation between p-wave velocity and N_{SPT} in the investigated soils.

1 INTRODUCTION

So far, there are many empirical studies getting a correlation between the shear wave velocity and the blow count from Standard Penetration Tests (V_s-N_{SPT}). This is a logical correlation because these magnitudes mainly depend on the shear strength of the soil skeleton.

The quantity of pore water only slightly changes the soil density (Qiu & Fox 2008) and has little influence on the V_s (Foti 2012).

The shear modulus of a soil (G) does not depend on the water content of a soil, but does depend on the effective stress, which in turn is affected by the pore pressure. This way, the aforementioned correlations are different for saturated and non-saturated soils.

Thaker & Rao (2011) calculated several correlations between V_s and N_{SPT} (see Table 1). It is interesting to note that they found better correlations for non-energy corrected values of N_{SPT}.

In practice, it is easier to perform p-wave testing than s-wave testing. So, even though there is much less done research about this issue, in this paper a correlation between V_p and N_{SPT} will be tried to find out.

Although it is relatively easy to get V_p, these dilatational wave velocities are more difficult to study because of the more complex multivariable mechanism around the propagation of these waves.

Table 1. Correlations between the shear wave velocity and the blow count from SPT tests.

Soil type	Correlation m/s	Correlation factor (R^2)
All soils	$V_s=59.72\cdot N_{SPT}^{0.42}$	0.77
Sandy soils	$V_s=51.21\cdot N_{SPT}^{0.42}$	0.78
Clayed soils	$V_s=62.41\cdot N_{SPT}^{0.42}$	0.78

Studies from Foti (2012) state that V_s depends mainly on G, but V_p depends also on the soil particle bulk modulus (K^{SK}) and water bulk modulus (K^F). This way, assuming complete saturation and solid incompressibility, we have the following dependencies (Equations 1 and 2):

$$V_s = f(G, n, \rho_s, \rho_F) \quad (1)$$

where n = porosity; ρ_s = solid particle density; and ρ_F = water density.

$$V_p = f(G, n, \rho_s, \rho_F, K^{SK}, K^F) \quad (2)$$

For unsaturated soils, Conte et al. (2009) introduced more new variables, as we can see in Equations 3 and 4:

$$V_s = f(G, n, \rho_s, \rho_F, S_r) \quad (3)$$

$$V_p = f(G, n, \rho_s, \rho_F, S_r, K^{SK}, K^F, K^a, \rho_a, \nu^{SK}, m_2^W) \quad (4)$$

where S_r=degree of saturation, K^a=air bulk modulus, ρ_a=air density, ν^{SK}=Poisson´s ratio, m^w_2=coefficient of water volume change due to matric suction variations.

V_p is affected by more variables than V_s is, so it is would seem reasonable to assume that a correlation between V_p and N_{SPT} is presumed to be affected by more parameters than the correlation between V_s and N_{SPT}.

There are several approaches to this issue. Ulugergerli & Uyanik (2007) proposed a range of possible values between an upper and a lower bound for clay-silt-sand-gravel deposits in western Turkey.

Bery & Saad (2012) also proposed a correlation for soils in Malaysia (sedimentary sands and clays over igneous rocks).

2 GEOTECHNICAL SURVEYING

2.1 *Site*

The field work was conducted at four different locations in Costa Rica (four different projected wind farms). One is called “Campos Azules” wind farm, another one is called “Altamira”. Both of them are located in Liberia, Guanacaste region. The third and the fourth wind farms are called “Vientos de Miramar” and “Vientos de la Perla”, and are situated close to Santa Rosa de Tilarán, also in the Guanacaste region (see Figure 1).

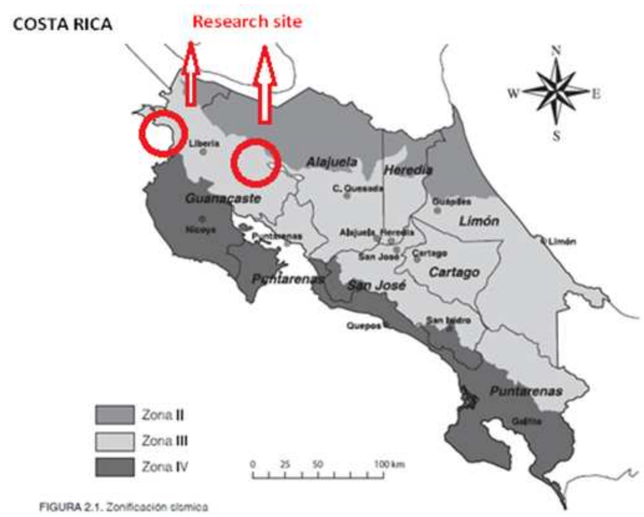

Figure 1. Research field site (from Código Sísmico de Costa Rica (2010)).

2.2 *Geological environment*

As this is a volcanic area, the geomorphology is a typical volcanic kind. At these four locations the geology is not quite different. At the surface there are volcanic ashes that mostly have turned into silty-clayed soil, because of weathering and alteration. These materials overlie a layer composed of volcanic rock fragments and blocks, that came from old lahar flows. Underlying these above mentioned layers there is a soft volcanic tuff layer. The latter layer is usually so deep that the tests analyzed in this research were not be carried out so deep to reach this tuff layer (in Santa Rosa de Tilarán zone, this tuff layer is even deeper than in Liberia zone).

2.3 *Tests performed*

The SPT tests were performed by Insuma Company with an old, but typical equipment in Costa Rica, as shown in Figure 2. The V_p were obtained using seismic refraction tests. These tests were carried out with a modern Pasi seismograph (Mod. 16S24-P) owned by INGITER, a university company. Twenty four geophones with a natural frequency of 10 Hz and 5 m span were used and a 6 kg sledge hammer was used to produce the seismic excitation.

The tests were performed at every location of a wind turbine mill. So, at some locations, there were directly comparable SPT and p-wave measurements. During this research, 61 data pairs were used to develop a new correlation between N_{SPT} and V_p that works in this type of volcanic soils in Costa Rica.

Figure 2. Equipment and tests carried out: SPT and seismic refraction tests.

3 RESULTS

In order to get the best possible correlation between N_{SPT} and V_p, the authors interpreted data pairs (N_{SPT}-V_p) in clearly comparable layers. If there was any doubt, the data were discarded.

Before researching and analyzing data, it was very difficult to predict which value of N_{SPT} would provide the best correlation with V_p, so several different N_{SPT} values were considered. First, the characteristic value with a 95% confidence interval ($N_{60,k}$), then the mean value of N_{SPT} in that layer (N_{60}). Then, the SPT results were corrected using the depth correction factor (Liao & Whitman 1986). So, in summary, the following two values of N_{SPT}: $(N_1)_{60,k}$ and $(N_1)_{60}$ were investigated.

No energy correction was used for two main reasons. The first one is because Thaker & Rao (2011) found the uncorrected values produced better correlations. The second reason is that, because of the kind of SPT drill used, and the age of the equipment, the energy efficiency will be around 60%.

Figures 3, 4, 5, 6 present V_p vs. $N_{60,k}$, N_{60}, $(N_1)_{60,k}$ and $(N_1)_{60}$ respectively. Best fit lines are presented on these figures, together with the Pearson´s correlation factors.

As we can see from those figures, the correlations are slightly better for average values rather than for characteristic values, but are much lower than might be expected for a V_s vs. N_{SPT} correlation.

It is interesting to note that the correlations without the Liao & Whitman (1986) depth correction are better than with the depth correction – possibly because the Liao & Whitman (1986) correction is intended for sand, rather than volcanic clays.

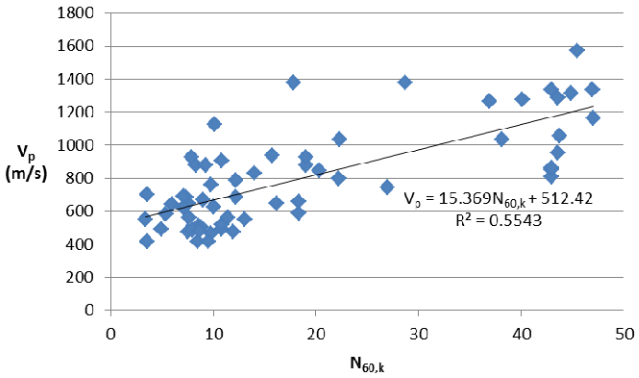

Figure 3. Correlation between characteristic value of N_{SPT} and V_p.

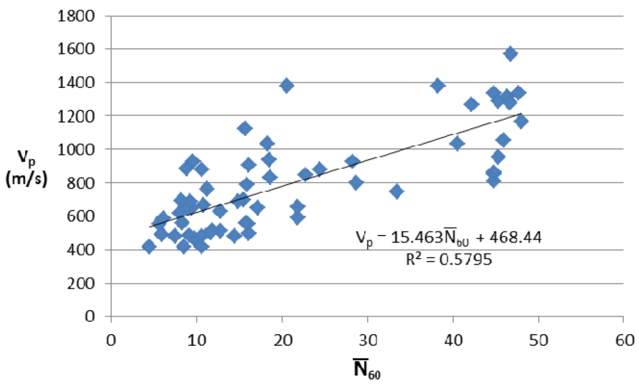

Figure 4. Correlation between mean value of N_{SPT} and V_p.

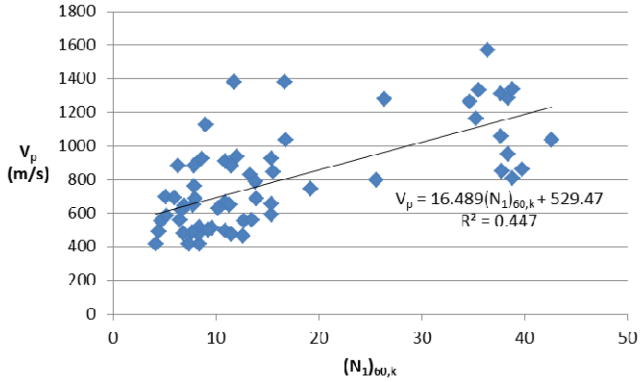

Figure 5. Correlation between characteristic value of N_{SPT} with depth correction and V_p.

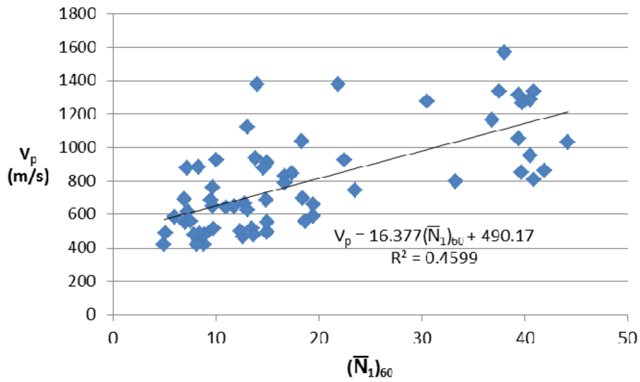

Figure 6. Correlation between mean value of N_{SPT} with depth correction and V_p.

4 DISCUSSION

The average value of N_{SPT}, without depth correction, provides the highest Pearson´s correlation factor, even though it is not as high as would be desirable. As explained during the introduction, there are many variables that affect dilatational wave velocities, so in the future a multivariable analysis would be required to improve these correlations.

In Figures 7, 8, 9, 10, these results are compared with the studies of Ulugergerli & Uyanik (2007) and Bery & Saad (2012). The Bery & Saad (2012) correlation can be seen to form a lower bound to the data presented in this paper, so using this correlation would result in overestimates of N_{SPT} at the sites investigated in this study

The data also fit within the wide-ranging Ulugergerli & Uyanik (2007) upper and lower bound correlations for volcanic soils. It may be seen that, for the data presented in this study, the Ulugergerli & Uyanik (2007) upper bound is much more conservative than the lower bound.

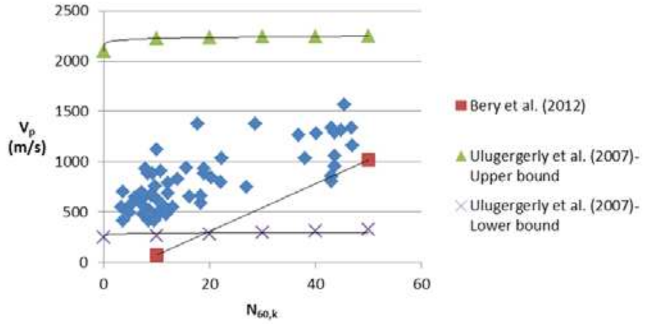

Figure 7. Analysis of Ulugergerli & Uyanik (2007) upper and lower bound and Bery & Saad (2012) correlation, in case of characteristic values of N_{SPT}.

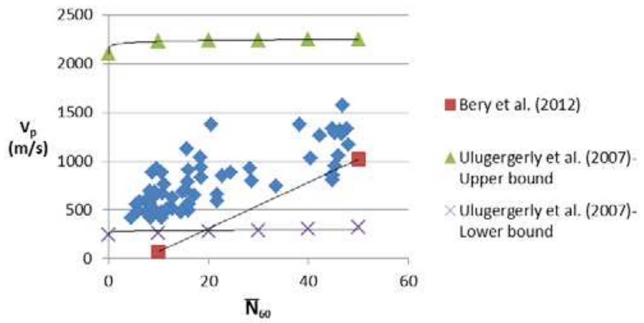

Figure 8. Analysis of Ulugergerli & Uyanik (2007) upper and lower bound and Bery and Saad (2012) correlation, in case of mean values of N_{SPT}.

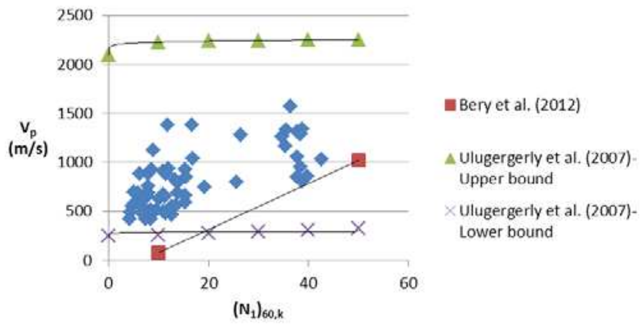

Figure 9. Analysis of Ulugergerli & Uyanik (2007) upper and lower bound and Bery & Saad (2012) correlation, in case of characteristic values of depth corrected N_{SPT}.

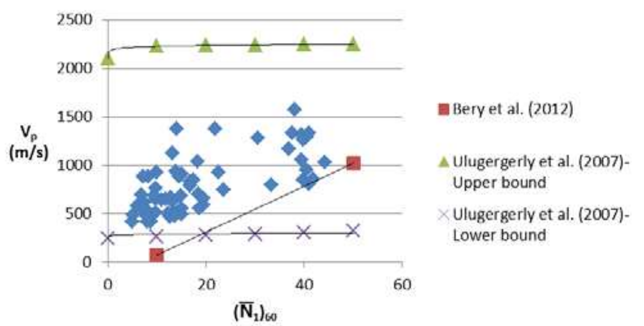

Figure 10. Analysis of Ulugergerli & Uyanik (2007) upper and lower bound and Bery & Saad (2012) correlation, in case of mean values of depth corrected N_{SPT}.

5 CONCLUSIONS

The best correlation for N_{SPT}-V_p is when using mean values of uncorrected (depth correction) values of N_{SPT}.

The results from this research lie within the wide-ranging correlation bounds proposed by Ulugergerli & Uyanik (2007) for volcanic soils.

The correlation proposed by Bery & Saad (2012) forms a lower bound to the data presented in this research, so using this correlation would result in overestimates of N_{SPT} at the sites investigated in this study .

Although there are clear trends in the measured data, the Pearson's correlation is lower than would be considered desirable. Therefore, a multivariable study would be needed to try and improve the reliability of these correlations.

As V_p depends on soil characteristics that will, vary between sites, it is likely that site-specific correlations will always be required at new sites – however, even in this situation, the site investigation cost might be reduced by performing a suitable combination of boreholes and p-wave tests.

6 ACKNOWLEDGEMENTS

We wish to thank MS ENERTECH S.L., the University of Burgos and INGITER S.L. for their support and funding in this research.

7 REFERENCES

ASTM 2010. D 4633-10, "Standard Test Method for Energy Measurement for Dynamic Penetrometers". ASTM International, West Conshohocken, PA.

ASTM 2011. D 1586-11 "Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils". ASTM International, West Conshohocken, P.

Bery, A.A. & Saad, R. 2012. Correlation of Seismic P-Wave Velocities with Engineering Parameters (NValue and Rock Quality) for Tropical Environmental Study. International Journal of Geosciences 2012; 3: 749-757.

Buzzi, O. 2010. On the use of dimensional analysis to predict swelling strain. Engineering Geology 2010; 116: 149-156.

CEN 2005. EN ISO 22476-2, Geotechnical investigation and testing - Field testing - Part 2: Dynamic probing. European Committee for Standardisation: Brussels, Belgium.

Colegio Federado de Ingenieros y de Arquitectos de Costa Rica 2011. Código sísmico de Costa Rica 2010. Editorial Tecnológica de Costa Rica: San José, Costa Rica.

Conte, E.A. et al. 2009. Shear and dilatational wave velocities for unsaturated soils. Soil Dynamics and Earthquake Engineering 2009; 29: 946-952.

Foti, S. 2012. Combined use of geophysical methods in site characterization, Geotechnical and Geophysical Site Characterization 4. CRC Press 2012; 43-61.

Liao, S.S. & Whitman, R.V. 1986. Overburden correction factors for sand. Journal of the Geotechnical Engineering Division, ASCE 1986; Vol. 112, No. 3: 373-377.

Maheshwari, B.K. et al. 2013. Relationship between Shear Wave Velocity and SPT Resistance for Sandy Soils in the Ganga Basin. International Journal of Geotechnical Engineering 2013; 7: 60-66.
Peck, R.B. et al. 1953. Foundation Engineering. John Wiley & Sons: New York, 1953.
Qiu, T. & Fox, P. 2008. Effective Soil Density for Small Strain Shear Wave Propagation, Geotechnical Earthquake Engineering and Soil Dynamics IV 2008; 1-9.
Sanglerat, G. 1972. The penetrometer and soil exploration: Interpretation of penetration diagrams - theory and practice. Elsevier Pub. Co.
Stroud, M.A. 1974. The Standard Penetration Test in insensitive clays and soft rocks, Proceedings of the 1st European Symposium on Penetration Testing 1974; Stockholm, Sweden: 367-375.
Terzaghi, K. & Peck, R.B. 1967. Soil mechanics in engineering practice. Wiley.
Thaker, T.P. & Rao, K.S. 2011. Development of statistical correlations between shear wave velocity and penetration resistance using MASW technique, 2011 Pan-Am CGS Geotechnical Conference: Toronto, Ontario, Canada.
Ulugergerli, E.U. & Uyanik, O. 2007. Statistical correlations between seismic wave velocities and SPT blow counts and the relative density of soils. Journal of Testing and Evaluation 2007; 35: 187-191.