

CORRELATION OF SHEAR WAVE VELOCITY WITH SPT-N FOR A TOWER-BUILDING SITE AT ERBIL CITY

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ABSTRACT

Measurement of shear wave velocity (V_s) plays a crucial role in ground movements around geotechnical structures such as building foundations in the urban area and tunnels. Basically, measuring V_s often requires when seismic properties of soils are essential to be calculated, such as elastic shear modulus. Multichannel analysis of surface wave (MASW) is one of the seismic methods which employs surface waves to measure V_s . It is often not available along with site investigation due to high cost, complicated technical analysis, noise pollution, space constraints, etc. Hence, it is essential to predict V_s through correlating it to other soil parameters such as standard penetration test blows count (SPT-N). Therefore, the main focus in the current study was to correlate between V_s and SPT-N using an empirical equation likely applied for clay soils. A complementary subsoil investigation was performed of a tower-building at Erbil City, including SPT-N values for three boreholes and their corresponding MASW measurements. These data were, in turn, used to estimate V_s from corrected SPT-N. The currently proposed equation compared with the existing ones in the literature. The comparison shows that the proposed equation predicts the values of V_s as good as those available in the literature for both of the datasets in the current and the previous studies.

KEYWORDS: Shear Wave Velocity; Standard Penetration Test; Site Investigation; Seismic Properties; Empirical Equation

1. INTRODUCTION

In the last three decades, the application of the shear wave velocity V_s is significantly increased to cover, e.g., creep, aging, soil anisotropy, cavity detection, assessing the liquefaction potential, sinkholes, building foundations in the urban area, tunnels, mapping stratigraphic layers, seismic response of soils (Atkinson, 1991; Dai et al., 2013; Hasan & Wheeler, 2014; Jovičić & Coop, 1998; Ng & Yung, 2008; Pennington et al., 2001; Seed et al., 1983). Dynamic response of soils is highly dependent on the small strain shear modulus G and shear wave velocity V_s . There is a strong correlation between these two parameters by Equation (1):

$$G = \rho V_s^2 \quad (1)$$

where ρ is the bulk density of the soil. The value of V_s is significantly changed by changing

soil density, void ratio, stress state, stress history, ageing, cementation, etc. (Callisto & Rampello, 2002; Dai et al., 2013; Hardin & Blandford, 1989; Houlsby & Wroth, 1991). G_{\max} or G_o is strain level-dependent; its value greatly reduces with increasing strain level (see, Atkinson, 1991). G_{\max} is calculated from V_s where the strain levels are less than 3% to 10% (Atkinson, 1991). V_s can be measured in the geotechnical laboratory by resonant column device (Allen & Stokoe, 1982; Hall & Richart, 1963) or bender element (Brignoli et al., 1996; Dyvik & Olsen, 1989; Hasan & Wheeler, 2016; Lee & Santamarina, 2005; Shirley & Hampton, 1978). Laboratory testing of V_s requires advanced testing equipment and undisturbed samples. However, small undisturbed samples will not represent the whole soil profile in the field. Therefore, in situ measurement of V_s is highly recommended. Even though such measurement is rarely performed in the most filed exploration

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due to, for example, extra cost in site investigation, space constraints, etc.

Geophysical methods such as Multichannel Analysis of Surface Wave (MASW) is one of the non-destructive testing (not requires borehole) popular field seismic method, which uses surface waves to measure V_s (Park et al., 1999). It is unlike other invasive field methods such as down-hole logging and cross-hole logging that requires boreholes (Andrus et al., 2004).

There are many statistical correlations between V_s and important variables such as SPT-N (Jafari et al., 2002), undrained shear strength (Dickenson, 1995) and cone penetration test resistance (Sykora, 1983) to predict the value of V_s , because, during most field exploration, the geophysical data do not often exist in the same area. Therefore, numerous researchers have proposed statistical correlations in the form of power function between SPT-N and V_s . Proposing such relations avoids geotechnical designers to perform additional geophysical tests in the same area where only geotechnical reports are available (Akin et al., 2011). A detailed review of the statistical correlation between V_s and SPT-N is presented by Dikmen (2009); Jafari et al. (2002) for a wide

range of soil types including sandy soils (Sykora, 1983), silty soils (Lee and Santamarina, 2005), clay soils (Imai, 1977) and all soils (Ohta & Goto, 1978). In the literature, almost all the correlations have been proposed in the form of $V_s = AN^B$ where A and B are constants.

In the current study, based on the measured data of V_s and SPT-N in the same area, a correlation between them is proposed in a specific form of the regression model for clay soils, which is different from those available in the literature. Then, the current proposed model is compared with the existing proposed models in the literature presented in Table 1. Further evaluation is performed on the current model by predicting the value of V_s from the existing dataset for clay soils in the literature using the current proposed model.

Table (1): Existing correlations between V_s and SPT-N only for clay soils

Equation No.	Author(s)	Equation form literature
1	Imai (1977)	$V_s = 80.2 N^{0.292}$
2	Lee (1990)	$V_s = 114.43N^{0.31}$
3	Athanasopoulos (1970)	$V_s = 76.55N^{0.445}$
4	Jafari et al. (2002)	$V_s = 27 N^{0.73}$
5	Hasancebi and Ulusay (2007)	$V_s = 97.89 N^{0.269}$
6	Dikmen (2009)	$V_s = 44 N^{0.48}$
7	Lee (1992) for Silt and Clay	$V_s = 122.7 (N+1.2)^{0.26}$
8	Lee (1992) for Clay	$V_s = 131.7 (N+1.2)^{0.24}$
9	Pitilakis et al. (1999)	$V_s = 128.1 N^{0.27}$
10	Ulugergerli and Uyanik (2007)	$V_s = 107.63 N^{0.237}$
11	Ohta & Goto (1978) Q*	$V_s = 82.4 N^{0.34}$

*Geological age; Q= Quaternary, the middle part of Erbil Plain is mostly covered by Quaternary sediments (Hassan et al., 2010).

2. METHODOLOGY

2.1 Field Work

2.1.1 Method of Drilling

The boring equipment used in carrying out the fieldwork was two multi-method drilling rigs using the rotary drilling method by wash the boring process. The thin wall tube samplers (Shelby Tube) used according to (ASTM D1587, 2000) for obtaining undisturbed samples. The depths of boring of (30 – 35) m were selected to extend to underneath the zone of influence of significant foundation pressure to relatively incompressible materials. The method of drilling was carried out following the standards of the American Society for Testing and Materials (ASTM D5783, 2018).

i. Disturbed Samples

The disturbed samples were obtained, according to ASTM D1586 (2018), at intervals of (2-3) meters, and as required to determine the

classification of the soil layers. The samples that were secured by the Standard Split Spoon Sampler were also used as disturbed samples. All disturbed samples were sent to the laboratory for further examination and testing; such as visual classification (ASTM D2488, 2017), specific gravity (ASTM D854, 2014), grain size distribution (ASTM D6913, 2017), and liquid and plastic limits (ASTM D4318, 2017). Table 2 shows index and geotechnical properties of soils in borehole No. 1.

ii. Undisturbed Samples

Undisturbed samples were obtained at (1-3) meter intervals or change of strata only. After extraction, the samples were trimmed off, capped with paraffin wax, and sealed properly at both ends. The samples were then dispatched to the laboratory for further examination and testing, such as natural moisture content and unit weight (ASTM D2216, 2019).

Table (2): Index and geotechnical properties of soils in B.H. No. 1

Location of Specimen			Index Properties				Sieve Analysis			
B.H. No.	Sample No.	Depth (m)	Sample Type	LL %	PL %	PI %	Natural Water Content %	Dry Density KN/m ³	Specific Gravity	Passing No. 200 %
1	1	0.0-0.5	DS							
	2	1.0-1.5	US				11.6	16.3		
	3	2.0-2.5	DS	41	27	14				54.2
	4	3.0-3.5	US				11.8	15.2	2.68	
	5	4.0-4.5	DS	45	24	21				
	6	5.5-6.0	DS							61.7
	7	7.0-7.5	DS	48	23	25				89.8
	8	8.5-9.0	US	49	28	21	21.8	15.9	2.70	
	9	9.5-10.0	DS							98.4
	10	11.0-11.5	DS	40	22	18				
	11	13.0-13.5	US				18.6	16.4	2.69	93.1
	12	15.0-15.5	DS	47	24	23				
	13	17.0-17.5	DS	38	22	16	17.3			91.2
	14	19.5-20.0	DS	34	21	13				64.7

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iii. In –Situ Testing

Standard Penetration Test (SPT)

In the course of drilling work, the consistency of the soil was measured at several depths by Standard Penetration Test (SPT). The test was performed following (ASTM D1586, 1999). The test involves recording the number of blows of 140 lbs. (63.5 kg) Standard Hammer with a 30-inch (76 cm) drop to drive the 2-inch (50.8 mm) diameter Standard Split Spoon Sampler into the soil a distance of 12 inches (30.5 cm). At the hard layers, the cone of (60) degree used instead of split spoon sampler to serve the same purpose as mentioned above.

The corrected N-values with depth are given in Figure 1.

2.1.2 MASW

In this study, a specific correlation between V_s and SPT-N is proposed, based on the two geotechnical reports (including field and laboratory tests) for more than three boreholes on the site of the foundation of the tower-building project in Erbil City, Kurdistan ($36^{\circ}10'47.28'' N$ $44^{\circ}01'29.79'' E$ elev 1371 ft

). From Engineering Consulting Bureau (ECB) - College of Engineering-Salahaddin University-Erbil and Andrea Engineering Testing Laboratory (AETL)-Baghdad, the MASW Survey for the foundation of a tower-building project was recommended in order to explore more the properties and behaviour of the soil layers deeper than 27 m from the foundation level. This recommendation suggested to that depth by ECB and AETL, because the results of field were slightly ambiguous due to collapsing behaviour of the soil in such depths. In addition, it was expected that cavities could be detected there based on previous investigations in the Erbil city.

Three MASW transverses were performed on the surface of the foundation of the tower-building by Amak Geophysical Exploration and Scientific Appliances Company on July 2019, to investigate the subsurface soil layers to a depth more than 40 m. Figure 2 shows the locations of the three MASW transverse along with the corresponding boreholes on the site. However, the Google map of the three MASW transverses shown in Figure 3.

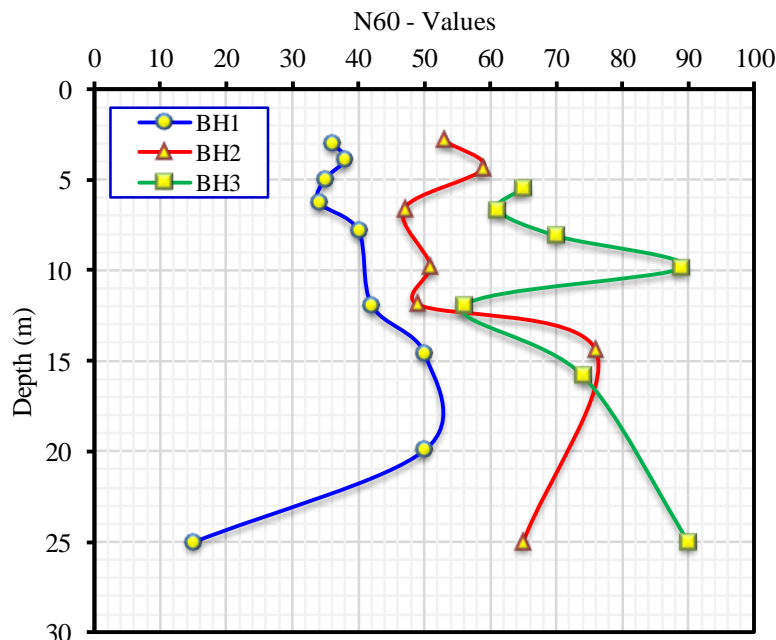


Fig. (1): N60 values versus depth of the three boreholes

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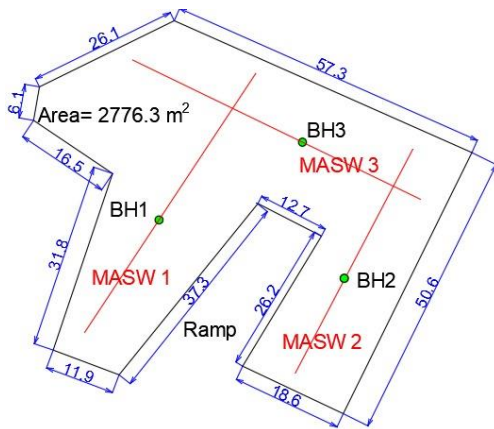


Fig. (2): The tower-building site plan with the locations of 3 boreholes and MASW-1, MASW-2, MASW-3 traverses



Fig. (3): shows the locations of MASW-1 (dark yellow), MASW –2 (Red), and MASW -3 (blue) at tower-building, Erbil.

In the current study, the following equipment was used to perform the three MASW transverse: 1) Terraloc Pro Seismograph (which is presented in Figure 4), 2) low-frequency geophones (which is also presented in Figure 4), 3) GeoGiga software (Seismic Pro 8,3– Surface Plus), 4) two cables set of 144.0 meters, a heavy machine that used as seismic source vibrator (Figure 7) and 5) Portable drilling machine.

The standard procedure of the MASW could

be shortly described as follow. First, field experimental data acquisition from a multichannel seismograph is carried out. Secondly, the experimental dispersion curve (Figure 5) and initial shear wave velocity (Figure 6) are plotted from signal processing of the acquiring filed records. Thirdly, the estimated shear wave velocity profile can be plotted from the inversion process of the dispersion curves.



Fig. (4): The seismograph (Terraloc Pro) at the tower-building site, Erbil.

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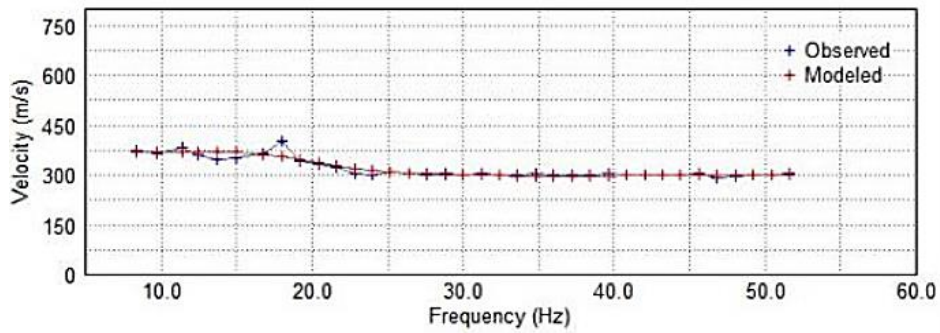


Fig. (5): Dispersion curves

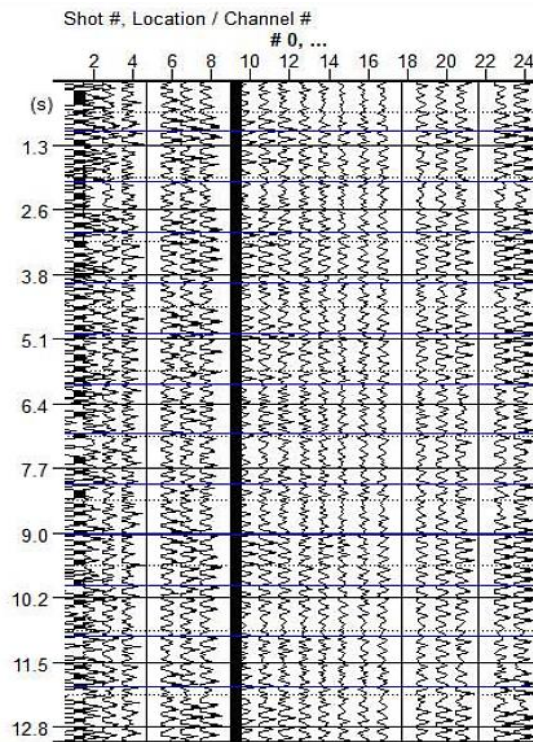


Fig. (6): MASW data processing software for initial shear velocities model

The MASW survey was carried out, in the present work, at the tower-building site using 26 channels seismograph, and low-frequency geophones (4.5 Hz). The MASW spread length is 24.0-48.0 meters using 24 geophones of low frequency. The inter-distance between two geophones is 1.0 – 2.0 meters for high resolution and depth. Active and passive recordings methods were followed in this survey (Park et al., 2005). For each MASW spread there are three recordings. The seismograph settings were arranged for 4.0 sec, 8.0, and 13.0 sec as recording intervals and 0.1 – 0.4 msec sampling

intervals. The hammer impact and vibrator machine (Figure 7) were used as sources for energy at different shot points distances. MASW-1 and MASW-3 traverses were 48.0 meters in lengths, while MASW-2 was 24.0 meters in length. At the MASW-2 location, there was limited space due to the existence of an under-construction building. The three traverses were at a level -7.0 meter from the natural ground (i.e. earthworks or excavations were done at this site). Therefore, the MASW results are all relative to the level - 7.0.

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Fig. (7) :The heavy machine that used as seismic source vibrator at tower-building site

3. RESULTS AND DISCUSSION

3.1 Subsurface Profile

The soil investigation works have passed through several processes to decide on the depth of the deep foundation that supposed to resist the load of a Residential Tower. The first round of the soil exploration was carried out by means of drilling single borehole to a pre-designed depth of 50 m. However, the drilling of the borehole has been terminated at a depth of around 30 m below the existing excavated ground level at around (-6 m to -7 m). The reason for the termination was the skipping of the drilling water through the strata, and the lack of the drilling water circulation indication of voids at the indicated depth and no further soils could be a lift to the surface. The mentioned tests were conducted in July 2019 by the Engineering Consultancy Bureau, College of Engineering, University of Salahaddin, Erbil. Consequently, it was recommended in the report that was prepared by the Engineering Consultancy Bureau of University of Salahaddin to seek the aid of geophysical study to explore the subsoil to extended depth further. The test was conducted on the same month of July 2019, and the conclusion of the tests indicated that there is a high porous material available from the depth of 25 m to 48 m below the excavated layer. This conclusion has proven that the outcome of the borehole's drilling where the wash water started to seep suddenly within the layer.

The subsoil strata encountered at the investigated locations show stratification of soil at the position of samples along with the depth for the investigated area. The subsoil strata at the site explored by three boreholes from 30 m to 35 m depth.

From the values of specific gravity, consistency indices and according to the Unified Soil Classification System (USCS), the majority of the Silty Clay layer is classified as CL, i.e., Silty Clay with low to medium plasticity while the thin Gravelly layers are categorized as GC. The water table was not encountered, during the time of the investigation.

3.2 The Proposed Empirical Equation

Field tests involved SPT-N on the tower-building site in Erbil was used to investigate potential expressions for shear wave velocity (V_s). As stated above, the Minitab 18 software (Minitab is a statistics package similar to Statistical Package for the Social Sciences, SPSS) was used to optimise the correlation between V_s and SPT-N, by examining a wide range of linear and non-linear regression equation forms. At the end of the optimisation, the following specific mathematical form for the relationship linking V_s and corrected N-values:

$$V_s^A = BN - CN^2 + DN^3 \quad (2)$$

where A, B, C, and D are constants.

The regression analysis of the Minitab 18 changes the coefficients of Equation (2) (A, B, C, and D) to determine a set of values that minimises the sum of the squares of the errors between predicted and measured values of the dependent variable (V_s). The regression analysis proposed the following best-fit values for the constants in Equation (2): A = 0.27, B = 0.22048, C = -0.00338, D = 0.00001. The corresponding value for the coefficient of determination R^2 , adjusted R^2 , and P-Value were 99.70%, 99.64%, and < 0.05, respectively. Therefore, the final form of Equation (2) is:

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$$V_s^{0.27} = 0.220481 N - 0.00338 N^2 + 0.00001 N^3 \quad (3)$$

The ability and the validity of the form in Equation (3) are rigorously examined by comparing it with the other equations or other datasets from in the previous works in the literature in the next sub-sections.

3.3 Comparison with other Equations from the Literature

In order to test the ability of the proposed expression in the current study to those have been proposed expressions in the literature, the experimental field test results from SPT-N were used to predict the values of V_s . Figure 8 shows the comparison between R^2 for the measured and predicted V_s using the currently proposed equation and the 11 previous equations, which presented in Table 1, for the dataset obtained in

this study. It can be observed from Figure 8 that the value of the R^2 for Equation (1) is the highest (0.4749). The second best value of the R^2 (0.4691) is generated by an equation proposed by Lee (1992); whereas, the rest of the equations seem that they predict very close values of the R^2 ranged between 0.3850 to 0.3862. This comparison suggests that the proposed expression in this study is performed as well as the other equations in Table 1 for clay soils at least for the field exploration dataset in this study. This confirms that it is possible to propose an equation to has a form differ than the common form of $V_s = AN^B$. To prove further that the form of Equation (1) works well, the Equation (1) tested by using the dataset from the literature (see the next subsection).

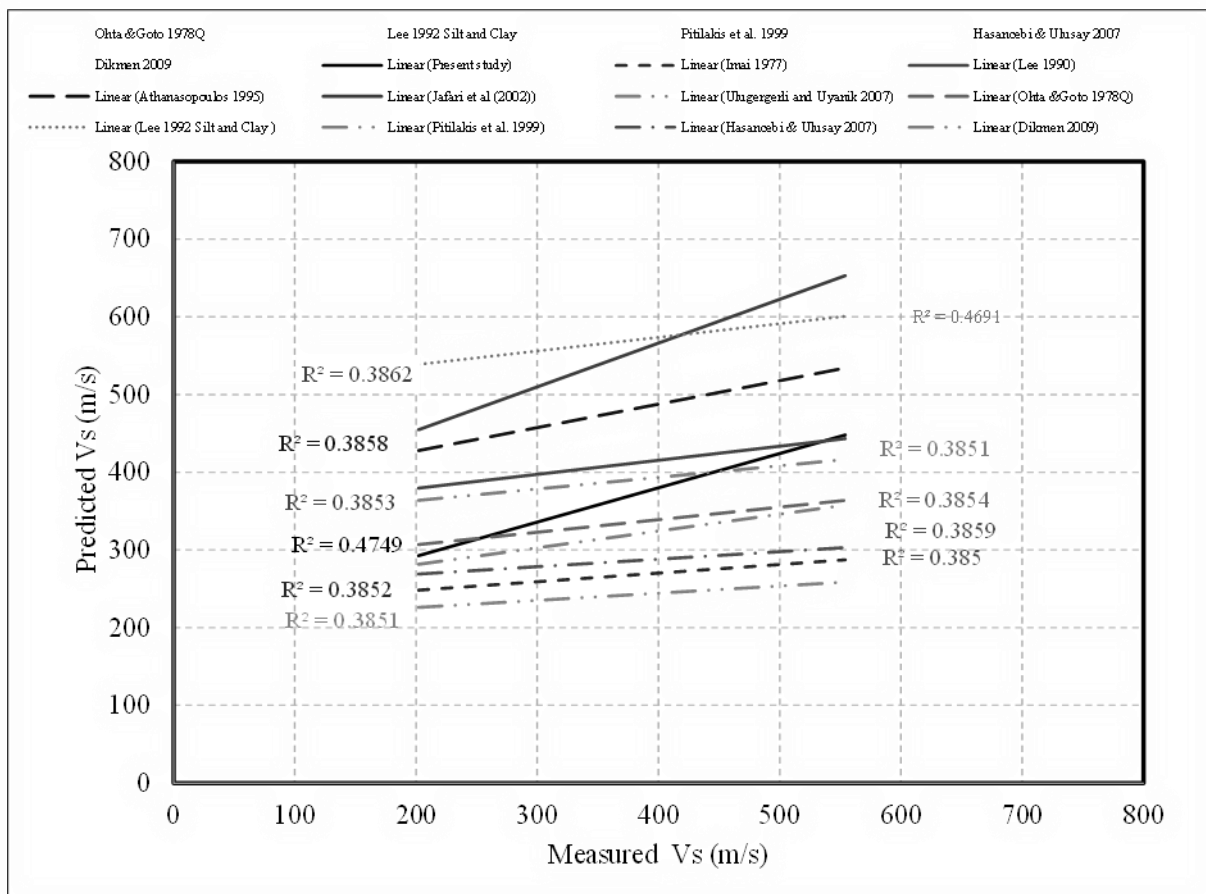


Fig. (8): R^2 between measured and predicted V_s for the current proposed and 11 previous equations

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3.4 Comparison Against other SPT-N Datasets from Previous Studies

Figure 9 shows the comparison of R^2 between measured and predicted V_s using Equation (1) for current dataset and two datasets from the literature to present the quality of the performance of the currently proposed equation. Investigation of Figure 9 reveals that the Equation (1) can almost equally predict very well the values of the V_s from the dataset in the present study and the dataset in the work of the Hasancebi and Ulusay (2007). Investigation of

Figure 9 also shows that the prediction of Equation (3) is slightly less good, where the dataset used from the work of Park et al. (1999). In comparison to the performance of the previous equations in the literature (see Figure 8), it is possible to mention that Equation (3) predicts the values of the V_s as good as the previous ones in the literature. Overall, the currently proposed equation can better predict the values of V_s than those in the literature, even though the form of the earlier is different from the latter.

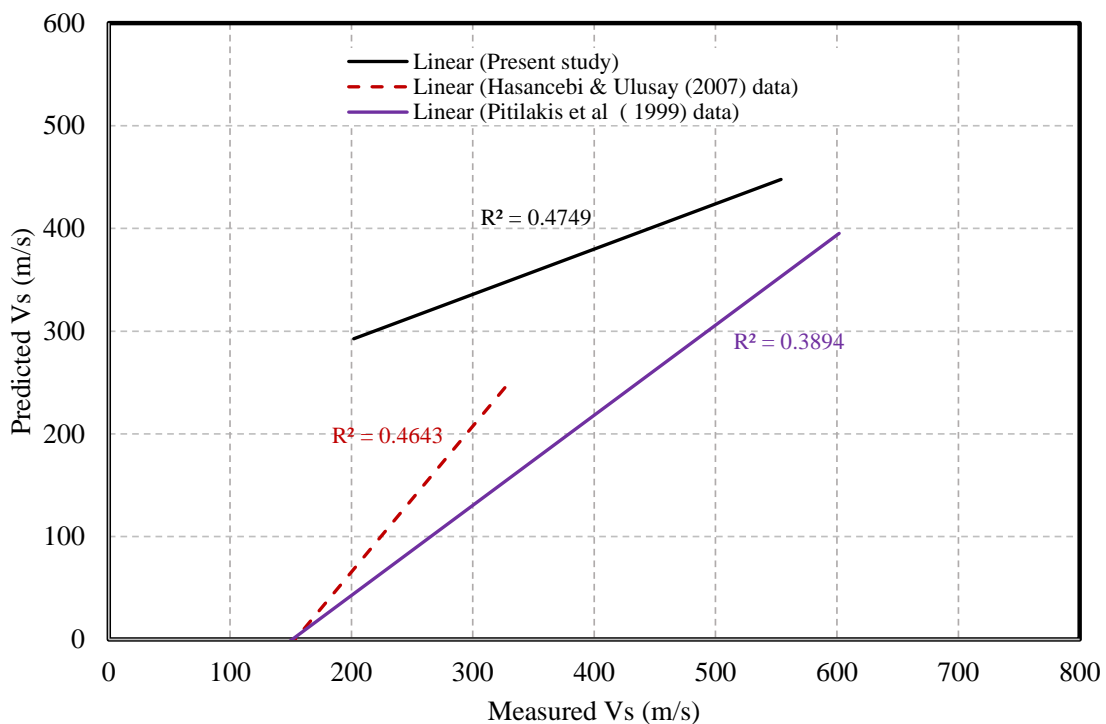


Fig. (9): R^2 between measured and predicted V_s using Equation (1) for current dataset and 2 dataset from the literature

4. CONCLUSIONS

In the current study, several conclusions may be briefly presented as follow:

1. A different form of an equation between V_s and N has been proposed, which can predict well the values of V_s .
2. The proposed equation in the present study is able successfully to predict the values of V_s using limited data from the current study or datasets from the literature.

3. The equation should be used with caution at this stage; however, in the near future, the proposed equation will be further tested using a massive dataset in Erbil city.

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