J Sustain Const Mater Technol, Vol. 7, Issue. 1, pp. 24–29, March 2022

Journal of Sustainable Construction Materials and Technologies
Web page info: https://jscmt.yildiz.edu.tr
DOI: 10.14744/jscmt.2022.10

Journal of Sustainable Construction Materials and Technologies

Research Article

Implementation of shear wave velocity and standard penetration test correlation for Edirne district, Turkey

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ARTICLE INFO

Article history
Received: 17 March 2022
Accepted: 22 March 2022

Key words:
Empirical correlation, multichannel analysis of surface waves, shear wave velocity, standard penetration test

ABSTRACT

It is critical to determine the shear wave velocity (V_s) for earthquake resistant construction design and ground improvement methods. V_s is used in geotechnical earthquake engineering and microzonation studies to calculate the stresses and strong motion characteristics that an earthquake will generate in the soil layers. Characterization of soil and rock small-strain shear modulus and shear wave velocity is an essential component of different seismic analyses such as ground classification, hazard analysis, site-response analysis, and soil-structure interaction. Due to the high expense of seismic testing in comparison to other field tests, these tests are often favored in more significant projects. In circumstances when field seismic testing cannot or only in a limited number of cases be undertaken, the need for correlations between shear wave velocity and other experimental data leads to calculation of V_s. In circumstances when undisturbed soil samples, such as gravel, sand, and silt, cannot be acquired, the Standard Penetration Test (SPT) has been effectively implemented, and numerous researchers have investigated the relationships between the obtained values and the shear wave velocity. It was discovered that the parameters influencing SPT-N number also influence shear wave velocity. Because the relationships presented in the literature are empirical formulae, they may not offer consistent findings for all soil conditions and soil types. The goal of this study is to determine the closest empirical relationships given in the literature by comparing derived SPT values to average shear-wave velocity to 30-m depth (Vs30) values obtained from Multichannel Analysis of Surface Waves (MASW) for the same sites in the Edirne area. Among the investigated relationships, the ones with the lowest error were recommended for estimate of V_s data in the locations with missing V_s data.

Cite this article as: Dehghanian K, Çaltılı E, Koçak Dinç B, Soysal HM. Implementation of shear wave velocity and standard penetration test correlation for Edirne district, Turkey. J Sustain Const Mater Technol 2022;7:1:24–29.

1. INTRODUCTION

The characteristics of earthquake motion in an area are significantly affected by the presence of soil deposits. Ground motion features can be made from either a simplified field classification method or a site-specific ground response analysis. For all these methods, shear wave velocity (V_s) is the most important parameter representing the hardness of the soil. It is useful in evaluating shear wave velocity, foundation stiffness, seismic site response, lique-

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Published by Yıldız Technical University Press, İstanbul, Turkey

faction potential, soil density, soil classification, soil stratigraphy, and foundation settlements [1–5]. The maximum shear modulus (G_{max}) can be measured in the laboratory using a resonance column device or bending elements. While void ratio and stress conditions can be reproduced in a disturbed sample, other factors such as soil texture and cementation cannot [1]. Laboratory testing requires very high quality, undisturbed samples. High quality sampling and testing is very expensive and often not possible for incompatible soils. Table 1 summarizes the effect of increasing various parameters for V_S.

Unlike laboratory experiments, geophysical tests do not require undisturbed sampling, maintain in situ tension during the experiment, and measure the response of large amounts of soil. Kramer (1996) discusses various geophysical methods for measuring shear wave. Shear wave velocities of soil profiles are determined using in situ seismic measurements. Because in situ measurements involve very low stress levels, the measured shear wave velocity can be used to obtain G_{max} at a given depth in a soil slump. However, G_{max} can also be estimated by empirical correlation to the results of in situ tests such as SPT [1].

The shear wave velocity profile at a site is usually obtained by performing wave propagation tests. However, the impact number (N) from the standard penetration test (SPT) is readily available for many geotechnical investigations. A number of studies have been carried out to determine empirical shear wave velocities for different soils [6–19]. Some of the empirical relationships use uncorrected SPT pulse counts, while others are based on energy corrected SPT pulse counts. Such relationships have been proposed for many different soils. Table 2 provides a summary of 20 empirical correlations based on SPT-N and V_s. These correlations are valid for all soils.

Table 1. The effect of increasing various factors on G_{max} and V_S [3]

Parameter	Effect of G_{max} on V_S
Confining stress	Increases as $\sigma`_{v0}$ increase
Void ratio	A decrease occurs with an increase in the void ratio
Over consolidation ratio (OCR)	Increases
Cementation	Increases

Table 2. Summary of empirical correlations based on SPT-N and V_s [20]

Researcher	V_s correlations
Kanai (1966)	V_s=19N$^{0.6}$
Ohba and Toriumi (1970)	V_s=84N$^{0.31}$
Fujiwara (1972)	V_s=92.1N$^{0.337}$
Ohsaki and Iwasaki (1973)	V_s=81.4N$^{0.39}$
Imai et al. (1975)	V_s=89.9N$^{0.341}$
Imai (1977)	V_s=91N$^{0.337}$
Ohta and Goto (1978)	V_s=85.35N$^{0.348}$
Imai and Tonouchi (1982)	V_s=97N$^{0.314}$
Jinan (1987)	V_s=116.1(N+0.3185)$^{0.202}$
Kalteziotis et al. (1992)	V_s=76.2N$^{0.24}$
Athanasopoulos (1995)	V_s=107.6N$^{0.36}$
Sisman (1995)	V_s=32.8N$^{0.51}$
Jafari et al. (1997)	V_s=22N$^{0.85}$
Kiku et al. (2001)	V_s=68.3N$^{0.292}$
Hasançebi and Ulusay (2007)	V_s=90N$^{0.309}$
Hanumantharao and Ramana (2008)	V_s=82.6N$^{0.43}$
Dikmen (2009)	V_s=58N$^{0.39}$
Uma Maheswari et al. (2010)	V_s=95.64N$^{0.301}$

2. GEOLOGY AND TECTONICS

The mentioned study area was carried out in Edirne, Merkez, Havsa and Enez districts. Edirne is located in the Thrace part of the Marmara Region in the northwest of Turkey. Edirne Province, with an area of 6,276 km^2, is located between 40°30' and 42°00' north latitudes and 26°00' and 27°00' east longitudes. According to the data obtained after the observations and drillings in the study area, units belonging to the Ergene Formation (Mie) and Çanakkale Formation (Miç), which are the dominant formations of the region, were observed under the current fill layer at the top. Çanakkale Formation Holmes (1966)'s Ergene formation; Ünal (1967)'s Ergene Group, Büyük Anafarlalar formation; Kellog (1973)'s Anafartalar and Kilitbahir formation; The Eceabat formation of Önem (1974); Saltik (1974)'s Gelibolu formation is the equivalent of Gazhanedere, Kirazlı and Alçıtepe formations. This contrast shows that only a single formation feature is dominant in the study area. To define the units geologically, yellowish-white or brownish-yellow, cross-layered sandstone and locally clayey sandstone, reddish, greenish colored claystone and slightly attached pebble-pebble lenses are observed [21–25]. Figure 1 shows the generalized geological map of the study area and Figure 2 shows the generalized stratigraphic section of the study area.

There is no significant active fault within the borders of Edirne province, but the Ganos fault, which passes just south of the province and has a high earthquake potential, forms the westernmost segment of the northern branch of the North Anatolian Fault and extends to the Saros Gulf.

Regional tectonically, in the North of the Thrace Region, normal fault systems determine the structure of the massif in general [26]. The first and most effective of these fault systems extending perpendicular to each other are the NW - SE trending normal faults, starting from the Bulgarian border and extending from the Çatalca vicinity to the Marmara Sea. The second system is the NE - SW fault which developed perpendicular to these faults, cutting and offsetting them.

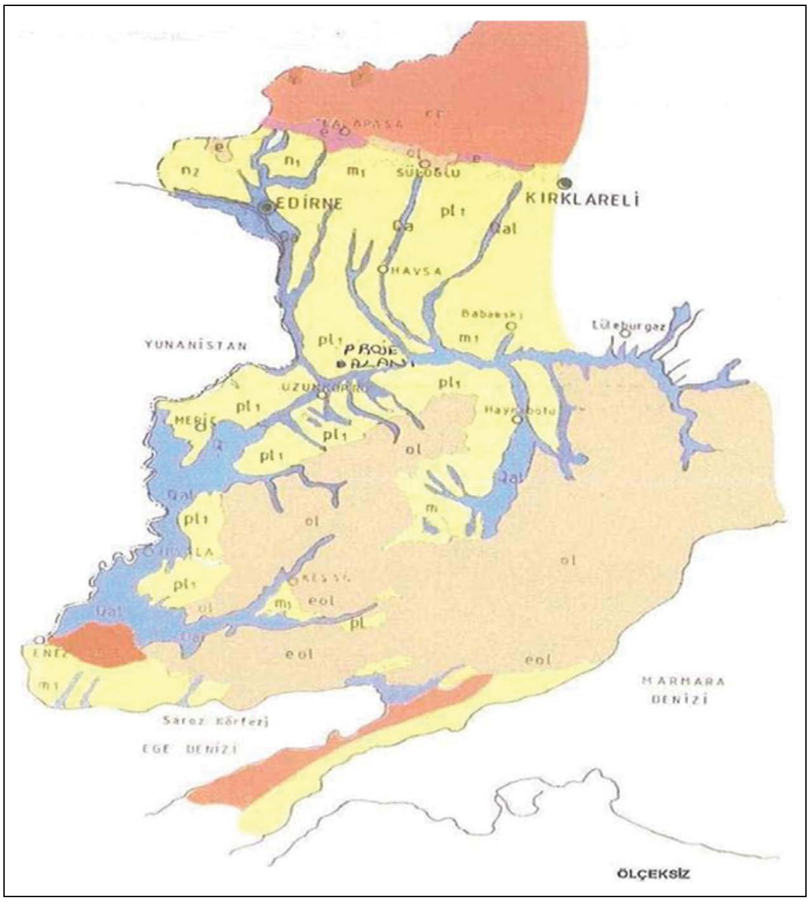

Figure 1. Generalized geological map of the study area (DSI, XI. Regional Directorate. 1996).

NW - SE normal faults; Starting from the Bulgarian border and traversing the massif from the border to Çatalca, the step has caused the fragmentation of the Paleozoic basement and the deepening of the sea towards the north-northeast, in the form of a fault bundle with five parallel extensions. The strike components of these faults could not be determined by the researchers in the field. However, in terms of kinematics, it is expected that the NE-SW strike-slip faults, which are the second fault system, will be offset as a natural result of their movement and the dextral strike components will develop. The most important NW - SE trending normal fault is the Sergen fault. The fault, which starts within the borders of Bulgaria and enters into the borders of Turkey around Malkoçlar village, loses its trace in the north of Kocayazı village, is traced in small pieces from place to place, and reappears around Kapaklı. Around Kömürköy, it disappears under Tertiary units. 66.6 km from the border to Kömürköy. This fault is normal fault and strike component could not be determined by the researchers. Approximately 8 km from the Sergen fault. In the southwest, a second fault bundle runs parallel to the Sergen fault between Devletliağaç and Koruköy. The fault beam, which is cut and offset in places, acquires a high-angle thrust character between Erikler and Koruköy. Figure 2 shows the locations of the faults within the provincial borders of Edirne on the digital map.

Table 3. V_s and SPT N values for boreholes in Edirne province

Borehole no	N_{av}	V_s30 (m/s)
2	27	345
8–1	40.5	407
8–2	30.66	407
11	29.11	387
15	17.55	323
24	35.285	395
26	11.17	337
27	13.22	251
28	22.33	357
37	34.33	346
57	10.44	269
64	25.142	365
79	24.55	325
81	18.88	273
90	43.125	377

Figure 2. Locations of faults on the digital map within the borders of Edirne province (Düzce University Journal of Science and Technology, 2017).

3. VS- SPT-N CORRELATION

In this study, SPT-N and V_s values obtained from 15 boreholes were used in the analysis. Average shear wave velocity (Vs30) and uncorrected mean SPT-N (N_{av}) values obtained from geophysical experiments are given in Table 3. In the literature, the effect of correcting N values on the proposed relationships was examined and it was found that the unadjusted N value provided better correlations [26]. Therefore, uncorrected N values were used in this study. For these data, 20 correlations shown in Table 2 were applied and compared with the V_s values obtained from MASW. Relationships that give the best result and the lowest error for the selected region are determined. The results of the comparisons are given in Table 4 for each borehole. In addition, for boreholes mentioned in Table 5, Athanasopoulos [14], Jafari et al. [15], Hanumantharao, and Ramana [18] correlations are compared with each other.

In the relationships shown in Table 5, the mean relative error is below 12% and the relationship suggested by Athanasopoulos (1995) gives the lowest error.

Table 4. Estimation of the best V_s - SPT N correlation for boreholes in Edirne province

Borehole no	Correlation	Relative error (%)
2	Hanumantharao and Ramana (2008)	1.22
8–1	Athanasopoulos (1995)	0.21
8–2	Jafari et al. (1997)	0.82
11	Jafari et al. (1997)	0.82
15	Jafari et al. (1997)	0.82
24	Athanasopoulos (1995)	1.75
26	Athanasopoulos (1995)	22.58
27	Hanumantharao and Ramana (2008)	0.13
28	Athanasopoulos (1995)	7.80
37	Jafari et al. (1997)	0.82
57	Jafari et al. (1997)	0.82
64	Athanasopoulos (1995)	5.88
79	Hanumantharao and Ramana (2008)	0.65
81	Jafari et al. (1997)	2.08
90	Hanumantharao and Ramana (2008)	10.55

Table 5. Correlation comparison for boreholes in Edirne province

Borehole no	Athanasopoulos (1995) Relative error (%)	Jafari et al. (1997) Relative error (%)	Hanumantharao and Ramana (2008) Relative error (%)
2	2.16	5.02	1.22
8–1	0.21	25.65	0.32
8–2	9.35	0.82	11.57
11	9.35	0.82	11.57
15	9.35	0.82	11.57
24	1.75	15.15	3.20
26	22.58	47.14	29.39
27	3.21	8.59	0.13
28	7.80	13.64	12.03
37	9.35	0.82	11.57
57	9.35	0.82	11.57
64	5.88	6.57	9.46
79	4.80	2.82	0.65
81	13.50	2.08	7.02
90	10.65	43.08	10.55
Mean relative error (%)	7.95	11.59	8.78

4. DISCUSSION AND CONCLUSIONS

In previous research, equations based on uncorrected SPT-N values have shown a slightly better fit than equations based on energy-corrected SPT-N values. Therefore, it is recommended for practical purposes to use an equation developed for all soil groups based on uncorrected impact counts in this study. In the study, field tests (SPT and MASW) were carried out to measure shear wave velocity V_s and standard penetration resistance N in selected regions in Edirne. Based on these field experiments, the relationship between V_s and N was investigated. Among the 20 investigated correlations, 3 correlations with the lowest error were selected and compared with each other. In addition, the mean of the relative errors was calculated for the selected correlations. All three correlations applied show good estimates for different regions, and as indicated in Table 5, Athanasopoulos (1995) correlation gives a lower error than the other 19 relationships and there is an 8% difference between the estimated V_s values and the actual values.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declare that they have no conflict of interest.

FINANCIAL DISCLOSURE

The author declared that this study has received no financial support.

PEER-REVIEW

Externally peer-reviewed.

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