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A COMPARATIVE STUDY OF SOIL CLASSIFICATIONS USING INTERNATIONAL APPROACHES

Elmon TORAMAN[1], Mert TOLON[2] and Derin N. URAL[3]

Abstract: Geotechnical investigation is a process in which the physical properties of a site are assessed for the purpose of determining which uses of the site will be safe. Geotechnical investigation is required before land can be developed or redeveloped. The goal of such investigation is to confirm that the land is safe to build on or to confirm the correct geotechnical rehabilitation methods for the existing buildings. The earthquake effect on existing buildings is important. Following the Kocaeli earthquake in Turkey, special soil investigation studies have been undertaken for highly important structures in order to decide on the necessity of retrofitting. It is known that, it is not always possible to make undertake in-situ testing to determine the shear wave velocity (Vs) in the urban area for small scale projects. Therefore, empirical correlations for shear wave velocity are gaining importance.

A study to determine site classification based on this investigation data is presented in this paper. In the case data set, there are no in-situ tests to determine the shear wave velocity. Empirical correlations from standard penetration tests (SPT) are used to determine the shear wave velocities (Vs) in the interpretative reports. In critical facilities, it is important to undertake geophysical testing to correctly determine site class, and to predict the building performances during an earthquake.

In this context, approximately one hundred boreholes are used. Initially, the standard penetration blowcount values (SPT-N value) are correlated to the shear wave velocities (Vs), then the site classification is determined based on U.S. Federal Emergency Management Agency (US - FEMA 356) standard (Table 1) and the standard of Specifications for Buildings to be Built in Earthquake Areas of Turkey (Turkey – DBYBHY). The soil classification results of both FEMA and Turkish standards are compared. Then direct SPT values are used to determine site class from tables presented in Specification for Buildings to be built in Earthquake Risk Areas in Turkey.

In conclusion, the effect of using different formulas to determine soil class is discussed. By determining the similarities and differences between the approaches, more accurate results can be attained in future soil classification studies.

Introduction

Geotechnical investigation is the process of collecting data for the purpose of determining soil properties. Soil properties are used for designing the structure and also deciding whether any construction activity on site whiteout any soil improvement or special foundation solution will be safe or not. Geotechnical investigation is also required to determine site class. Site classification is done for the purpose of categorizing the study region based on soil investigation data to select appropriate design parameters.

The planning and execution of geotechnical site investigation is required at initial stages of the project. Similarly investigation studies are also required or recommended for seismic rehabilitation of buildings. The purpose of such investigation is to confirm that the soil conditions are safe for the existing building or to decide on the appropriate geotechnical rehabilitation methods for the existing buildings.

As seismic geotechnical investigations involve several types of seismic analyses, geophysical site investigation studies should be included into investigation scope. In case of

[1]Geotechnical Engineer, Arup Mühendislik ve Müşavirlik, Istanbul, Turkey, elmon.toraman@arup.com
[2] Assistant Professor, Civil Engineering Department, Nişantaşı University, Istanbul, Turkey, mert.tolon@nisantasi.edu.tr
[3] Professor, Civil Engineering Department, Istanbul Technical University, Istanbul, Turkey, derin@itu.edu.tr

lack of data, they are replaced by various correlations presented in the literature. Frequently in engineering practice, assumptions are employed at various stages of the data interpretation. In seismic geotechnical analysis, it is often difficult to decide on the correct assumption for analyses.

The performance of structures during an earthquake is critical and structures behave differently based on local soil characteristics under similar seismic characteristics. In Turkey, following the earthquakes of 1999, the number of retrofitting projects for disaster preparedness has increased. Therefore, retrofitting projects are performed by the government aiming to mitigate the risk.

In the city of Istanbul, Turkey, special soil investigation studies have been undertaken for highly important structures in order to decide on the necessity of retrofitting. The objective of these studies is to conduct the vulnerability assessment and prepare the preliminary retrofitting designs, and make cost estimates for the selected public buildings including schools, hospitals, emergency centres. In such studies, the first step of the projects was to conduct geotechnical site investigations. In these projects, boreholes and in-situ tests were performed in addition to the geotechnical and rock mechanics laboratory tests of the samples obtained during the site investigations. Although direct measurement if Vs_{30} is preferable, it is not always feasible to perform in-situ testing to determine the shear wave velocity (Vs) in the urban area, for small scale projects. Therefore, the empirical correlations for the shear wave velocity are widely used and are gaining importance.

A study to determine site classification based on soil investigation data is presented in this chapter. In the case dataset, there are no direct in-situ measurements to characterize the shear wave velocity from geophysical methods. Empirical correlations from standard penetration tests (SPT) are used to indirectly estimate shear wave velocities (Vs) in the interpretative reports. In the case of critical facilities, it is important to undertake geophysical testing to correctly determine site class, and to predict the building performances during an earthquake.

In this context, approximately one hundred boreholes are used in the present study. Initially, the standard penetration blow count values (SPT-N value) are correlated to the shear wave velocities (Vs), then the site classification is determined based on U.S. Federal Emergency Management Agency (US - FEMA 356) standard, as well as the standard of Specifications for Buildings to be Built in Earthquake Areas of Turkey (Turkey – DBYBHY) from the shear wave velocities.

In conclusion, the influence of using different formulas to determine Vs_{30} and also the site class is discussed. By determining the similarities and differences between these approaches, more accurate results can be attained in future soil classification studies.

SPT Resistance and Shear Wave Velocity Empirical Correlations Relationship

Shear wave velocity is a fundamental geotechnical characteristic that acts as the main input of quantitative earthquake engineering and the main controller of site response. Site specific ground response analysis requires direct measurement of shear wave velocity of the site. Shear wave velocity of soils is an indicator of shallow soil response to ground shaking and is the primary indicator of dynamic soil properties. Vs_{30} is described as the average shear wave velocity measured for the first 30 m. of ground. In-situ geophysical seismic measurements such as down hole, cross hole, seismic CPT were used to evaluate Vs_{30}. Obtained shear wave velocity values can also be used to determine site class based on international standards. But in every case, it is not always feasible to perform in-situ geophysical testing, due to high cost or lack of space to undertake the test. In such cases, empirical correlation formulas between different strain amplitude tests are used.

Higher cost and lack of respective expertise, results in shear wave velocity testing not routinely performed in industry and engineering practice. By making use of the abundant SPT data in site investigation program, statistical means to obtain the relationship between Vs and standard penetration resistance (SPT-N) is greatly supported by researchers and industries. Conveniences, efficiency, and cost saving are three main advantages of empirical regression equations. (24)

SPT is the most often and universally used in situ test. For this reason several empirical correlations are concentrated between SPT blow counts and Vs.

There are numerous relationships between shear wave velocity and Standard Penetration Test (SPT) blow-counts used when geophysical testing is not available. Correlations are based on soil type, depth effect, soil type, fine content, and geological age. But most of the empirical relationships are concentrated between SPT-N values and Vs30. Some of the correlations use SPT (N) values which were converted to the equivalence of shear wave velocity values following relations.

Considering nonlinearity as the nature of soils, most published correlations are valid to particular sites without separate considerations of soil types. The trends of these correlations are similar. The reason is that both cohesionless and cohesive soils are not separable in each borehole. Dikmen (2009) stated that shear wave velocity of sandy soils is higher than cohesive soils, which is in contradiction with results of Tsiambaos and Sabatakakis (2011).
Thus, these correlations may not be user friendly unless soil could be differentiated based on engineering or geological classification.

A summary of established correlations developed and used in the past 50 years is given in Table 1. The published regression was divided into three groups, namely all soil types, cohesionless soil and cohesive soil. By considering soil non-linearity, this paper only concentrates on the correlations which are applicable for all soil types. These independent correlations are established for various sites from the world, including Japan, USA, Greece, Taiwan, Turkey, India, Iran, and Korea, among others. The variation between earlier correlations among researchers is mainly due to the geotechnical conditions of studied sites. Although most of the correlations are comparable and in good trend, direct application to other regions are not suggested due to the different practice of SPT and shear wave investigation works. (24)

Table 1. Correlation between Vs and N

Researcher	All soil type	Cohesionless soil	Cohesive soil
Kanai (1966)	$Vs = 19N^{0.6}$		
Ohba and Toriumi (1970)	$Vs = 84N^{0.31}$		
Shibata (1970)		$Vs = 32N^{0.5}$	
Imai and Yahimura (1970)	$Vs = 76N^{0.33}$		
Ohta et al. (1972)		$Vs = 87N^{0.36}$	
Fujimara (1972)	$Vs = 92.1N^{0.337}$		
Ohsaki and Iwasaki (1973)	$Vs = 81.4N^{0.39}$	$Vs = 59.4N^{0.47}$	
Imai and Yoshimura (1975)	$Vs = 92N^{0.329}$		
Imai et al. (1975)	$Vs = 89.9N^{0.341}$		
Imai (1977)	$Vs = 91N^{0.337}$	$Vs = 80.6N^{0.331}$	$Vs = 102N^{0.292}$
Ohta and Goto (1978)	$Vs = 85.35N^{0.348}$	$Vs = 88N^{0.34}$	
JRA (1980)		$Vs = 80N^{0.33}$	$Vs = 100N^{0.33}$
Seed and Idriss (1981)	$Vs = 61.4N^{0.5}$		
Imai and Tonouchi (1982)	$Vs = 97N^{0.314}$		
Seed et al. (1983)		$Vs = 56.4N^{0.5}$	
Sykora and Stokoe (1983)		$Vs = 100.5N^{0.29}$	
Okamoto et al. (1989)		$Vs = 125N^{0.3}$	
Lee (1990)		$Vs = 57.4N^{0.49}$	$Vs = 114.43N^{0.31}$
Imai and Yoshimura (1990)	$Vs = 76N^{0.33}$		

Yokota et al. (1991)	Vs = $121N^{0.27}$		
Kalteziotis et al. (1992)	Vs = $76.2N^{0.24}$	Vs = $49.1N^{0.50}$	Vs = $76.6N^{0.45}$
Raptakis et al. (1995)		Vs = $100N^{0.24}$	Vs = $184.2N^{0.17}$
Athanasopoulos (1995)	Vs = $107.6N^{0.36}$		
Sisman (1995)	Vs = $32.8N^{0.51}$		
Iyisan (1996)	Vs = $51.5N^{0.516}$		
Jafari et al. (1997)	Vs = $22N^{0.85}$		
Chien et al. (2000)		Vs = $22N^{0.76}$	
Kiku et al. (2001)	Vs = $68.3N^{0.292}$		
Jafari et al. (2002)	Vs = $22N^{0.85}$	Vs = $19N^{0.85}$	Vs = $27N^{0.73}$
Hasancebi and Ulusay (2007)	Vs = $90N^{0.309}$	Vs = $90.82N^{0.319}$	Vs = $97.89N^{0.269}$
Hanumantharao and Ramana (2008)	Vs = $82.6N^{0.43}$	Vs = $79N^{0.434}$	
Lee and Tsai (2008)	Vs = $137.153N^{0.229}$	Vs = $98.07N^{0.305}$	Vs = $163.15N^{0.192}$
Dikmen (2009)	Vs = $58N^{0.39}$	Vs = $73N^{0.33}$	Vs = $44N^{0.48}$
Uma Maheswari et al. (2010)	Vs = $95.64N^{0.301}$	Vs = $100.53N^{0.265}$	Vs = $89.31N^{0.358}$
Tsiambaos and Sabatakakis (2011)	Vs = $105.7N^{0.327}$	Vs = $79.7N^{0.365}$	Vs = $88.8N^{0.370}$
Anbazhagan et al. (2012)	Vs = $68.96N^{0.51}$	Vs = $60.17N^{0.56}$	Vs = $106.63N^{0.39}$

$Vs= AN^B$
A: controls the amplitude
B: controls the relationship curvature

International Standards

U.S. Federal Emergency Management Agency (US - FEMA 356) Standard

According to FEMA, soil classification is based on shear wave velocity or standard penetration test (SPT) as well as plasticity index (PI), water content (w), and undrained shear strength (s_u). Where Vs data are available for the site, direct results of tests shall be used directly to classify the site. In cases where geophysical test data is not available, blowcount shall be used for cohesionless soil sites (sands, gravels), and s_u data for cohesive soil sites (clays). For rock in profile classes B and C, classification shall be based either on measured or estimated values of vs. Classification of a site as Class A rock shall be based on measurements of v_s either for material at the site itself, or, for rock having the same formation adjacent to the site; otherwise, Class B rock shall be assumed. Class A or B profiles shall not be assumed to be present if there is more than 3 m. of soil between the rock surface and the base of the building. (8)

If there is insufficient data available to classify a soil profile as Class A through C, and there is no evidence of soft clay soils characteristic of Class E in the vicinity of the site, the default site class shall be taken as Class D. If there is evidence of Class E soils in the vicinity of the site, and no other data supporting selection of Class A through D, the default site class shall be taken as Class E. (8)

Below in Table 2, site classification for FEMA is given.

Table 2. U.S. FEMA 356 related standard. (3)

Local Site Class	Definitions
A	Hard rock with average shear wave velocity Vs> 1524 m/s
B	Rock with 762 m/s. ≤ Vs ≤ 1524 m/s
C	Very dense soil and soft rock with 366 m/s <Vs ≤ 762 m/s, or with either standard blow count N > 50, or undrained shear strength > 96 kPa
D	Stiff soil with 183 m/s <vs ≤ 366 m/s or with 15 < N ≤ 50, or 48 kPa<su ≤ 96 kPa

E	Any profile with more than 3 m. of soft clay defined as soil with plasticity index PI > 20, or water content w > 40 percent, and su< 24 kPa or soil profile with Vs< 183 m/s
F	Soils requiring site-specific evaluations: (i) Soils vulnerable to potential failure or collapse under seismic loading, such as liquefiable soils, quick and highly-sensitive clays, collapsible weakly-cemented soils (ii) Peats and/or highly organic clays (H > 3 m. of peat and/or highly organic clay, where H = thickness of soil) (iii) Very high plasticity clays (H > 8 m. with PI > 75) (iv) Very high plasticity clays (H > 8 m. with PI > 75)

The parameters Vs, N and su are, respectively, the average values of the shear wave velocity, SPT blowcount, and undrained shear strength of the upper 30 m. of soils at the site. These values can be calculated from the equations.

Standard of Specification for Buildings to be built in Earthquake Risk Areas of Turkey (DBYBHY)

According to DBYBHY soil class is initially is divided into four categories, based on SPT blow count number, relative density, unconfined compressive strength and shear wave velocity (Table 3). After grouping sites, it is classified based on soil groups as well as layer thickness (Table 4).

Table 3. Turkish DBYBHY related standard-Soil Group

DBYBHY					
Soil Group	**Description of Soil Group**	**Standard Penetration (N/30)**	**Relative Density (%)**	**Unconfined. Compressive Strength (kPa)**	**Drift Wave Velocity (m/s)**
A	1. Massive volcanic rocks, unweathered sound metamorphic rocks, stiff cemented sedimentary rocks 2. Very dense sand, gravel... 3. Hard clay and silty clay…	— > 50 > 32	— 85—100 —	> 1000 — > 400	> 1000 > 700 > 700
B	1. Soft volcanic rocks such as tuff and agglomerate, weathered cemented sedimentary rocks with planes of discontinuity…… 2. Dense sand, gravel......... 3. Very stiff clay, silty clay…	— 30—50 16—32	— 65—85 —	500—1000 — 200—400	700—1000 400—700 300—700
C	1. Highly weathered soft metamorphic rocks and cemented sedimentary rocks with planes of discontinuity 2. Medium dense sand and gravel.... 3. Stiff clay and silty clay.....	— 10—30 8—16	— 35—65 —	500 — 100—200	400—700 200—400 200—300
D	1. Soft, deep alluvial layers with high ground water level 2. Loose sand........... 3. Soft clay and siltyclay…..	— < 10 < 8	— < 35 —	— — < 100	< 200 < 200 < 200

Table 4. Turkish DBYBHY related standard- Local Site Class.

Local Site Class	Soil Group according to Table 3 and top most Soil Layer Thickness (h1)
Z1	Z1 Group (A) soils Group (B) soils with h1 ≤15 m
Z2	Group (B) soils with h1 > 15 m Group (C) soils with h1 ≤15 m
Z3	Group (C) soils with 15 m < h1 ≤50 m Group (D) soils with h1 ≤10 m
Z4	Group (C) soils with h1 >50 m Group (D) soils with h1 > 10 m

Analysis

Data used is consisting of soil investigation studies which have been conducted for 30 different public institutions or hospitals in Istanbul to decide on the necessity of the retrofit of the buildings. SPT data derived from 100 different boreholes are used in the analysis. 30 different correlation formulas which are valid for all soil types are used. The reason for selecting these formulas is their heavy use in industry and are recognized formulas within the literature (24) Uncorrected N values are used in the correlations. The average N values are calculated for every 5m depth intervals then correlated to Vs values. The chart below shows Vs values correlated for SPT-N 15 value at 0 to 5 m. depth interval and per site classification as per DBYH and FEMA (Figure 1).

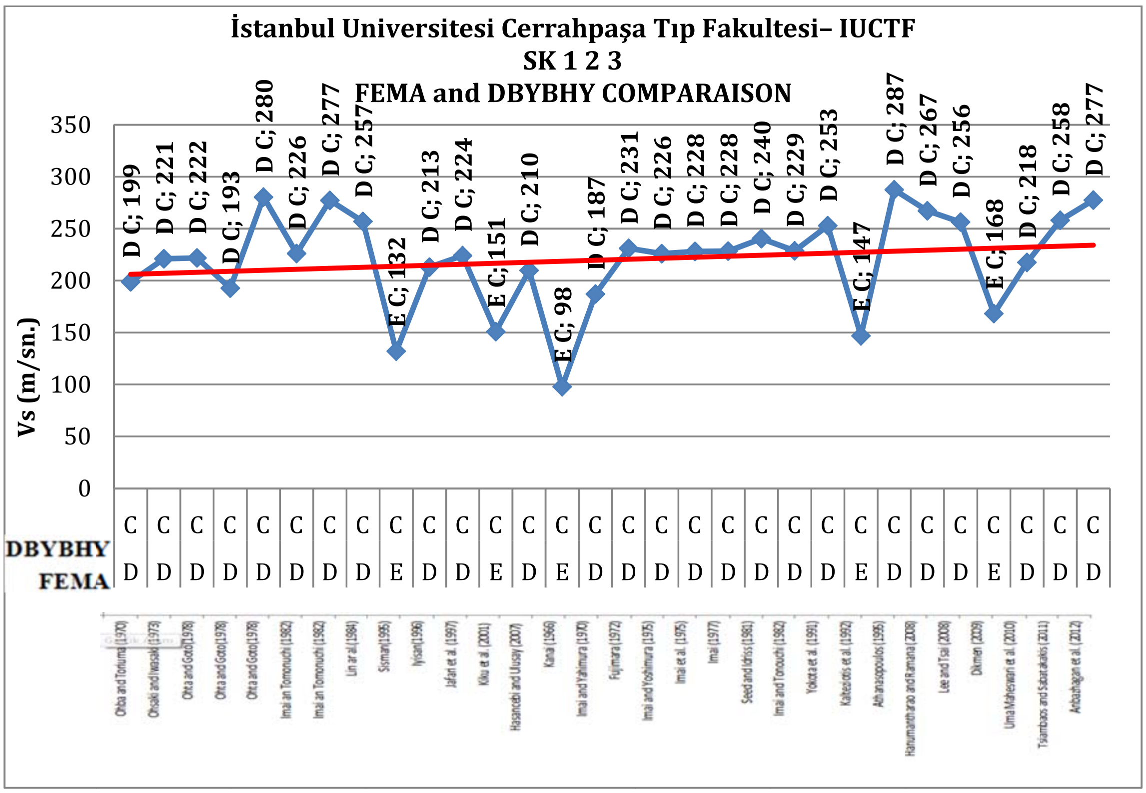

Figure 1. The chart of Vs_{30} values correlated for SPT-N 15 value at 0 to 5 m. depth interval and per site classification as per DBYH

Results

The optimum correlations formulas are given below, in the Table 5.

Table 5. The results of optimum correlations formulas for evaluating shear wave velocity from the corrected STN-N values.

Fujimara (1972)	$Vs = 92.1N^{0.337}$
Imai and Yoshimura (1975)	$Vs = 92N^{0.329}$
Imai et al. (1975)	$Vs = 89.9N^{0.341}$

Conclusion

This paper outlined the effect of usage of different correlation formulas to assign site class according to two different codes used in two different countries. According to the analysis, among the 30 different correlation formulas recently used within the industry formulas proposed by Kalteziotis et al. (1992) gave the minimum shear wave velocity (Vs) values. On the other hand Jafari et al. (1997) formula resulted with the maximum values.

Jafari et al. (1997) and Kanai (1996) formulas for shear wave velocity calculations resulted in differentiation of soil class according to FEMA classification. Soil classification according to FEMA is more sensitive to correlation formulas while the Turkish standard “DBYBHY” is more consistent for these criteria. For the Turkish standard “DBYBHY”, the result are distributed in two types of soil classifications, on the other hand in the FEMA different types of soil classifications can be seen when different scientists’ correlations are used.

As a result, the use of Fujimara (1972), Imai and Yoshimura (1975) or Imai et al. (1975) shear wave velocity correlation formulas and usage of FEMA soil classification standard is useful for evaluating the most suitable soil types.

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