Estimation of shear wave velocity from SPT N-values: Case study of Algiers area

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ABSTRACT: Shear wave velocity is a basic engineering tool required to define dynamic properties of soils. In many instances, it may be preferable to determine Vs indirectly by common in situ tests, engineers opt for empirical correlations between shear wave velocity (Vs) and reliable static field test data like standard penetration test (SPT) N-value, CPT (Cone Penetration Test) values etc., to estimate shear wave velocity or dynamic soil parameters. The relation between Vs and SPT N-values of Algiers area is predicted using the collected data and it is also compared with the previously suggested formulas of Vs determination by measuring Root Mean Square Error (RMSE) of each model. Algiers area is situated in high seismic zone (Zone III [RPA 2003]), therefore the study is important for this region. The principal aim of this paper is to compare the field measurements of Down-hole test and the empirical models to show which one of these proposed formulas is applicable to predict and deduce the shear wave velocity values.

1 INTRODUCTION

Shear wave velocity (Vs) is a key parameter necessary to properly evaluate dynamic response of soil (Shukla et al. 2015).This important soil parameter, can be used in a broad range of applications, including mapping stratigraphic layers, conducting pre-construction site characterization studies, calculating dynamic properties of soils, evaluating the liquefaction potential, and detecting cavities, tunnels, and sinkholes (Fathenia et al. 2015)

A shear wave velocity profile can be established and measured directly in the field by conducting a seismic survey without boring and penetration. It is preferable to determine Vs directly by in situ tests, such as by seismic measurements (Field measurement of shear wave velocity includes cross-hole test, down-hole test, seismic refraction [...]) (Dikmen 2009). However, seismic in-situ tests are not always economically feasible to conduct these surveys at all locations (Tan et al. 2012, Tumwesige et al. 2014, Kirar et al. 2016), especially in urban areas, the high noise levels associated with these tests. Therefore, it is necessary to determine Vs through indirect methods such as the standard penetration test (SPT) or the Cone Penetration Test (CPT), which are commonly used for conventional geotechnical site investigations (Shooshpasha et al. 2013).

In geotechnical engineering, many soil parameters are associated with the standard penetration test (SPT). SPT is a dynamic in situ test, in which a sample tube is driven into the ground to a depth of 45 cm in three successive increments of 15 cm by a 63.5 kg hammer (European Standard is 65 kg) free falling a distance of 76 cm onto an anvil mounted on top of the drill rods. The result quoted is the number of blows (N) required advancing the tube for the last 30 cm. SPT- N is significant in site investigation, along with other geotechnical parameters such as Vs (Dikmen 2009).

The SPT is one of the oldest, most popular, and commonly used in situ test for soil exploration in soil mechanics and foundation engineering because of simplicity in the equipment and test procedure. SPT is a widely used in situ test conducted in a borehole. SPT-N values are used to describe and evaluate geotechnical characteristics of soil (Anbazhagan et al. 2016). The correlation can be used to estimate geotechnical parameters in areas where no geophysical investigations exist. There is no theoretical relationship between destructive (SPT) and non-destructive methods (seismic methods). However, several empirical relationships exist for different soil types which appear to be site dependent (Fathenia et al. 2015).

2 MATERIAL AND METHODS

2.1 *Geophysical investigations*

The field work included SPT borings, and seismic studies, namely **Down-hole**. Data acquisitions for all

49 selected sites (as shown in Fig. 1), were accomplished using a Down-hole Test in order to estimate shear wave velocity values.

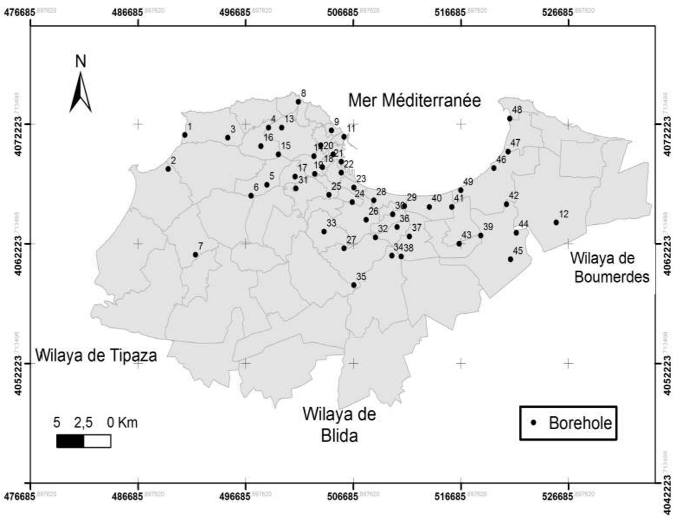

Figure1. Location of 49 boreholes in the study site

Table1. Locations and coordinates of different boreholes

N° borehole	Commune	X	Y
		m	m
1	Ain Benian	491145	4071385
2	Ain Benian	489580	4068525
3	Ain Benian	495101	4071143
4	El -Hammamet	498992	4072053
5	Dely brahim	498676	4067240
6	Dely Brahim	497277	4066318
7	Souidania	492113	4061287
8	Bologhine	501630	4074131
9	Bab El Oued	504654	4071898
10	Casbah	505667	4071166
11	Rouiba	525523	4064083
12	Oued Koriche	503706	4070284
13	Bouzereah	500096	4071927
14	Bouzereah	503127	4069524
15	Beni Messous	499835	4069741
16	Beni Messous	498207	4070360
17	Ben Aknoun	501258	4067846
18	El Biar	503754	4068624
19	Alger Centre	503213	4068008
20	Alger Centre	504899	4069711
21	Alger Centre	505556	4069181
22	Sidi-Mhamed	505570	4068289
23	Belouizdad	506795	4066997
24	El Madania	506594	4065715
25	El Mouradia	504181	4066266
26	Kouba	507895	4064393
27	Kouba	505840	4061825
28	Hussein Dey	508554	4065800
29	Hussein Dey	511452	4065709
30	El Magharia	510350	4064603
31	Hydra	501483	4066855
32	Bir Mourad Raïs	508725	4062871
33	Bir Khadem	503928	4063273
34	DJASR KASENTINA	510213	4061328
35	DJASR KASENTINA	506754	4058765
36	BachDjarah	510797	4063877
37	Bourouba	512042	4063104
38	El Harrach	511325	4060994
39	Dar el Beida	518461	4063087
40	Mohamadia	513767	4065473
41	Mohamadia	515997	4065293
42	Bab Ezzouar	520848	4065710
43	Bab Ezzouar	516552	4062143
44	Dar el Beida	521713	4063066
45	Dar el Beida	521360	4060680
46	Bordj El Kifan	519807	4068257
47	Bordj El Bahri	521052	4070112
48	Bordj El Bahri	521240	4072702
49	Bordj El Kifan	516721	4066631

2.2 *Geotechnical investigation Correlations between SPT -N- and Vs of the previous studies*

The geotechnical investigations were carried out using standard penetration tests (SPT). This latter was conducted involving drilling of boreholes at the locations of geophysical investigations within the study area, the drilling logs were prepared. 1024 SPT data were collected from 49 soil borings.

2.3 *Correlations between SPT -N- and Vs of the previous studies*

Many empirical correlations are existing. However, it is very difficult to rate one over another since confidence level of the each correlation vary site to site. In present study, SPT N-value and shear wave velocity data of 49 boreholes are reviewed in order to compare actual measured values with estimated through these correlations (Shukla et al. 2015).

Majority of the published models are often expressed in the form of a power regression function given by Equation 1:

$$V_s = a * N^b \quad (1)$$

Where:

V_s = shear wave velocity in [m/s];

a and b = regression constants which depend on the correlation coefficient;

N = measured -N- values.

Generally, as a increases b decreases for the same strata (Tumwesige et al. 2014, Anbazhagan et al. 2016, Kirar et al. 2016).

The empirical relation between SPT-N- and V_s values would be useful for the sites where it is difficult to conduct surface wave test for determining shear wave velocity value, which would be further useful in determining dynamic properties and site class (Anbazhagan et al. 2016).

A significant body of research can be found in the literature for correlations between SPT-N and V_s (Dikmen 2009). These correlations are also used in the sites or study areas where geotechnical materials are similar (Anbazhagan et al. 2016).

A summary of published empirical correlations that describe the relationship between SPT-N- and V_s for all soil types is given in Table 2.

Table2. Summary of proposed correlations used in the comparison for all

Authors	V_s (m/s)
Ohba & Toriumi (1970)	$84N^{0.31}$
Imai &Yoshimura (1970)	$76N^{0.33}$
Fujiwara (1972)	$92.1N^{0.337}$
Ohsaki &Iwasaki (1973)	$82N^{0.39}$
Imai (1977)	$91N^{0.337}$
Seed &Idriss (1981)	$61N^{0.5}$
Imai &Tonouchi (1982)	$97N^{0.314}$
Jinan (1987)	$116.1(N+0.3185)^{0.202}$
Yokota et al. (1991)	$121N^{0.27}$
Athanasopoulos (1995)	$107.6N^{0.36}$
Iyisan (1996)	$51.5N^{0.516}$
Hanumantharao & Ramana (2008)	$82.6N^{0.43}$

The variation between suggested correlations is mainly due to the various geotechnical conditions of each studied site and also different equipment and methods of field investigations.

As an example, Imai and Yoshimura (1975) studied the relationship between seismic velocities and some index properties over 192 samples and developed empirical relationships for all soils, Iyisan (1996) examined the influence of the soil type on SPT-N versus Vs correlation using data collected from an earthquake-prone area in the eastern part of Turkey (Dikmen 2009).

The shear wave velocity (Vs) is estimated through 12 correlations proposed by various researchers by using SPT-N- values. The latter values are used as input to estimate shear wave velocity using correlations. It is important to note that Vs is actually measured using down-hole test method.

3 RESULTS AND DISCUSSION

It is important to note that all the empirical correlations used for estimation of shear wave velocity are well researched and validated using field data.

The proposed models were fitted to the experimental data as shown in Figure 2 in an attempt to establish if they can be used to predict shear wave velocity in the study area.

Models such as Fujiwara (1972) and Imai (1977), were closer from the experimental measurements implying that these relationships are good predictors of shear wave velocity for soils in the study area (see Figure 3).

Some of the models predicted shear wave velocities gave poor predictions such as: Jinan (1987), Imai & Yoshimura (1970) and Ohba & Toriumi (1970).

Ohsaki & Iwasaki (1973), Seed & Idriss (1981), Athanosopoulos (1995), Iyisan (1996), Hanumantharao & Ramana (2008) overestimated the shear wave velocities as the SPT-N-values increased.

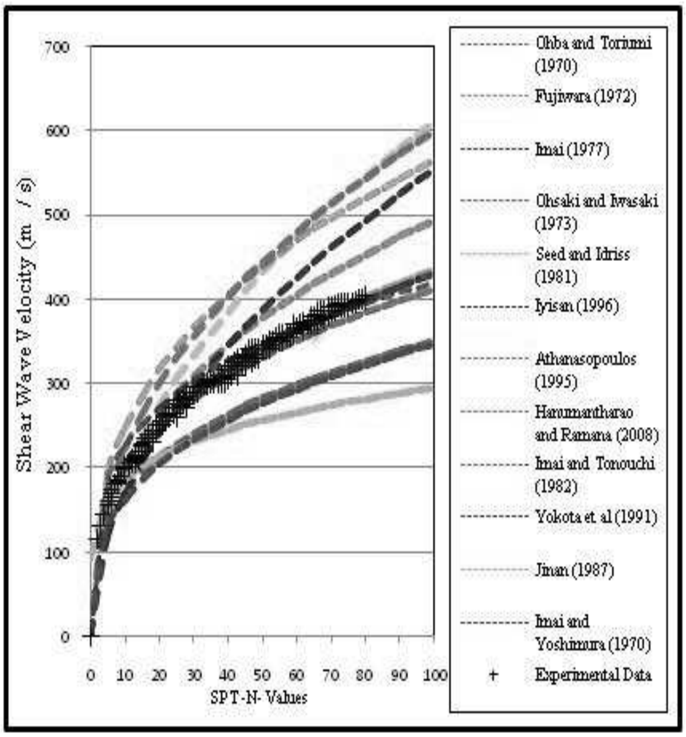

Figure 2. A comparison with the existing correlations from literature superposed on field data used in this study

In order to compare the experimental data and the results of the different models in predicting the shear wave velocity values, Root Mean Square Error (RMSE) values of the proposed correlation was compared. As shown in Figure 3.

Root mean square error (RMSE) is widely employed in model evaluation studies. As a standard metric for model errors (e.g. McKeen et al. 2005, Savage et al. 2013, Chai et al. 2013). Every statistical measure condenses a large number of data into a single value. Using the RMSE helps to provide a complete picture of the error distribution (Chai et al. 2014).

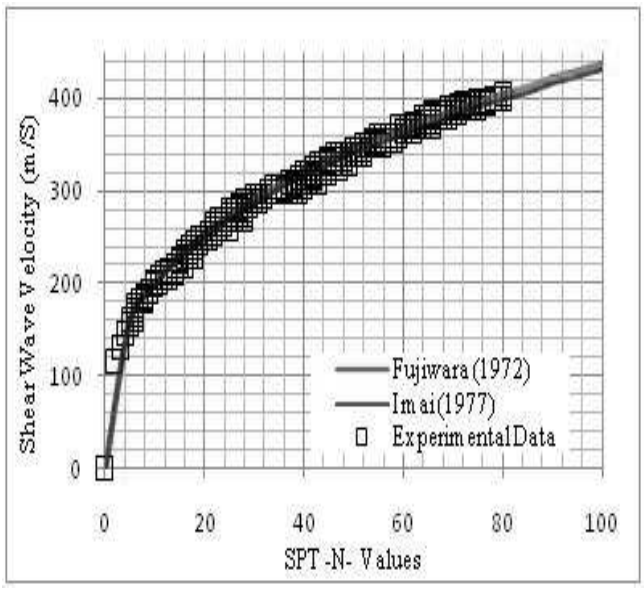

Figure 3. Field data and the proposed correlations of Fujiwara and Imai

We assume that we alredy have n samples of model errors calculated as (e_i, n,, i = 1,2, . . . , n). e_i is defined as the difference between mesured value and model.

$$RMSE = \sqrt[2]{\frac{1}{n}\sum_{i=1}^{n} ei^2} \qquad (2)$$

Fujiwara model has lower error value than all the other suggested correlations studied in this research with RMSE of 3.30 (m/s) followed by Imai model with RMSE of 3.45 (m/s) (see Fig. 4).

These latter models were tested using the available data from boreholes 6 and 11 as an example (see Fig. 5).

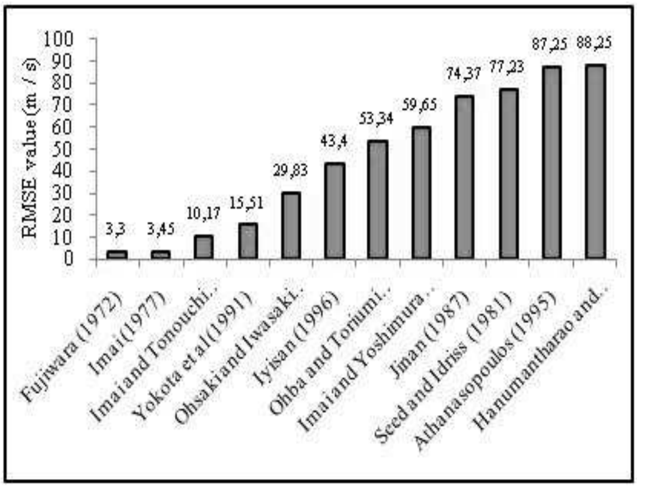

Figure 4. Representation of RMSE values of different models used in this study

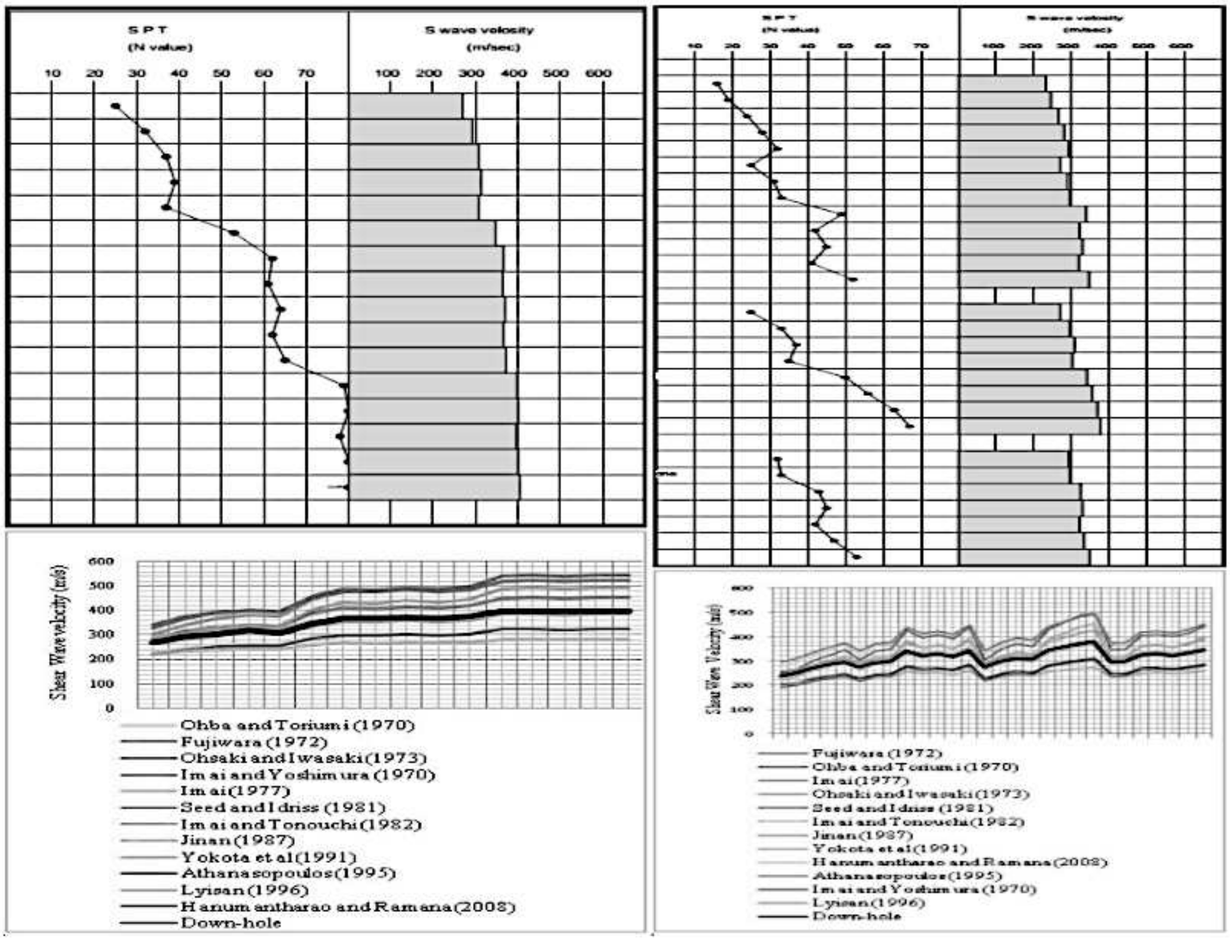

Figure 5. Comparison of shear wave velocity values between Down hole and empirical correlations results: a)- borehole n°6, b)- borehole n°11

4 CONCLUSION

Traditionally, SPT was found to be popular among geotechnical engineers in order to estimate the strength of the soil. The down-hole or cross hole profiling methods allow in situ measurements of the shear -wave velocity with depth. However, the performance of these methods for site characterization can be rather difficult and expensive in urban areas because these methods require boreholes (Kirar et al. 2016). It is not economically feasible to conduct test at all sites. Therefore, a reliable empirical correlation between shear wave velocity and standard penetration resistance (SPT-N-) would be useful since the ease of obtaining the SPT-N- from site investigation report. In the present study, 49 boreholes data were collected from the sites across Algiers area. These data were analysed statistically and compared with previous results within the literature. This paper has been made to verify the applicability of empirical correlations between SPT-N- values with shear wave velocity (Vs). It reveals that the empirical correlations can be used reliably for estimation and prediction of shear wave velocity for a given profile.

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