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EMPIRICAL CORRELATION OF SHEAR WAVE VELOCITY AND N-SPT VALUE FOR JAKARTA

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ABSTRACT: This paper proposes an equation representing shear wave velocity (Vs) as a function of SPT blow count (N-SPT). The equation is generated by statistical regression of site investigation data at many building project in Jakarta. The N-SPT values and Vs values were obtained from the same boreholes between 2005 and 2012. The Vs values were obtained by the downhole seismic survey. A total of 22 building and 35 borings provided 234 pairs of N-SPT and Vs values were used to get a regression equation. The new and previously suggested formulae have been compared and evaluated by using the same dataset. Wave propagation analysis require Vs as an input parameter, and the empirical equation may be useful for estimating Vs at site where only N-SPT data available. The information of empirical correlation can and perhaps should be considered in developing microzonation map of Jakarta as inputs in a continuous process of risk assessment and disaster mitigation risk reduction.

Keywords: Downhole seismic survey, shear wave velocity, standard penetration test, Jakarta soil, in-situ test

1. INTRODUCTION

The shear-wave velocity of soils plays an important role in the design of geotechnical structures under dynamic loads. It is used mostly for determining the seismic site categories (e.g., Indonesian Building Code SNI 1726-2002) and for input of ground motion prediction equations where Indonesia has large strain problems related to seismic loading. In Indonesia, the shear-wave velocity is typically measured using the seismic downhole test. However, the equipment is not widely available and, consequently, the test is generally too expensive to perform for most construction projects. On the other hand, the standard penetration test method (SPT) is one of the most common in-situ tests because its equipment is widely available and it is easy to perform

Numerous relations between SPT blow count, N-SPT, and shear wave velocity, Vs, exist in the literature. Early efforts utilized laboratory results to develop correlations, and the correlations were subsequently refined as field measurement of Vs became more common and data became available. The most common functional form for the relations proposed in the literature is $Vs=a \times N\text{-}SPT^b$, where the constants a and b are determined by statistical regression of a data set.

A study to develop correlations among penetration test results and shear-wave velocity for soils from Indonesia is currently being conducted. This present paper present the development of a correlation between the resistances obtained from SPT and shear-wave velocity for soils from Jakarta area

2. GEOTECHNICAL AND SEIMOTECTONIC SETTING

2.1 Geological condition

Geologically, the study area, Jakarta is dominated by quaternary sediment and, unconformably, the base of the aquifer system is formed by impermeable Miocene sediments which are cropping out at the southern boundary, which were known as Tanggerang High in the west, Depok High in the middle and Rengasdengklok High in the east. They acted as the southern basin boundary. The basin fill, which consist of marine Pliocene and quaternary sand and delta sediments, is up to 300 m thick.

Individual sand horizons are typically 1 - 5 m thick and comprise only 20% of the total fill deposits. Silts and clays separate these horizons [1], [2]. In detail, Reference [3] differentiated the lithology in this area into some formations and explained as follows (Fig. 1).

Based on boreholes data in surrounding area of Jakarta processed by Reference [3], the geological formation were found in subsurface are grouped into:

a. Rengganis Formation consists of fine sandstones and clay stone outcropped in the area of Parungpanjang, Bogor. Unconformably, this formation is covered by coral limestone, marl, and quartz sandstone.

b. Bojongmanik Formation consists of interbedded of sandstone and clay stone, with intercalated limestone.
c. Genteng Formation consists of volcanic eruption material such as andesitic breccias and intercalated tuffaceous limestone.
d. Serpong Formation, intebedded of conglomerate, sandstone, marl, pumice conglomerate, and tuffacueous pumice.
e. Coral Limestone, Holocene age and found in Seribu Island Complex in Jakarta Bay, consist of coral colony, coral fragment, and mollusk shell.

Beside those above lithology, there are found Banten Tuff, young volcanic eruptive material, fan deposits, paleo and recent beach ridge deposits which are deposited parallel to recent coastal line.

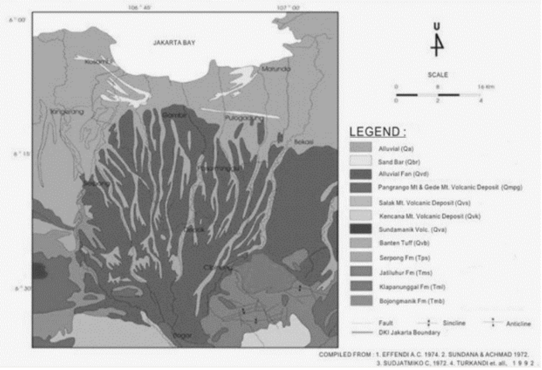

Fig. 1 Geological map of the Greater Jakarta and its surrounding area.

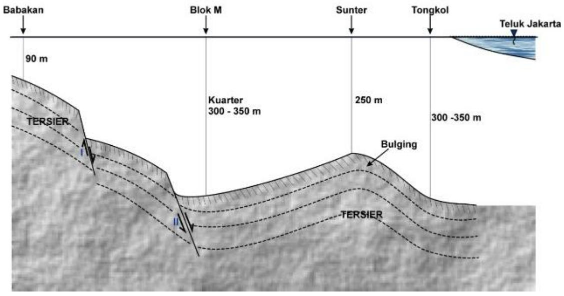

Fig. 2 Bedrock profile of Jakarta

2.2 Seismotectonic settings

Jakarta is located in a tectonically very active area. The study site is surrounded by a number of active faults. The Indo-Australia Subduction Zone, Sunda Fault, and Lembang Fault are the most important earthquake sources in the study site. The 2009 West Java earthquake, which resulted in extensive loss of life and damage to structures particularly in the Sukabumi Region, was also felt in Jakarta and its vicinity. General condition of the mayor tectonic features was shown in Fig. 3.

3. TEST PROGRAM

The test program considered in this study was conducted in 22 locations; in each location a series of standard penetration tests and a series of shear-wave velocity measurements performed using the seismic downhole test method were conducted in one bore-hole. The coordinate of locations are shown in Table 1 and Fig. 4.

Fig. 3 Major tectonic feature of Jakarta region

Table 1 Test location in this study

ID	Coordinate		Soil Types	ID	Coordinate		Soil Types
	Longitude	Latitude			Longitude	Latitude	
1	106.8336	-6.2282	Soft soil	12	106.8384	-6.30495	Soft to Stiff soil
2	106.8764	-6.17113	Soft soil	13	106.8162	-6.21073	Soft to Stiff soil
3	106.9081	-6.15226	Soft to stiff soil	14	106.6279	-6.24064	Stiff soil
4	106.8277	-6.22972	Stiff soil	15	106.8353	-6.21677	Stiff soil
5	106.788	-6.23653	Stiff soil	16	106.8236	-6.1992	Stiff soil
6	106.7976	-6.21092	Soft to stiff soil	17	-	-	Stiff soil
7	106.7942	-6.24675	Soft to stiff soil	18	106.8143	-6.24707	Stiff soil
8	106.6279	-6.24064	Soft to stiff soil	19	106.7847	-6.23671	Stiff soil
9	106.8267	-6.22923	Soft to stiff soil	20	106.8197	-6.21167	Stiff soil
10	-	-	Stiff soil	21	106.7893	-6.1691	Soft soil
11	106.78	-6.29142	Stiff soil	22	106.8341	-6.22476	sedang

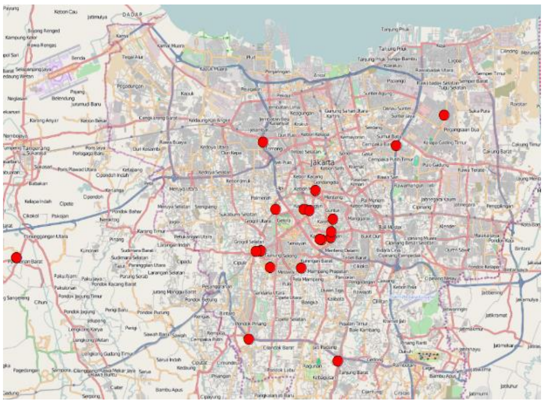

Fig. 4 Locations of geotechnical and downhole investigations

Standard Penetration Tests were performed along borings with intervals of 1.5 m to 2m. Standard Penetration Test procedure and equipment followed the ASTM D 1586 – 84 [4], “Standard Method for Penetration Test and Split Barrel Sampling of Soils”. The resistance of soil is represented by the N-SPT value. The number of blows of hammer striking drilling rod to cause 3x6" penetration of the split spoon at the tip into the soil was counted. The N-SPT value is the total number of blows for the last 2x6" penetration.

The seismic downhole tests were performed in accordance with ASTM D7400 – 08 [5]. The tests were conducted using 3-component, OYO Borehole Pick Model 3315 geophone and McSeis 24-channel portable engineering seismograph. The shear-wave velocity was measured at 1.0 m interval. The seismic shear-wave was generated using the 28-kgf, T6-6061 aluminum alloy shear-wave source equipped with ground coupling spikes. The method is illustrated in figure below.

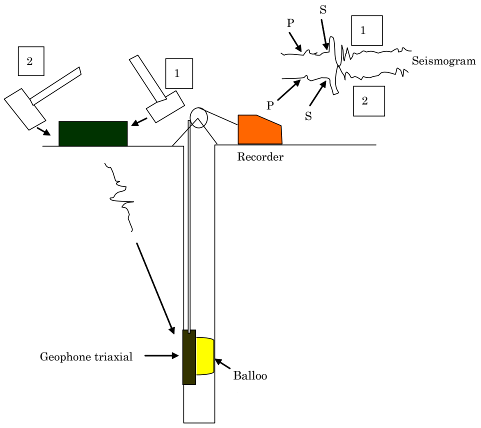

Fig. 5 Downhole seismic survey illustration

4. PROPOSED EMPIRICAL CORRELATIONS FOR VS–N-SPT

A significant number of correlations have been published on various soil types (Table 2). Reference [6] pointed out that geological age and type of soil are not predictive of Vs while the uncorrected N-SPT value is most important. Reference [7] examined the influence of the soil type on N-SPT versus Vs correlation using data collected from an earthquake-prone area in the eastern part of Turkey. The results showed that, except for gravels, the correlation equations developed for all soils, sand and clay yield approximately similar Vs values. Reference [8] presented a detailed historical review on the statistical correlation between N-SPT versus Vs. Reference [9] studied similar statistical correlations using 97 data pairs collected from an area in the north-western part of Turkey and developed empirical relationships for sands, clays, and for all soils irrespective of soil type.

Significant differences exist among the various published relations, which are likely partially caused by differences in geology, but also by errors in measurements of N-SPT and Vs. Resolving the differences among published relationships is beyond the scope of this study.

Example data from ID 11 is shown in Fig. 6. The graphs show the Vs profile and N-SPT profile at the site. The Vs profiles were typically recorded at 1 m intervals, whereas the N-SPT values were recorded at much coarser sampling intervals typically 1.5m or larger. A number of possible approaches were considered for selecting an appropriate Vs value to associate with each N-SPT value for statistical regression.

Table 2 Some existing correlations between N-SPT and Vs

Author(s)	ID	Equation(s)
Ohta and Goto (1978)	A	$85.3N^{0.341}$
Imai and Tonouchi (1982)	B	$96.9*N^{0.314}$
Sykora and Stokoe (1983)	C	$100.5N^{0.29}$
Jinan (1987)	D	$116.1(N+0.3185)^{0.202}$
Iyisan (1996)	E	$51.5N^{0.516}$
Jafari et al. (1997)	F	$22N^{0.85}$
Kiku et al. (2001)	G	$68.3N^{0.292}$
Hasancebi and Ulusay (2007)	H	$90N^{0.309}$

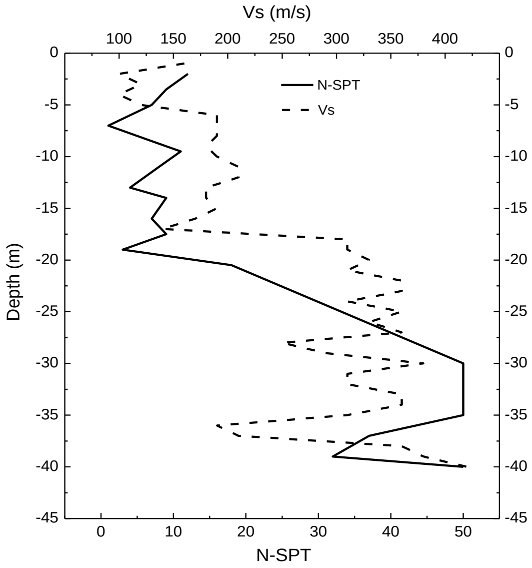

Fig. 6 Example variation of N-SPT and Vs for statistical regression

In this study, 234 data pairs (N-SPT and Vs) were employed in the assessments. The correlations were developed using a simple regression analysis for the existing database. New relationships were proposed between uncorrected Vs (m/s) and corresponding N-SPT. (Fig. 7). The following relationships with its correlation coefficients (r) are proposed between Vs (m/s) and N-SPT values.

$$Vs = 105.03N^{0.286} \quad (r = 0.675) \qquad (1)$$

Comparisons between the measured Vs and Vs predicted from (Eq. (1)) are presented in Fig. 8. The plotted data are scattered between the lines with 1:0.5 and 1:2 slopes, with smaller Vs values (Vs < 300 m/s) falling close to the line 1:1.

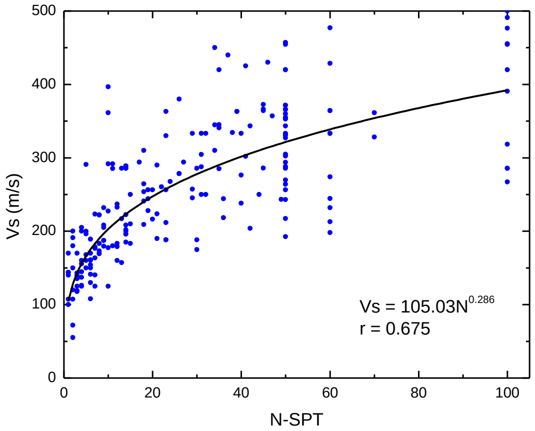

Fig. 7 Present correlation between N-SPT and Vs

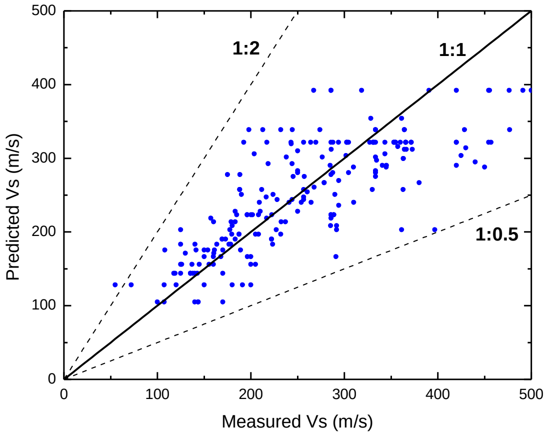

Fig. 8 Measured versus predicted shear wave velocities

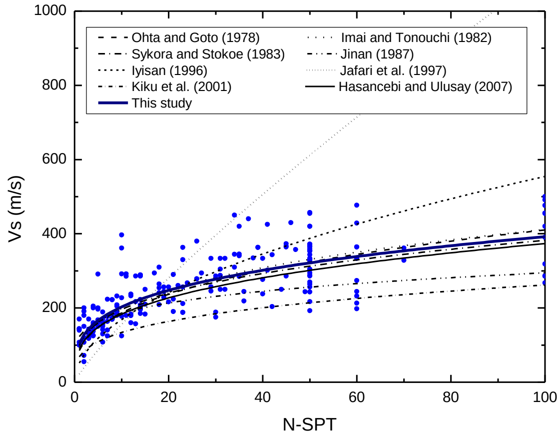

Fig. 9 Comparisons between proposed and previous correlations for N-SPT and Vs

Equation (1) are plotted in Fig. 9 together with several of the earlier regression equations given in Table 2. Some of the correlations fit the data points reasonably well, though there is tremendous difference in the range of V_s values predicted for a given N-SPT value. It is unclear how much of these deviations are caused by natural variability in soil deposits, how much is caused by errors in measurements of *N* and V_s, and how much is caused by exclusion of overburden correction in the existing relations. All the equations including the equation of the present study (Eq. (1)) yield similar Vs values. There is only a slight difference between Eq. 1 and those developed by Reference [10] and Reference [11]; Eq. (1) proposed in this study estimates Vs values considerably closer to those derived from most of the existing equations.

Future efforts should aim to reduce the variability in these relations by utilizing only high-quality measurements of N-SPT and Vs, and properly incorporating the influence of overburden. This effort would involve re-interpretation of the data available in published relations, which is beyond the scope of this paper.

5. CONCLUSION

In this study, based on the geotechnical and geoseismic data from the Jakarta area, an attempt was made to develop new relationships between N-SPT and Vs to indirectly estimate the Vs to be used for practical purposes. The regression equations developed in this study compare well with most of the previous equations and exhibit a good prediction performance. Therefore, the use of an equation developed for all soils based on uncorrected blow-counts is recommended for practical purposes.

A likely application of the correlations presented in this work is the calculation of the thirty-meter shear wave velocity, Vs_{30}, which is defined as 30m divided by the travel time of a vertically propagating shear wave in the upper 30m. Vs_{30} is a required input for the Next Generation Attenuation models and is therefore needed to quantify seismic hazard. Geotechnical site investigations at many older sites contain boring logs, but no geophysical measurements. Obtaining a rough estimate of Vs_{30} based on the recorded boring logs could therefore be useful for assessing seismic hazard at sites with that lack geophysical measurements, and for identifying whether geophysical measurements are necessary to further refine the estimate of Vs_{30}.

The differences between existing and proposed equations are mainly due to the specific geotechnical conditions of the studied sites, the quantity of processed data and the procedures used in undertaking the SPTs and geoseismic surveys. The proposed relations are not an accurate substitute for geophysical measurements, and uncertainty in the predictions should be considered when using the relations.

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