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DEVELOPING EMPIRICAL CORRELATION BETWEEN SHEAR WAVE VELOCITY AND STANDARD PENETRATION RESISTANCE USING MASW METHOD

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ABSTRACT
The shear wave velocity (VS) is one of the important parameters that represent the stiffness of the soil layers. The shear wave velocity profile is typically measured by conducting wave propagation tests in the field such as seismic Reflection Test, seismic Refraction Test, suspension logging test, seismic down hole (up hole) test, spectral analysis of surface waves (SASW), Multichannel Analysis of Surface Wave (MASW), etc. But usually it is not economically possible to perform these tests at all the sites. Therefore, a reliable empirical relationship between VS and N-value would be significant advantage; the correlation between N-value and VS can be utilized to evaluate geotechnical parameters in regions where boreholes are not available or geophysical investigation exist. On the other hand, shear wave velocity can be used to estimate several soil parameters through many empirical correlations. In this study, two site investigations for two different sites in Malaysia have been conducted, three SPT test accompanied with MASW test was conducted in first site, while two SPT test and MASW test were conducted in second site. After collecting all the data of SPT and shear wave velocity VS, this study has developed a new relationship between N value and shear wave velocity VS.

INTRODUCTION
Geophysical methods provide the chance to overcome some of the issues that occur in the conventional ground investigation methods. Several approaches exist with the potential of offering sections and profiles, so that the area between boreholes can be assessed to check whether soil characteristics at the boreholes are representative of that area in between [1]. One of these approaches is the MASW. Unlike other seismic methods such as reflection test and refraction test, etc., the MASW method has advantages in many respects. Firstly, the in-situ survey is easier because of the strong nature of surface-wave energy that can be created through a simple impact source (sledgehammer) and by following simple field procedure. Secondly, the data-processing steps are often very simple that it does not need very experienced user for reliable calculations of optimum processing parameters. Thirdly, surface waves respond most effectively to different types of near-surface irregularities that are common goals of geotechnical investigation [2]. Because of all these advantages, the chance of an effective survey is often higher with the MASW method than with other seismic techniques when dealing with recognition of near-surface irregularities.

Many correlations between N-value and shear wave velocity VS exist in the literature. The N-value is one of the essential parameters in ground investigations as it used in several empirical equations to estimate other parameters [3]. On the other hand, shear wave velocity is beneficial in the estimation of foundation stiffness, site classification, liquefaction potential, soil density, earthquake site response, foundation settlements and soil stratigraphy. Early experiments used laboratory results to introduce empirical equations, but that equations were subsequently refined as the in-situ measurement of VS became more public and data became obtainable. A significant number of empirical equations have been published on different types of soil [4] (Table 1).

Clear variances exist among the different published correlations, because some of the early relations have developed based on field data often involved blow counts were not corrected for rod length, sampler inside diameter, energy. Hence, it is not possible to recognize whether bias is introduced by hammer efficiency, nonstandard samplers, etc. Moreover, different methods of calculating VS were used in the correlations; these different methods provide different resolutions for VS measurements at different depths [5].

Table 1. Empirical equations from previous literature

AUTHOR(S)	ALL SOILS	SAND	SILT	CLAY
Shibata (1970)	-	$V_s = 31.7\ N^{0.54}$	-	-
Ohba and Toriuma (1970)	$V_s = 84\ N^{0.31}$	-	-	-
Imai and Yoshimura (1975)	$V_s = 76\ N^{0.33}$	-	-	-
Ohta et al (1972)	-	$V_s = 87.2\ N^{0.36}$	-	-
Fujiwara (1972)	$V_s = 91.1\ N^{0.337}$	-	-	-
Ohsaki and Iwasaki (1973)	$V_s = 81.4\ N^{0.39}$	-	-	-
Imai et al (1975)	$V_s = 89.9\ N^{0.341}$	-	-	-
Imai (1977)	$V_s = 91\ N^{0.337}$	$V_s = 80.6\ N^{0.331}$	-	$V_s = 80.2\ N^{0.292}$
Ohta and Goto (1978)	$V_s = 85.35\ N^{0.348}$	-	-	-
Seed and Idriss (1981)	$V_s = 61.4\ N^{0.5}$	-	-	-
Imai and Tonouchi (1982)	$V_s = 96.6\ N^{0.314}$	-	-	-
Sykora and Stokoe (1983)	-	$V_s = 100.5\ N^{0.29}$	-	-
Jinan (1987)	$V_s = 116.1\ (N+0.3184)^{0.202}$	-	-	-
Okamoto et al (1989)	-	$V_s = 125\ N^{0.3}$	-	-
Lee (1990)	-	$V_s = 57.4\ N^{0.49}$	$V_s = 105.64\ N^{0.32}$	$V_s = 114.43\ N^{0.31}$
Athanasopoulos (1995)	$V_s = 107.6\ N^{0.36}$	-	-	$V_s = 76.55\ N^{0.445}$
Sisman (1995)	$V_s = 32.8\ N^{0.51}$	-	-	-
Iyisan (1996)	$V_s = 51.5\ N^{0.516}$	-	-	-
Kanai (1966)	$V_s = 19\ N^{0.6}$	-	-	-
Jafari et al (1997)	$V_s = 22\ N^{0.85}$	-	-	-
Kiku et al (2001)	$V_s = 68.3\ N^{0.292}$	-	-	-
Jafari et al (2002)	-	-	$V_s = 22\ N^{0.77}$	$V_s = 27\ N^{0.73}$
Hasancebi and Ulusay (2006)	$V_s = 90\ N^{0.309}$	$V_s = 90.82\ N^{0.319}$	-	$V_s = 97.89\ N^{0.269}$
Dikmen (2009)	$V_s = 58\ N^{0.39}$	$V_s = 73\ N^{0.33}$	$V_s = 60\ N^{0.36}$	$V_s = 44\ N^{0.48}$
Pitilakis et al (1999)	-	$V_s = 145\ (N_{60})^{0.178}$	-	$V_s = 132\ (N_{60})^{0.171}$
Hasancebi and Ulusay (2006)	$V_s = 104.79\ (N_{60})^{0.26}$	$V_s = 131\ (N_{60})^{0.205}$	-	$V_s = 107.63\ (N_{60})^{0.237}$

Design codes recommend a combination of in-situ penetration resistance and laboratory tests, allowing for the scatter of such correlations. This study deals with the relation between N-value and the shear wave velocity VS. In this paper there are three stages of analysis. Firstly, analysis of boreholes from site investigation (SI) report. The second stage was analyzing the raw data of Multi-channel Analysis of Surface Wave (MASW) method, using SeisImager software. The third stage was making the correlation between Standard Penetration Tests N-value and the shear wave velocity VS to achieve the objectives of the research.

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This paper did a comprehensive study on the soil for two particular sites by conducting several boreholes and tests to obtain N-value and shear wave velocity which ultimately lead to determine many soil parameters that can be useful if the sites used for future construction projects. Both of the sites located in Malaysia–Johor state, first site was near to school locally named (SMK Banang Jaya), second site was near to hospital locally named (Klinik Desa Sejagong), Figure (1).

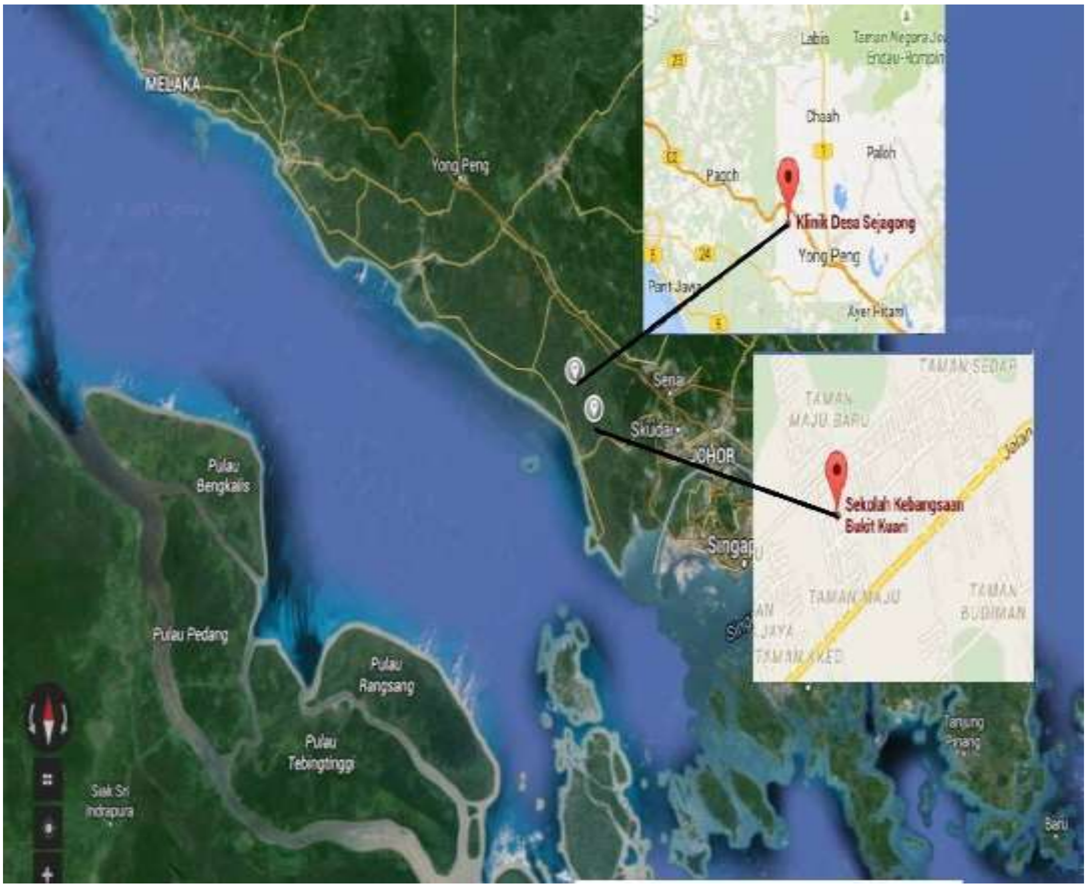

Figure 1: Map of the sites for this study

RESULTS AND DISCUSSION

Analysis of boreholes

Before constructing any building or structures, the first thing to do is the ground investigation. Ground investigation is considered the most important part in geotechnical engineering. There are a lot of information can be obtained from site investigation such as the N-values, depth of borehole, type of soil and ground water level. All of those information are valuable in the structural designing works [6]. In this study, boreholes were conducted from two site in Johor state/ Malaysia.

There are three boreholes at the first site (SMK Banang Jaya). N-values were fluctuated with the depth at all the boreholes. As an average of three boreholes, starting from 0 to 6 meters depth, N-value fluctuating in the range 0 to 10. The second layers, when the depth in the between 6 to 19.5 meters, N-value was 10 to 20, Figure (2). Only one from three of boreholes that achieve SPT-N is 50, with a depth is 18 meters.

For the second site (Klinik Desa Sejagong), N-values were 0 to 10 at 0 to 6 meters, both of boreholes at Klinik Desa Sejagong are terminated at the 9 meters depth, Figure (2).

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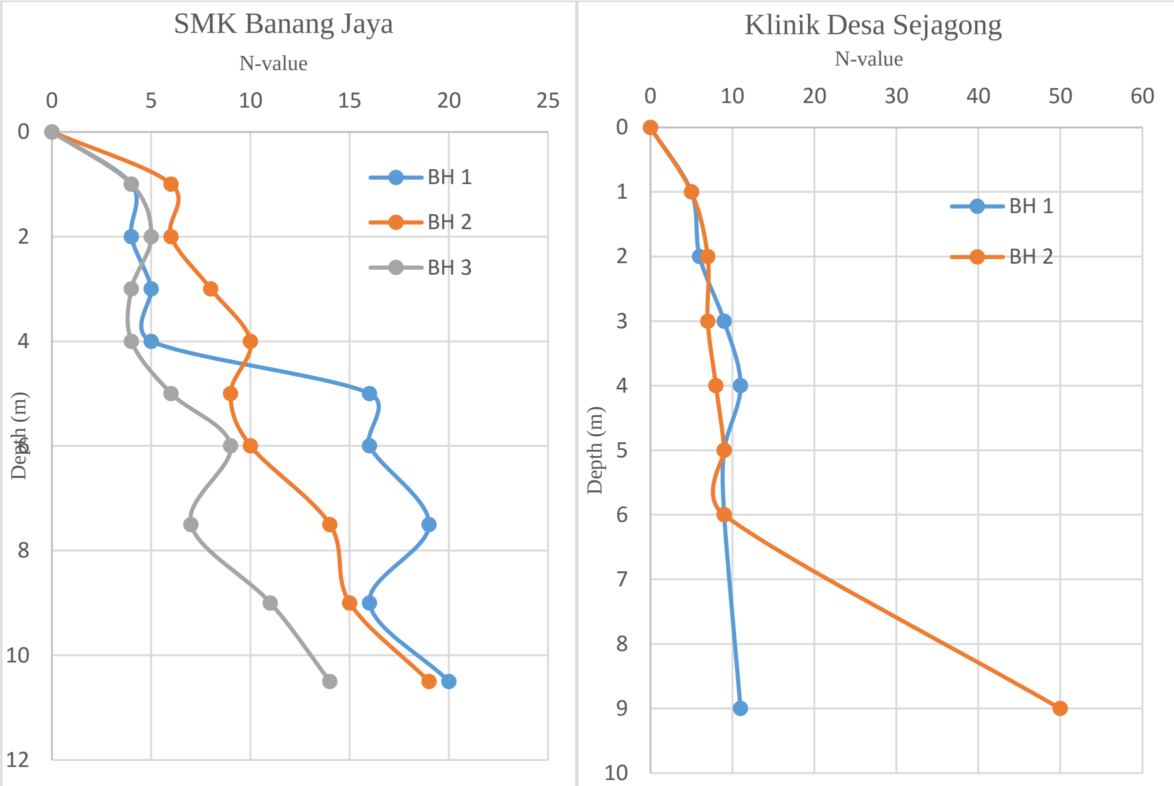

Figure 2: Variation of N-value with depth at two sites

In order to be in the picture, the soil composition of both of the sites was identified. Figure (3) shows soil composition of these two sites based on the analyzing of site investigation data.

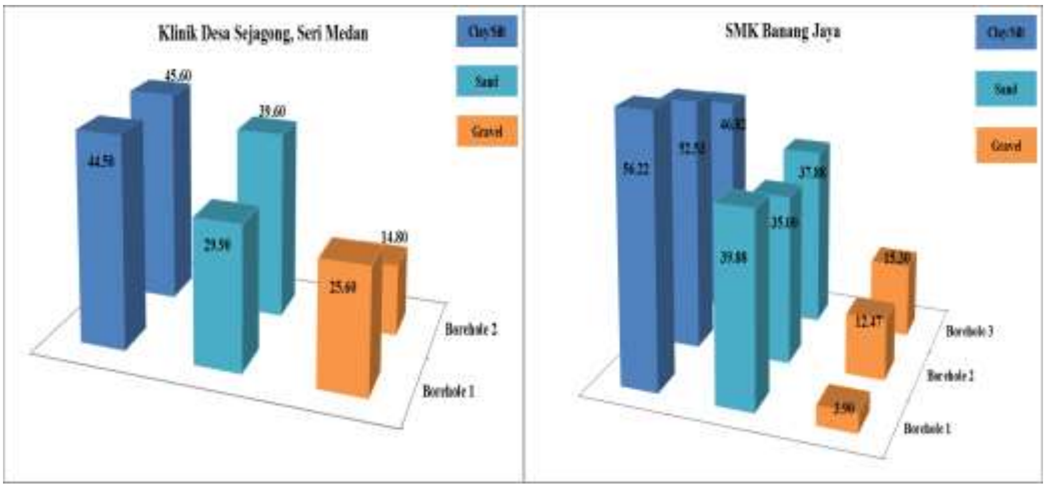

Figure 3: soil composition for two sites

According to Figure (3), there are small differences of soil composition between both of the sites. Where, the composition of clay/silt at Banang Jaya was varying from 46% to 56%, while composition of clay/silt at Klinik Desa Sejagong was less than 45%.

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Multi-channel Analysis of Surface Waves (MASW)

Multichannel Analysis of Surface Waves (MASW) method involves a source of energy such as a sledgehammer impact on the ground. Vibrations created due to sledgehammer impact are received by interconnected electromagnetic geophones (receivers) set up vertically and in a linear array at a constant spacing in the ground surface to get the Rayleigh wave phase velocity dispersion curve. Numerous sledgehammer shots are made to ensure that reliable and clear dispersion curves are found [7].

MASW test was conducting at the SMK Banang Jaya in order to measure shear wave velocity at that site, a seismograph device and 24 geophones and 7 kg sledge hammer were used to generate waves that were analyzed using SeisImager software. The spacing between geophones was 2 meters and the offset was 5 meters from the seismic source and geophone. Seismograph displays the shot record in the time domain. It was found (as shown in Figure 4) that the shear wave velocity increase with increasing of depth and the maximum value of shear wave velocity was at maximum depth while the minimum value of shear wave velocity was at minimum depth. Note that, it is not always shear wave velocity increase with the depth in general cases because it depend on the density of the soil layer itself, sometimes soft soil layer exists in deeper levels in the ground and that will result lower VS values. In general, higher shear wave velocity occur in denser soil layer.

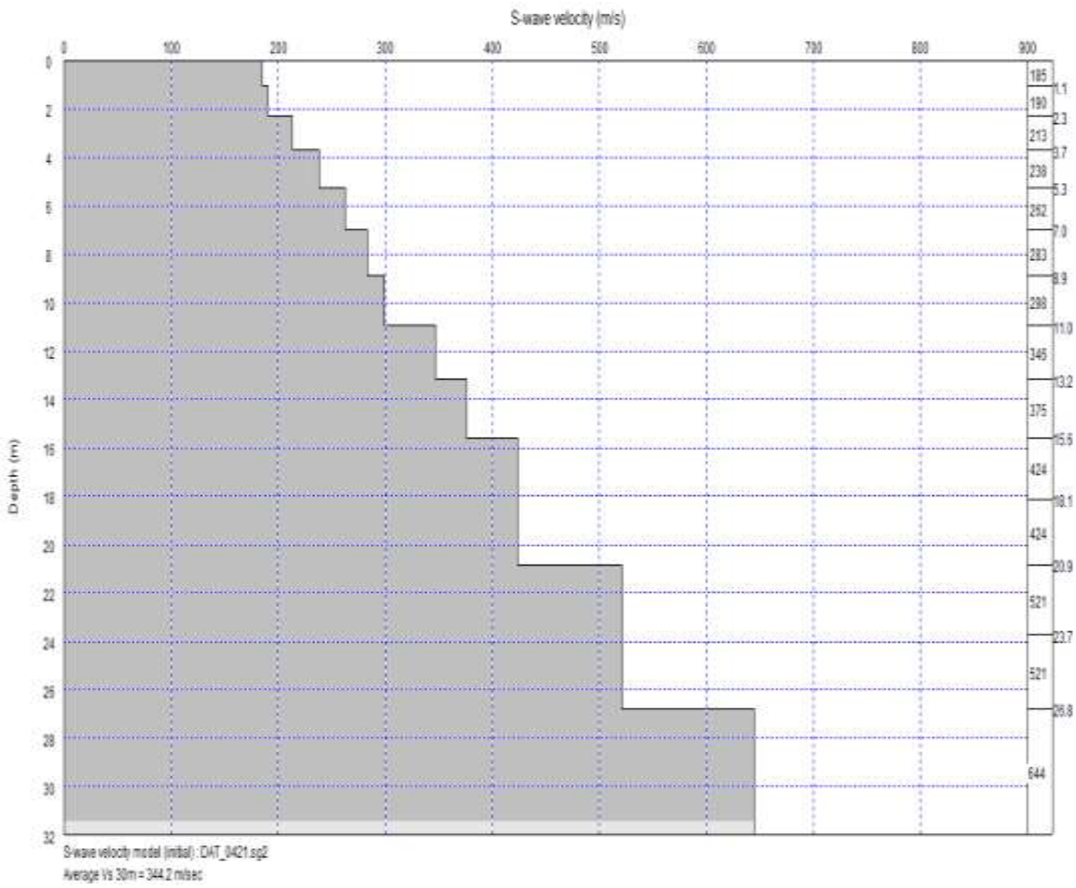

Figure 4: Variation of shear wave velocity with depth at SMK Banang Jaya

MASW was also conducting at Klinik Desa Sejagong, a seismograph device and 24 geophones and 7 kg sledge hammer were used to generate waves that were analyzed using SeisImager software. The spacing between geophones was 3m, the offset was 10 meters from the seismic source and geophone. After hit the ground by sledgehammer, the seismograph displays the shot record in the time domain.

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Similar to the first site (SMK Banang Jaya), shear wave velocity at the second site (Klinik Desa Sejagong) has followed same behavior in which shear wave velocity directly proportional with the depth (Figure 5), after comparing results of boreholes with MASW results, it was found that the N-value and shear wave velocity almost having same behavior, means both of them increasing with the depth and that was encouraging to develop the intended correlation between these terms.

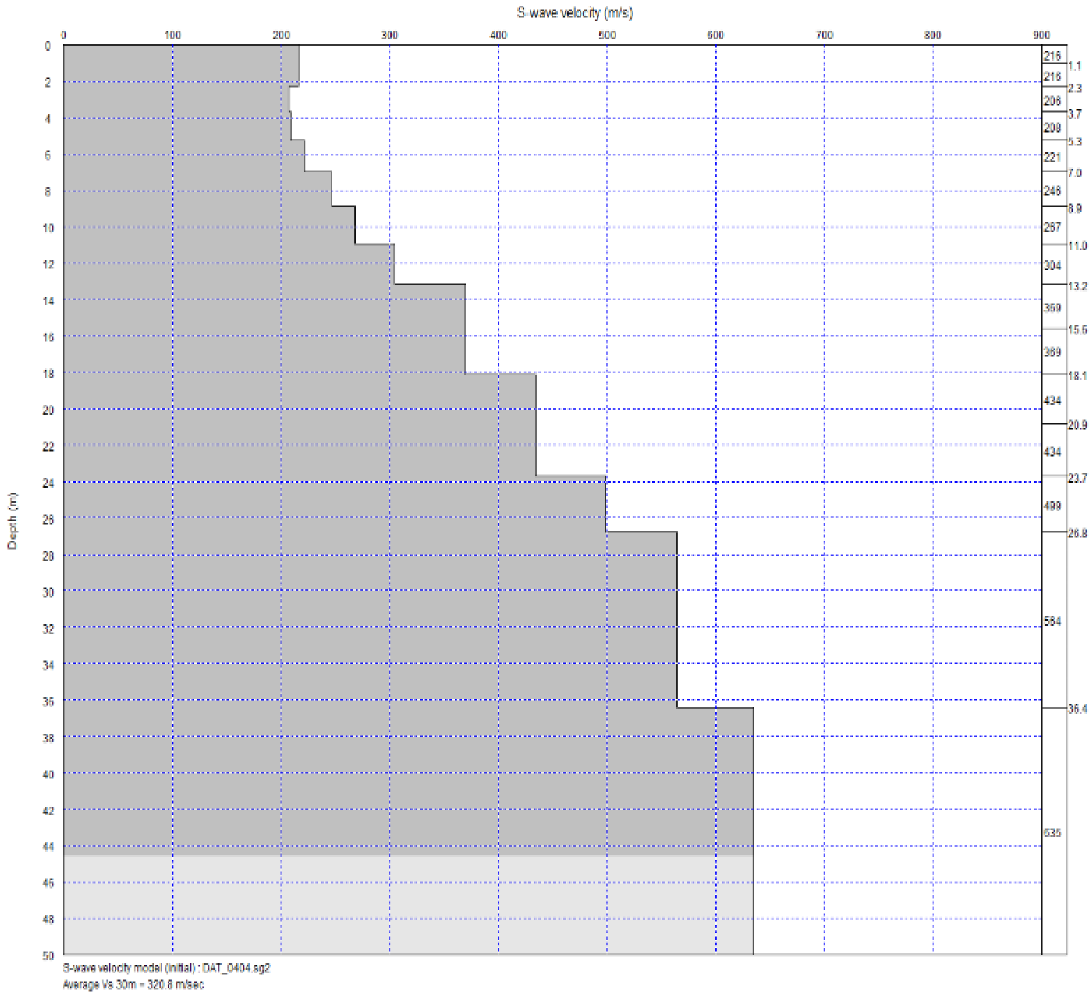

Figure 5: Variation of shear wave velocity with depth at Klinik Desa Sejagong

Correlation between Shear Wave Velocity and SPT-N

Shear wave velocity (Vs) is one of the most common parameter in assessing the soil stiffness of a region. The relationship between N-value and shear wave velocity has been considered since the 1960s. Nowadays, estimation of the shear wave velocity profile plays a vital role in the seismic characterization of subsoil [8].

Field tests to measure the shear wave velocity profile are preferable, but in the same time it is not economically feasible for large areas. Therefore, N-value is a reliable to be employed to estimate the shear wave velocity of a region [9].

The simple regression analysis was used to introduce the new empirical equation based on average of N-value of three boreholes conducted in SK Banang Jaya as shown in Figure (6).

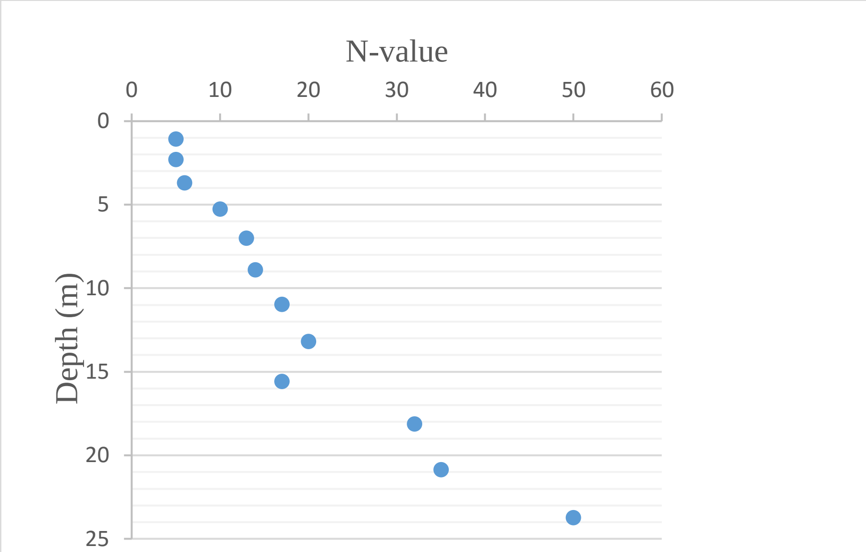

Figure 6: Average of N-value versus depth at SK Banang Jaya

The new empirical correlation for this site is:
N = 0.113 Vs - 19.953
The relationship between N-value and shear wave velocity shown in Figure (7), the accuracy of this equation $R^2 = 0.857$.

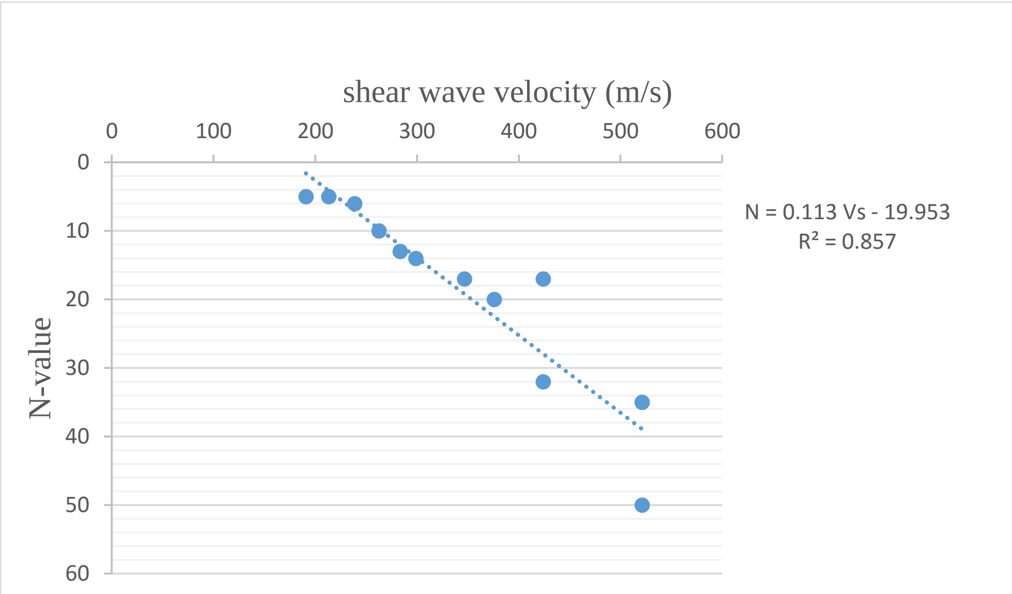

Figure 7: The relationship between N-value and shear wave velocity at SK Banang Jaya

Following same procedure to develop empirical correlation at SK Banang Jaya, new empirical correlation was developed between N-value and s-wave at Klinik Desa Sejagong by taking average of N-value of two boreholes that conducted in that site as shown in Figure (8).

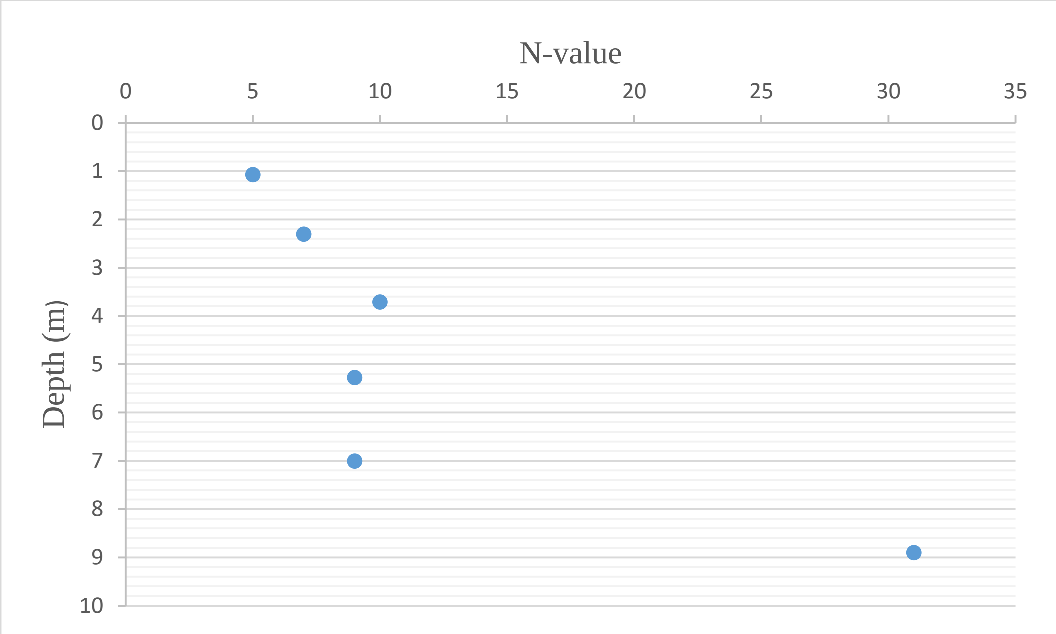

Figure 8: N-value versus depth at Clinic Desa Sejagong

The new empirical correlation for this site is:
N = 4.4643 Vs - 3.2857
The relationship between N-value and shear wave velocity shown in Figure (9), the accuracy of this equation R^2 = 0.7231.

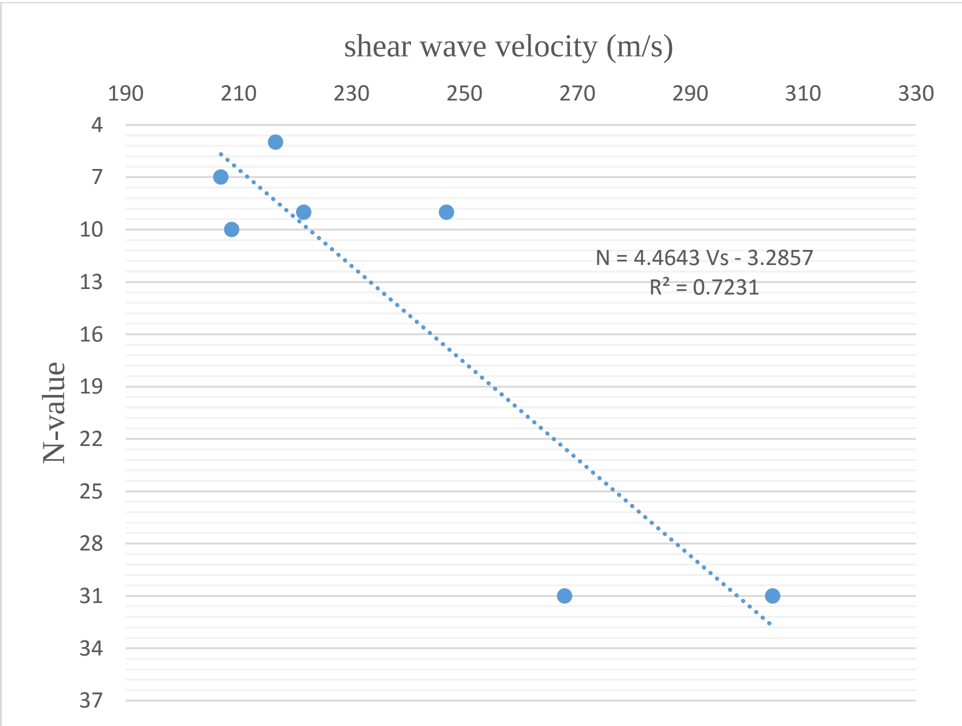

Figure 9: The relationship between N-value and shear wave velocity at Clinic Desa Sejagong

A careful evaluation of the technical literature illustrated that a perfect correlation between the aforementioned parameters does not necessarily exist and is usually site-specific, which means, the obtained correlations are specified only for the mentioned sites and for the sites that having same soil profile [3].

CONCLUSION

- Borehole is a one conventional method and used to evaluate the local site conditions. The advantage of this method is that the accuracy of the data obtained from drilling. However, borehole method is very expensive and slow.
- In this study, based on the Geotechnical and Geo-seismic data from the Clinic Desa Sejagang and SK Banang Jaya area, developing a new relationships between N value from SPT and shear wave velocity from MASW have been made
- S-wave velocity of the ground easily to obtain with surface-wave methods and Phase velocity of surface-waves is sensitive to the S-wave velocity
- The MASW surface wave technique provides a rapid, cost effective and reliable approach to obtaining such data.
- 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 SPT and Geo-seismic surveys, therefore, the proposed relations are not highly accurate but it can be used to have a picture about the specified sites.
- For the Clinic Desa Sejagang, the equation for this correlation was
  N = 4.4643 Vs - 3.2857
  The accuracy of this equation $R^2 = 0.7231$
- For the SK Banang Jaya, the equation for this correlation was
  N = 0.113 Vs - 19.953
  The accuracy of this equation $R^2 = 0.857$

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