26 May 2010, 4:45 pm - 6:45 pm

# Field Measurement of Dynamic Soil Properties of Tropical Meta-Sediment Residual Soils

Zamri Chik
*Universiti Kebangsaan Malaysia, Malaysia*

Susy K. Ariestianty
*Department of Public Work, Indonesia*

Sri Atmaja P. Rosyidi
*Muhammadiyah University of Yogyakarta, Indonesia*

Khairul Anuar Mohd. Nayan
*Universiti Kebangsaan Malaysia, Malaysia*

Mohd. Raihan Taha
*Universiti Kebangsaan Malaysia, Malaysia*

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

# FIELD MEASUREMENT OF DYNAMIC SOIL PROPERTIES OF TROPICAL META-SEDIMENT RESIDUAL SOILS

**Zamri Chik**
Universiti Kebangsaan Malaysia
43600, Bangi, Selangor, Malaysia

**Susy K. Ariestianty**
Center of Res. & Dev. Roads & Bridges
Dep. of Public Work, Bandung, Indonesia

**Sri Atmaja P. Rosyidi**
Muhammadiyah Univ.of Yogyakarta
55183, Bantul, Yogyakarta, Indonesia

**Khairul Anuar Mohd. Nayan**
Universiti Kebangsaan Malaysia
43600, Bangi, Selangor, Malaysia

**Mohd. Raihan Taha**
Universiti Kebangsaan Malaysia
43600, Bangi, Selangor, Malaysia

## ABSTRACT

The study area which was located in Peninsular Malaysia comprised of residual meta-sedimentary soil derived Kenny Hill Formation. The dynamic soil properties of tropical meta-sediment residual soils were measured using non-destructive seismic method known as Multi-channel Analysis of Surface Wave (MASW) method. Twenty four geophones were located on ground in order to measure surface wave propagation. By inversion of dispersion curve, the shear wave velocity profile could be calculated and obtained. For most site investigations, other conventional method of field testing had been conducted such as drilling and Standard Penetration Test (SPT). This paper, however, attempts to obtain the comprehensively characteristics of dynamic soil properties of meta-sediment residual soils using the multi-channel analysis of surface wave (MASW) method and field soil tests. The comparison between the measurement results of all testing was conducted to evaluate the appropriateness of MASW results. The result shows that lateral variation and complexity of the meta-sediment residual soil stratification was found in the location. Thus, the soil dynamic properties at each layer can be properly estimated. A good agreement of soil bearing capacity was also found from MASW method compared to field soil tests.

## INTRODUCTION

The calculation of soil dynamic properties can be performed by measuring shear wave velocity directly using seismic in situ test. Many techniques of seismic in situ test have been developed to measure the shear wave velocities (Vs). One of these methods is Multi-channel Analysis of Surface Wave Method (MASW) developed by Park et al (1996). MASW method is built as an advance technique from previous method known as Spectral Analysis of Surface Wave (SASW) that has been developed by Nazarian and Stokoe (1984). Data collection using MASW method can be carried out effectively and faster. Moreover, data processing can be performed consistently and generate a smooth dispersion curve from the dispersion contour image that capable to differentiate any seismic events more visibly (Park et al, 1998, 2001; Ryden et al, 2004). As the final result, one dimensional (1-D) and two-dimensional (2-D) profiles were produced to visualize subsurface condition vertically and laterally (Xia et al, 2000).

In this study, MASW method and conventional method of Standard Penetration Test (SPT) were conducted to acquire the shear wave velocity of the site. The comparison between these methods will be presented and then the appropriateness of the MASW results was analyzed. Moreover the validation with the bore log data obtained from drilling test was also performed. Subsequently, the correlation to asses the soil bearing capacity from shear wave velocities (Vs) will also be discussed briefly in this paper. During the time, the calculation of soil bearing capacity from Standard Penetration Test (SPT) number is widely used in geotechnical engineering practice. Since many empirical correlations of shear wave velocities (Vs) and SPT number (N) have been proposed and used, a straight correlation of soil bearing capacity and (Vs) may be developed as an alternative method. Beside that, in situ measured shear wave velocity (Vs) as single filed index can be represented and reflects the real soil condition that contain the contributions of the void ratio, effective confining stresses, stress history, shear and compressive strengths, geologic age etc (Tezcan, 2006).

## RESEARCH METHODOLOGY

The study area is located on the Peninsular Malaysia, which is within Univesiti Kebangsaan Malaysia (UKM), Bangi, Selangor, Malaysia, as shown in Figure 1. In the area, conventional soil investigations have been conducted at several locations. Drilling and Standard Penetration Test (SPT) were performed to acquire soil profiles and the value of soil strength. The survey lines of MASW method were then selected adjacent to the drilling points. The location of drilling points and all the survey lines of MASW method were presented also in Figure 1.

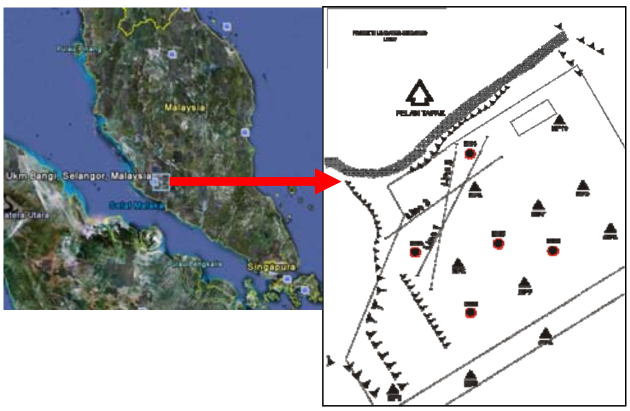


*Fig. 1. The map of study area and the location of drilling test and survey lines of MASW method*

The shear wave velocities (*Vs*) were obtained from SPT results using empirical correlation that have been proposed and developed by some researchers such as Imai and Tonouchi (1982), Seed and Idriss (1981), Lee (1990), Athanasopoulos (1995), Nayan (1995), Hasancebi and Ulusay (2006) and Dikmen (2009). After that, these results were compared with in situ shear wave velocities (*Vs*) from MASW method.

All the procedures in the data collection and data processing of MASW method are adopted from Park et al (1998, 1999, 2002), Penumadu and Park (2005) and Xia et al (1999). Heavy sledge hammer with weight of 16 lb (7.3 kg) as source, 24 geophones of 4.5 Hz and one seismograph (Seistronix RAS 24) are all the equipments that utilized to collect and record the seismic data. Field configurations have been chosen with geophone spacing (*dx*) of 1 m and 2 m and the source distance to the first geophone ($x_1$) of 5 m and 10 m.

A record length of 1000 ms was chosen to cover investigations of soft to hard material. Consecutive shots gathered for each configuration was obtained by moving the adopted source-receiver configuration several times that the two dimensional (2-D) tomography profiles can be acquired. Subsequently, all the seismic records are processed using a computer software program of SurfSeis version 2.01 that developed by Kansas Geology Survey (KGS) Texas.

## RESULTS AND DISCUSSION

### Geology Condition

The study area is a part of the Kenny Hill Formation. In general, Kenny Hill Formation is rock formation consist of inter-bedded sandstones and shale of Upper Silurian-Devonian age. As the metamorphism process occurred, the internal structure of shale changed and then formed phylite. These rock masses arrangement of this formation is also namely as composite rocks which constitutes of more than one type of rock (Mohamed, 2004). Most these rock mass are of sedimentary to meta-sedimentary formation. The meta-sedimentary formation consists of sandstone and siltstone inter-bedded with clay shale ranging from one centimeter to one meter thickness. The inter-bedded structure was occurred because of the geological sedimentation process (Mohamed et al, 2007).

### Field Test and Laboratory Results

From the drilling test, the soil type and stratification of subsurface of study area were obtained as seen in Figure 2. Generally, based on BH3 and BH4, the area is dominantly comprised of silt inter-bedded with sandy silt, sandy clay and gravelly silt layers at certain depths. The soil strength obtained from SPT were also shown in Figure 2, where the minimum N value at upper layer is 3 and the maximum value found at about 12 m and 15 of depth.

Based on laboratory test result, the soil was classified (Unified Soils Classification Systems: ASTM D4287) as inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity (ML), as seen in Figure 3.

Other results of laboratory test that show basic properties of soil of study area such as Atterberg limit, moisture content, sieve and hydrometer analysis can be seen in Figure 4, where density and specific gravity were summarized at Table 1.

### MASW Results

Thirteen 1-D shear wave velocities (*Vs*) profiles of three survey lines were obtained as the results from MASW method. One of the results is given in Figure 5. Two dimensional *Vs* profile was formed by correlating five *Vs* profiles. From the profile, the soil condition and soil strength at each depth can be identified. Over all, the range of shear wave velocities (*Vs*) of each survey lines were summarized and given in Table 2. Subsequently, the shear wave velocities (*Vs*) obtained from several empirical correlations was also given.

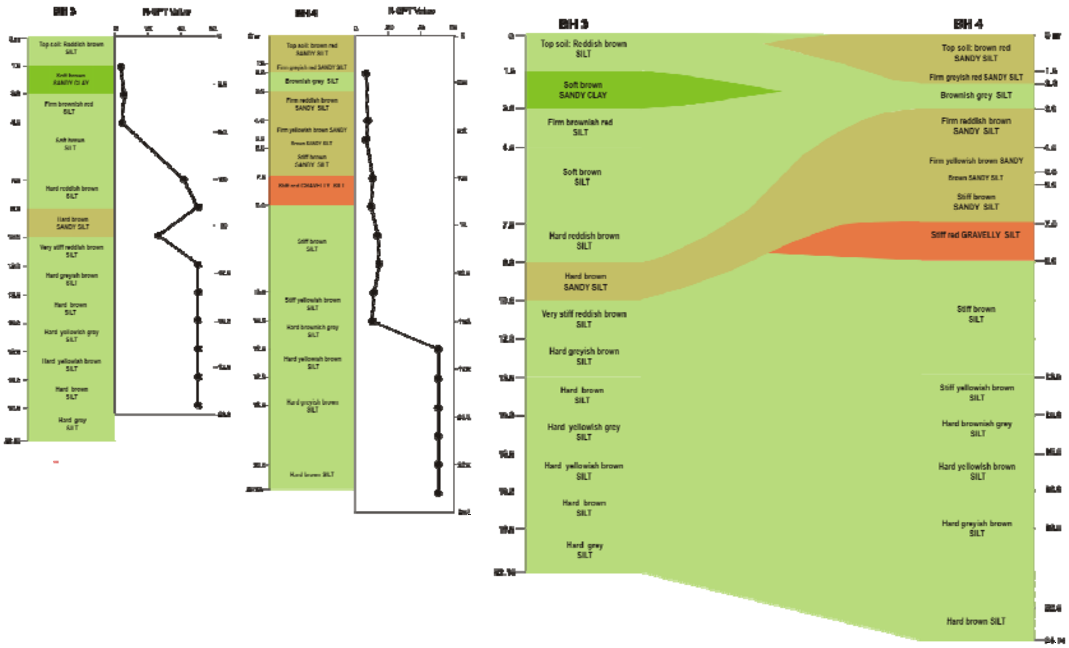


*Fig. 2. Borelogs combined with SPT results and soil profile from correlation of Borelog BH3 and BH4*

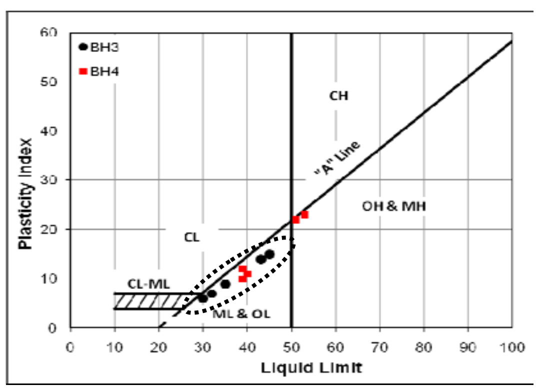


*Fig. 3. Soil Classification of Study Area (USCS)*

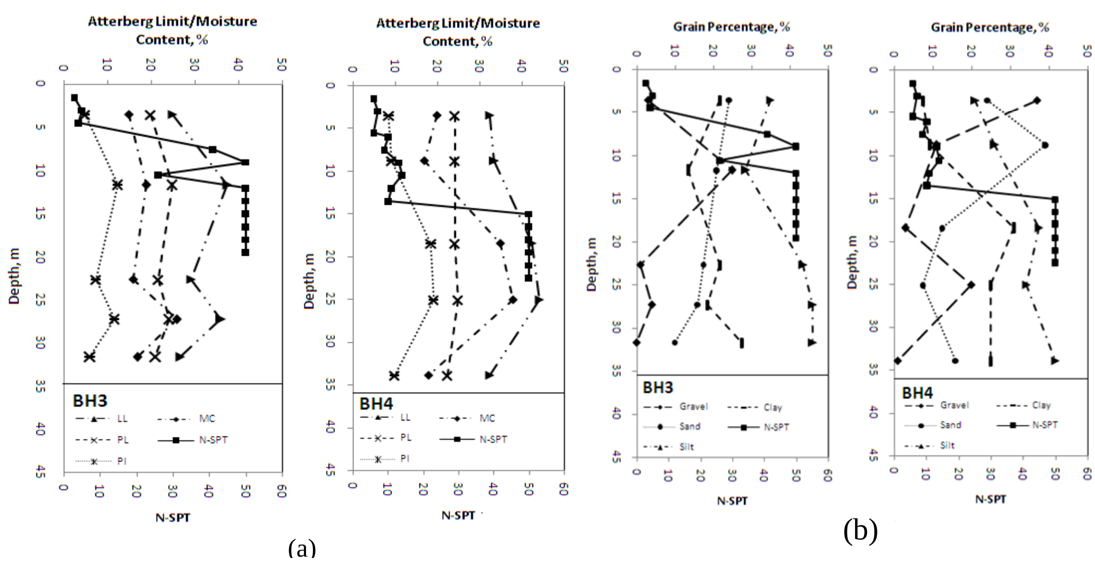


*Figure 4. (a) Atterberg limit and moisture content value, (b) particle size distribution value of soil of study area*

Tabel. 1 Density and specific gravity value of soil of study area

| Borehole | Depth m | Density Bulk $Mg/m^3$ | Specific Gravity | Soil Description |
|---|---|---|---|---|
| BH3 | 2.0 – 2.5 | 2.095 | 2.6 | Soft brown sandy clay |
| BH4 | 2.0 – 2.5 | 2.051 | 2.7 | Brownish grey silt |
| | 5.5 – 6.0 | 2.119 | 2.67 | Brown sandy silt |

In this study, empirical correlation of SPT number (N) from Imai and Tonouchi (1982), Lee (1990), Seed and Idriss (1981), Athanasopoulos (1995), Nayan (1995), Hasancebi and Ulusay (2006) and Dikmen (2009) were utilzed to calculate shear wave velocities (*Vs*). The empirical correlations of each researcher were given in Table 3 and the results were plotted together with the average shear wave velocities (*Vs*) of MASW, as seen in Figure 6.

The shear wave velocities (*Vs*) of MASW method that were plotted as black dots in Figure 6 lie in the range value of shear wave velocities (*Vs*) obtained from previous correlations. Particularly with the correlation from Athanasopoulos (1995) and Lee (1990) that proposed for all soil type and silt. These correlations have the most similar and nearest shear wave velocities (*Vs*) range than other correlations. It shows that soil type has only small influence on these correlations.

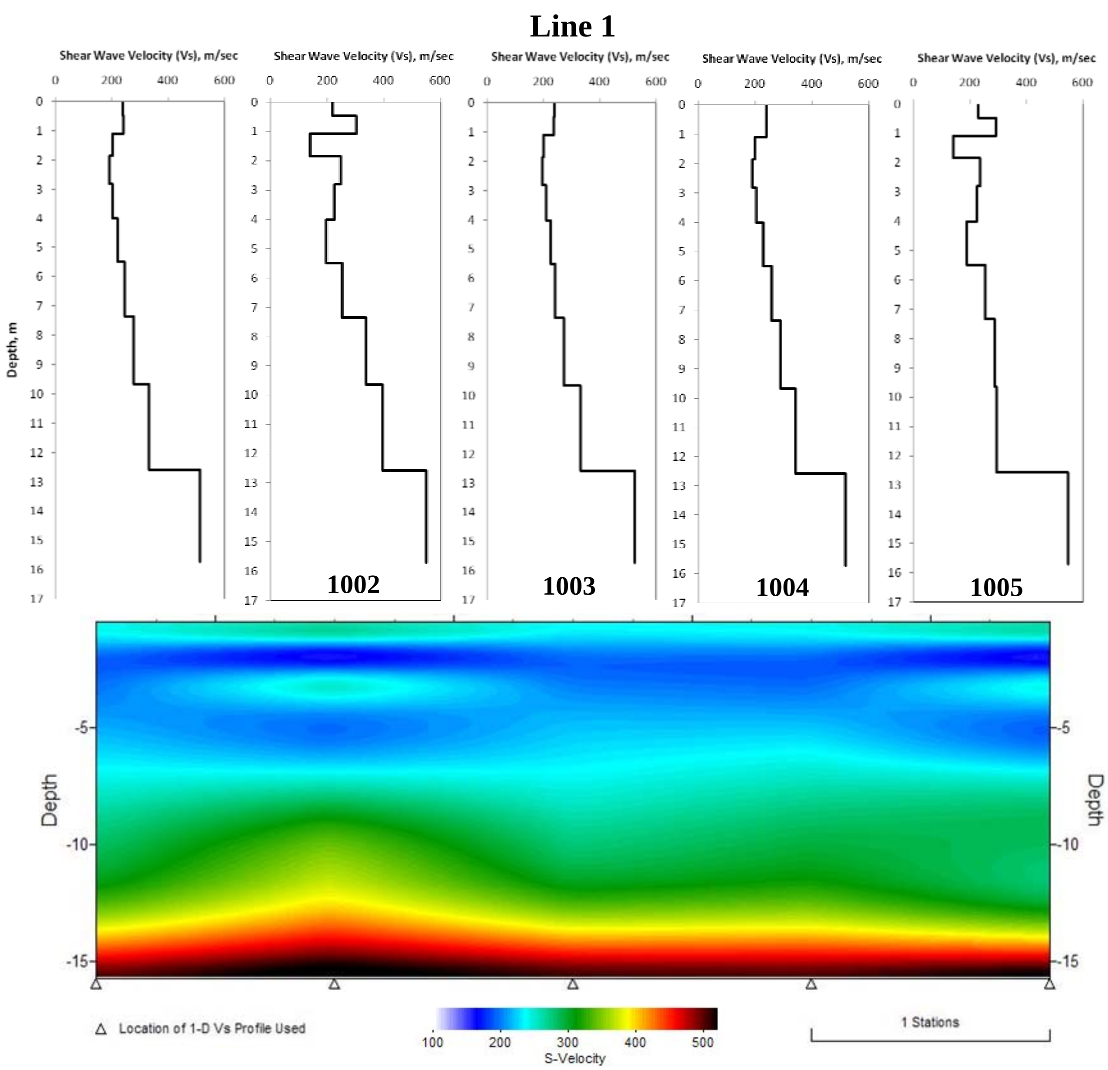


*Fig. 5. Shear Wave Velocities (Vs) Profile as the Results of MASW Method*

Table 2. Value ranges of shear wave velocity (Vs) obtained from MASW and N-SPT correlations

| | Value Ranges of *Vs* (m/sec) | | |
|---|---|---|---|
| | Line 1 | Line 2 | Line 3 |
| 1. $Vs_{\text{-MASW}}$ | 198.63 – 680.19 | 153.97 – 943.07 | 196.34 – 804.91 |
| 2. $Vs_{\text{-correlation}}$ : | | | |
| • Imai & Tonouchi (1982) | 136.82- 330.98 | | |
| • Lee (1990) | 150.14 - 369.40 | | |
| • Seed & Idriss (1981) | 106.35 - 434.16 | | |
| • Athanasopoulos (1995) | 159.80 - 439.99 | | |
| • Nayan (1995) | 176.51 – 312.34 | | |
| • Hasancebi & Ulusay (2006) | 123.38 – 301.46 | | |
| • Dikmen (2009) | 89.11 – 245.35 | | |

Table 3. Empirical correlations of shear wave velocities (Vs) and SPT number (N) from some researchers

| **Researchers** | ***Vs* Correlation (m/sec)** | **Correlation Coefficient** | **Soil Type** | **Location** |
|---|---|---|---|---|
| Seed & Idriss (1981) | $Vs = 61.4\ N^{0.5}$ | | All soil | USA |
| Imai & Tonouchi (1982) | $Vs = 97\ N^{0.314}$ | r = 0.868 | All soil | Japan |
| Lee (1990) | $Vs = 105.64\ N^{0.32}$ | | Silt | |
| Athanasopoulos (1995) | $Vs = 107.6\ N^{0.36}$ | r = 0.73 | All soil | Greece |
| Nayan (1995) | $Vs = 2.89N + 167.84$ | r = 0.88 | All | Malaysia |
| Hasancebi & Ulusay (2006) | $Vs = 90N^{0.309}$ | r = 0.73 | All soil | Turkey |
| Dikmen (2009) | $Vs = 60N^{0.36}$ | r = 0.71 | Silt | Turkey |

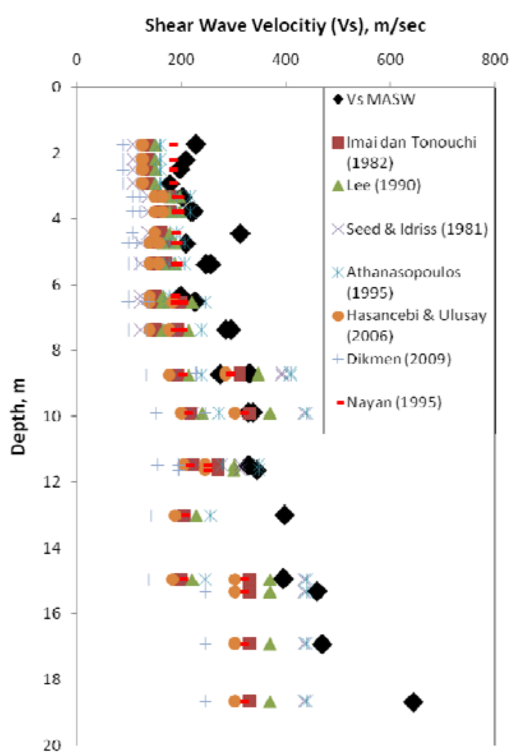


*Fig. 6. Shear wave velocities (Vs) from MASW method and empirical correlation of SPT number (N)*

Validation with bore log of BH3 and BH4 as the result of drilling test were also made to observe the reliability of MASW results. Figure 7 implies that the values of shear wave velocities (*Vs*) are consistent with the bore log data. The changes in soil layer (soil type and strength) were also followed by shear wave velocities (*Vs*) changes. The depth of soil layer changes was found not too precise. But this difference is small and the changes of soil layer still can be observed consistently. Otherwise, the difference may occur due to the variation and changes of (*Vs*) laterally and vertically where the position of the survey lines was not exactly placed adjacent to the bore hole.

According to the investigation results of study area which is discussed here, MASW method implied and proved to be an alternative method to identify subsurface condition. The method is simple and faster either in field application, acquisition or processing data, else it also cost effective. All of these make the MASW method have some advantages than other seismic methods (Thitimakorn, 2006; Stokoe et al, ). The disadvantages of MASW method in processing data that only consider the fundamental mode in inversion analysis and aliasing problem in wave-number domain (Stokoe et al, 2004), was shown as minor affects since overall results have a good agreement with SPT and drilling test results.

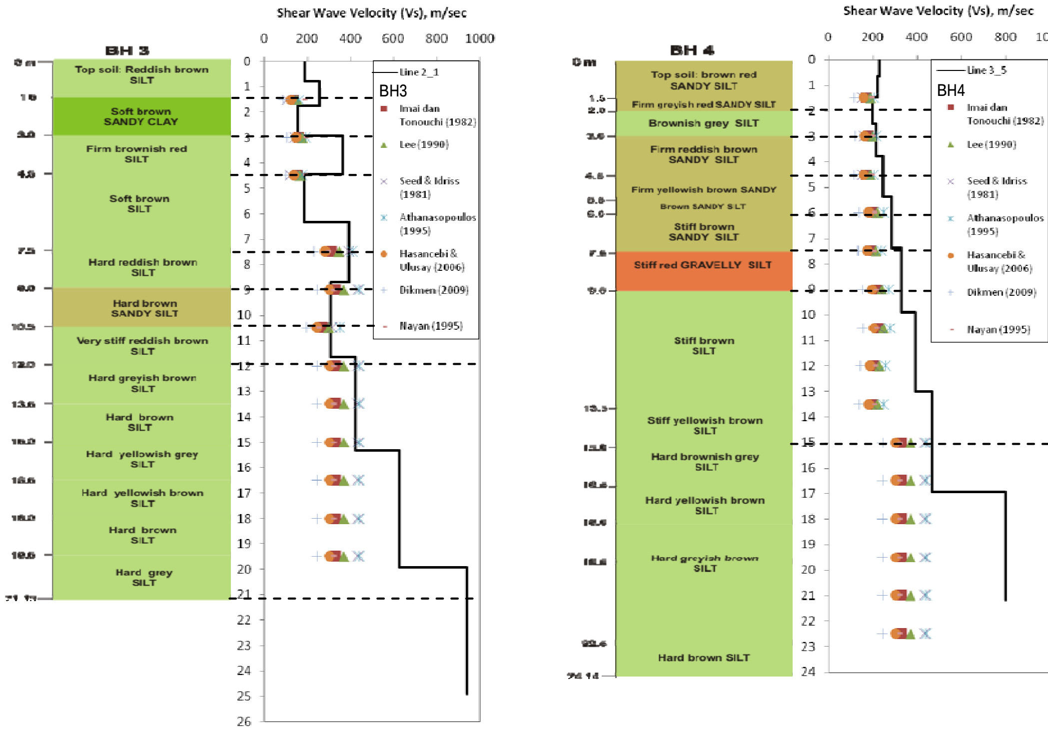


*Fig. 7. Borelog data compared with Vs profile of MASW method*

Soil Bearing Capacity

As mentioned early in the beginning, Tezcan (2006) has developed and proposed the correlation between allowable soil bearing capacity ($q_a$) and shear wave velocities ($Vs$). The correlation is built based on a variety of case histories of site investigations, including extensive bore-hole data, laboratory testing and geophysical prospecting in Turkey. In this study a straight correlation between ultimate soils bearing capacity ($Q_{ult}$) and shear wave velocities ($Vs$) was proposed based on all data result from SPT and MASW method.

In calculating the ultimate bearing capacity from SPT results, many formulas can be applied. And in this study, the ultimate bearing capacity, $Q_{ult}$, is calculated from the sum of skin friction, $Q_s$, and end bearing, $Q_p$,:

$$Q_{ult} = Q_s + Q_p \qquad (1)$$

where, the skin friction term is a summation of layer resistances:

$$Q_s = \alpha \, .Cu.As \qquad (2)$$

and the end bearing term is:

$$Qp = Cu \, .Nc \, .Ap \qquad (3)$$

$Nc$ = 9.0 for clays and silty clays.

The ultimate soil bearing capacity of study area was then obtained as can be seen in Figure 8. Subsequently, the correlation between the ultimate bearing capacities ($Q_{ult}$) and shear wave velocities ($Vs$) are evaluated using all the data. The result is shown in Figure 9.

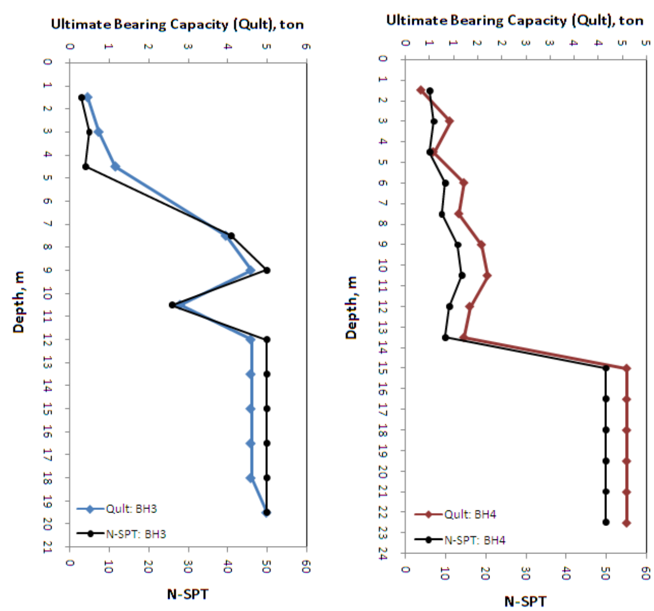


*Fig. 8. Ultimate soil bearing capacity profile of study area*

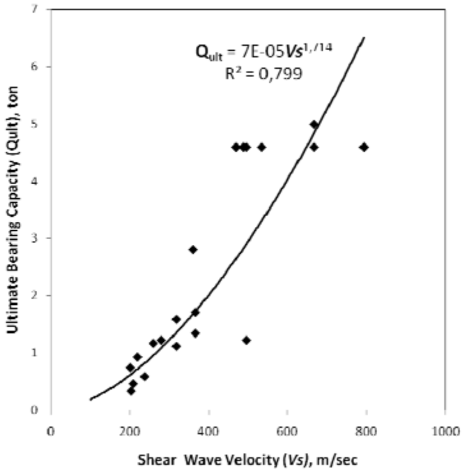


*Fig. 9. The correlation between ultimate bearing capacity and shear wave velocity*

This correlation still has many shortcomings and needs to be further developed in the future with data of greater accuracy. Nevertheless, it may become an alternative option in preliminary assessment of ultimate soil bearing capacity in geotechnical investigation.

## CONCLUSIONS

The conclusions from the results in this study that have been evaluated and discussed are:

- The results of Multi-channel Analysis of Surface Wave (MASW) method in this study show a reliable and good agreement value with either Standard Penetration Test (SPT) or drilling test results.
- Proposed correlation between ultimate soil bearing capacity ($Q_{ult}$) and shear wave velocities ($Vs$) may appear become a promising and reliable method that can reduce the cost and time due to extensive in situ and laboratory testing as required in conventional approach.


## ACKNOWLEDGEMENTS

This research is sponsored by the Science Fund No. 01-01-02-SF0338 from the Ministry of Science, Technology and Innovation, Malaysia.


## REFERENCES


Athanasopoulos, G.A. [1995], "Empirical correlations Vs-NSPT for soils of Greece: a comparative study of reliability", *Proc.7th Int. Conf. on Soil Dynamics and Earthquake Engineering*, pp. 19–36.

Coyle H.M. and R.R. Castello [1981], "New design correlations for piles on sand", *Journal of the Geotechnical Engineering Division*, Vol. 106, pp. 965-986.

Das, B.M. [1990], "*Principles of Foundation Engineering*", PWS-Kent Publishing Company, Boston.

Dikmen, U. [2008], "Statistical correlations of shear wave velocity and penetration resistance soils", *J. Geophys. Eng*., No. 6, pp. 61–72.

Hasancebi, N. and R. Ulusay [2006]. "Empirical correlations between shear wave velocity and penetration resistance for ground shaking assessments", *Bull. Eng. Geol. Environ*., No. 66, pp. 203–13.

Imai, T. and K. Tonouchi [1982], "Correlation of N-value with S-wavevelocity and shear modulus", *Proc. 2nd European Symp. of Penetration Testing* (Amsterdam), pp. 57–72.

Iskandar, M. [1998], "Geologi kawasan Kampus Universiti Kebangsaan Malaysia dan geofizik kejuruteraan kawasan tanah runtuh Kamsis Ibu Zain", Bachelor Degree Thesis, Universiti Kebangsaan Malaysia.

Lee, S.H. [1990], "Regression models of shear wave velocities", *J.Chin. Inst.Eng*. pp.13519–13532.

Meyerhof, G.G. [1976], "Bearing Capacity and Settlement of Pile Foundations", *Journal of the Geotechnical Engineering Division*, Vol. 102, No. GT3, pp. 197-228.

Nazarian, S. [1984], "In situ determination of elastic moduli of soil deposits and pavement systems by spectral-analysis-of-surface-waves method", Ph.D. Dissertation, the University of Texas at Austin.

Nayan, K.A.M. [1995], "Pencirian Tanah Baki Granit Menggunakan Kaedah Pengukuran Halaju P dan S", Master Thesis, Universiti Kebangsaan Malaysia.

Park, C.B., R.D. Miller and J. Xia [1998], "Imaging dispersion curves of surface waves on multi-channel record": [Expanded Abstract]: *Soc. Explor. Geophys*., pp. 1377-1380.

Park, C.B., R.D. Miller and J. Xia [1999], "Multi-channel analysis of surface waves (MASW)", *Geophysics*, Vol.64, 3, pp. 800-808.

Park, C.B., R.D. Miller and J. Xia [2001], "Offset and resolution of dispersion curve in multichannel analysis of surface waves (MSW)", *Proceedings of the SAGEEP 2001*, Denver, Colorado, SSM-4.

Park, C.B., R.D. Miller and H. Miura [2002], "Optimum field parameters of an MASW survey". [Exp. Abs.]: *SEG-J*, Tokyo, May 22-23, 2002.

Penumadu, D. and C.B. Park. [2005], "Multichannel analysis of surface wave (MASW) method for geotechnical site characterization", *Proc. of the Geo-Frontiers Conference,* Austin, Texas.

Seed, H.B. and I.M. Idriss [1981], "Evaluation of liquefaction potential sand deposits based on observation of performance in previous earthquakes", *ASCE National Convention* (MO), pp. 81–544.

Stokoe, K.H. II, Joh, S.H. and Woods, R.D. [2004], "Some contributions on in situ geophysical measurements to solving geotechnical engineering problems", *Proc. of 2nd International Conference on Site Characterization*, Porto, Portugal.

Tezcan, S.S, A. Keceli and Z. Ozdemir [2006], "Allowable bearing capacity of shallow foundations based on shear wave velocity", *Journal of Geotechnical and Geological Engineering,* Vol. 24, pp. 203-218.

Xia, J., R.D. Miller, C.B. Park and J. Ivanov. [2000], "Construction of 2-D vertical shear-wave velocity field by the multichannel analysis of surface wave technique", *Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP 2000),* Arlington, pp. 1197-1206.

Xia, J., R.D. Miller and C.B. Park [1999], "Estimation of near-surface shear-wave velocity by inversion of rayleigh waves", *Geophysics*, Vol. 64, 3, pp. 691-700.