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**Research Paper**

# SHEAR WAVE VELOCITY PROFILING ANALYSIS FOR SITE CLASSIFICATION USING MULTI-CHANNEL ANALYSIS OF SURFACE WAVE (MASW)

Ismail. R[1], Ibrahim. A[1], Adnan. A[2]
[1]*School of Civil Engineering, College of Engineering,*
*Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.*
[2]*School of Civil Engineering, Faculty of Engineering,*
*Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.*
*Corresponding Author: rozaina4076@uitm.edu.my*

***ABSTRACT:*** *In seismic engineering, the dynamic property of the soil is one of the most important aspects in ground response analysis. Dynamic property is significantly affected by local soil deposits. Shear wave velocity ($V_s$) of soil is one of the main parameters in determining the amplification factor on the ground surface. This study aims to determine the shear wave velocity profile of the bridge at Kangkar Merlimau by using multi-channel analysis of surface wave (MASW) method. All the acquired raw data from the MASW field test was analysis and it can be summarized to three major steps: i. filter the wiggle plot to the analyzable range of frequency of Rayleigh wave; ii. develop the dispersion curves of Rayleigh wave phase velocity and iii. inversion of dispersion curve to obtain the Vs profiles. The filter and the development of dispersion curve processes were carried out by using Pickwin software (SeisImager/SW). Results show that the soils for the bridge at Kangkar Merlimau is having the quite low $V_{s30}$ ranging from 127.0 m/s to 128.4 m/s. The soils are classified as Class E which can be considered soft soil according to Uniform Building Code (UBC). Based on the N-SPT value by using an empirical formula, the value of $V_{s30}$ is ranging from 101.22 m/s to 151.87 m/s by using different empirical formulas. It can be concluded that the value of $V_{s30}$ for bridge by using MASW is accepted since the value is nearest to the value of numerical equation from N-SPT value based on borehole data at Kangkar Merlimau site.*

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## I.INTRODUCTION

Impact of earthquakes has been one of the major concerns of scientists and engineers for a long time. Many studies have been made to mitigate the seismic responses of structures due to seismic loads [1-27]. In seismic engineering, the most important aspect is to determine the dynamic properties of the subsurface geo-material structure. The dynamic soil properties give significant influences on the seismic response and performance of the structure above such as fundamental period and seismic demand and capacity. However, lacking understanding of the geological information of the site often resorted to structure and environmental failures. Impact of earthquakes has been one of the major concerns of scientists and engineers for a long time.

Shear wave velocity (Vs) has become the one of the most important properties in seismic site characterization from which in-situ dynamic shear modulus of soil is determined due to its direct relationship with shear modulus via the soil mass density as well as its relative ease of measurement ([28,29]. The dynamic shear modulus ($G_{max}$) can be determined by the following expression:

$$G_{max} = \rho \cdot V_s^2$$

According to Luna and Jadi [30], the measured Vs is generally considered as the most reliable parameter in obtaining the $G_{max}$ for a soil deposit. The shear modulus is used to perform more advanced soil modeling and dynamic response of the soil-structure interactions. Shear modulus at low strain levels, $\gamma$ (< 10-4 %) as measured by geophysical techniques will provide the elastic parameter for foundation analysis or earthquake engineering study. Besides, shallow Vs has long been recognized as a most important parameter in variable ground motion amplification and seismic site response for sedimentary formation [31]. Kuo et al. [32] claimed that determination of shear-wave velocity is the key factor in theoretical simulation, strong ground motion prediction as well as amplification behavior of the site. Site characterization in calculating seismic hazards is usually based on the near surface Vs. Since the amplitude of the shear-wave is responsible in most damage in earthquake events, a lot of the research is emphasized in estimating subsurface shear-wave velocity rather than other geotechnical parameters.

The site amplification ratio and fundamental period as the function of Vs may give a significant impact on the structures above the soil. The softer soil beneath the structures generally may induce higher amplification to the seismic waves and resulted in severe damage to the structures during earthquakes. During the structure's fundamental period, T1 must be kept away from the site period to avoid the resonance effect. In engineering practices, generally the structures are designed as fixed foundations with the assumption of fixity of the basement. However, the deformability of the soils beneath the structures may significantly magnify the intensity of the seismic demand of the structures.

Most of the applications, average $V_s$ from the surface to the depth of 30 m, $V_{s30}$ is used for site classification. $V_{s30}$ is commonly adopted by competent building codes to classify the sites for earthquake resistant design of structures and as a predictor of earthquake ground motion amplification and potential hazard for soil [33]. The $V_{s30}$ for soil can be determined by the following expression:

$$V_{s30} = \frac{30}{\sum_{i=1}^{n} \left( \frac{Z_i}{V_{si}} \right)}$$

where Zi is the thickness of the i-th layer and $V_{si}$ is the Vs of the i-th layer. Site classification plays an important role in the seismic design for the building structures. Different in site classifications will give different elastic response spectrums. The higher elastic response spectrum for softer soil (Class D) induces higher seismic demand to stiffer soil (Class B) and hence larger seismic load in structure design. The site classification or soil categorization using $V_{s30}$ is well documented in Uniform Building Code, UBC (1997) as shown in Table 1.

**Table 1 UBC site classification.**

| Site Classification | Soil description | $V_{s30}$ (m/s) |
|---|---|---|
| A | Hard rock | >1500 |
| B | Rock | 760-1500 |
| C | Very dense sand or soft rock | 360-760 |
| D | Stiff soil | 180-360 |
| E | Soft soil | <180 |

## II.RESEARCH BACKGROUND

Surface wave methods have been used in many decades by researchers and engineers in road pavement, soil's structure, and foundation assessment; liquefaction, buried obstacles detection and geotechnical site characterization [34, 29, 35, 32, 36, 37]. This method is also used to determine dynamic properties of soils, particularly the soil's shear wave velocities, as well as the shear modulus in the seismic site classification [40, 41, 42]. These properties are key parameters in predicting the soil response and soil-structure systems to seismic loading [30]. Multichannel analysis of surface wave method (MASW) is one of the primary choices of method to determine specific soil properties. In addition, the surface wave method is also capable of providing higher vertical and lateral resolution in shallow near surface profile without suffering limitation as in refraction method, i.e., unable to detect hidden layer of soil and velocity inversions [41].

MASW method is a non-invasive method recently developed to estimate Vs profile from surface wave energy. The multi-station recording of MASW method permits a single survey of a broad depth range and high levels of redundancy with a single field configuration [42]. A multichannel shot gathered decomposed into a swept frequency record allows the fast generation of an accurate dispersion curve. This dispersion curve is used to determine the shear-wave velocity profile of the medium. As the frequency increases, penetration of surface waves decreases. Thus, high frequencies propagate through shallow layers and vice versa. According to Park et al. [43], the accuracy of dispersion curves determined using this method is proven through field comparisons of the inverted shear-wave velocity profile with a down-hole Vs profile. MASW method has been effectively utilised to measure near surface Vs [31].

## III.METHODOLOGY

The study area consists of RC bridge which is located at Kangkar Merlimau (1°58'21.87"N, 103°2'57.95"E), Johor. MASW test was carried out at the end of the bridge for result consistency checking. Noise from surroundings such as moving vehicles and raining is avoided during creating the impact source for better signal of seismic waves. The geophones are deployed vertical, firmly, and as near as possible to the residual soil.

**Field Test Setup**

The field configuration of MASW is illustrated in Figure 1. MASW test for site was carried out by employed GEOMETRICS Geode Ultra-Light Exploration Seismograph, a 24-channels seismograph with single geode operating software (SGOS) connected to the controller (a heavy-duty laptop). Total of 24 units of 4.5 Hz natural frequency of vertical geophones was used to detect the surface waves. Geophones were deployed linearly with the interval of 0.5 to 2.5 m [38]. An active source was created by using an 8 kg sledgehammer vertical hit on a striker plate. The nearest source to geophone offsets is in the range of 5 to 20 m to meet the requirement of different types of soil hardness suggested by Xu et al. [44] as shown in Table 2. The data acquisition parameters for the MASW test are summarized in Table 3. The test was repeated by applying the active source at the front, back (nearest offsets) of the spread to obtain the consistency of the wave signal. Two sets of data were collected for each nearest offset as the backup data for the test.

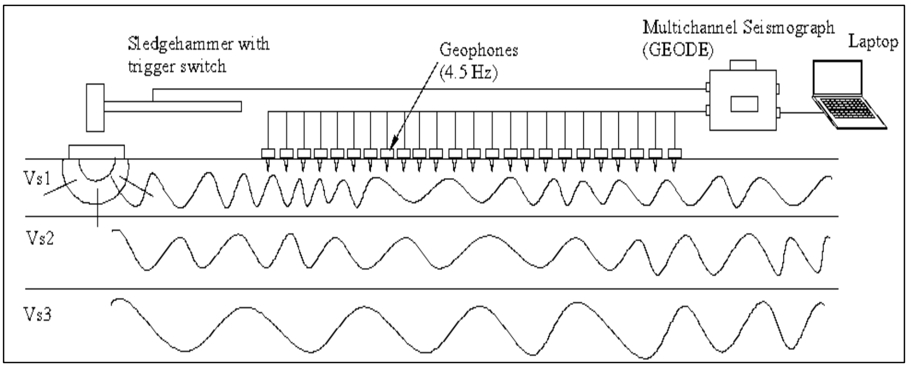


**Figure 1 MASW test field configuration**

[1].

**Table 2 Suggested offsets corresponding to shallow shear wave velocity**

| Material Type | Shear Wave Velocity, $V_s$ (m/s) | Offset (m) |
|---|---|---|
| **Very soft** | $V_s < 100$ | 1 - 5 |
| **Soft** | $100 < V_s < 300$ | 5 - 10 |
| **Hard** | $300 < V_s < 500$ | 10 - 20 |
| **Very hard** | $V_s > 500$ | 20 - 40 |

**Table 3 Data acquisition parameters**

| Parameter | Description |
|---|---|
| Geophone interval | 0.5 – 2.5 m |
| Neisst offset | 5, 10, 15 and 20 m |
| Sampling rate | 0.125 ms |
| Record length | 1 s |
| Receiver/ geophone | 4.5 Hz vertical |
| Source | 8 kg sledgehammer |
| Number of stackings | 5 |

**Data acquisition and procedures**

All the acquired raw data from the MASW field test was analysis and it can be summarized to three major steps: i. filter the wiggle plot to the analyzable range of frequency of Rayleigh wave; ii. develop the dispersion curves of Rayleigh wave phase velocity and; ii inversion of dispersion curve to obtain the $V_s$ profiles. The filter and the development of dispersion curve processes were carried out by using Pickwin software (SeisImager/SW). The raw wiggle plot obtained from the field test was filtered into the frequency range between

4 to 85 Hz to reduce the random noise effect and the interference of other seismic waves to ensure that surface waves are used in the generating of dispersion curve. The amplitude of body wave and higher mode of Rayleigh wave may dominate over the fundamental mode at higher frequencies range if the noise recorded during field test is not well filtered. Only the fundamental mode of Rayleigh wave which between the analyzable frequencies range from 3 to 85 Hz was considered [37] to generate dispersion curve with signal to noise ratio (S/N). WaveEq software was employed to develop the one-dimensional $V_s$ profile through inversion analysis of the dispersion curve.

## IV.RESULTS AND DISCUSSION

The dispersion curves and shear wave velocity profiles for Kangkar Merlimau generated by the MASW test are shown in Figure 2. Generally, dispersion curves generated by MASW for both sites give clear and consistent signals in the fundamental mode of surface waves. Besides, both sites possess very low shear wave velocity profiles ranging from 74 – 195 m/s various from the soil surface to the 30 m depth. The low shear wave velocity may be associated with the thick layer of soft silty clay in the study area. From the borehole site, very low $N_{spt}$ values (ranging from 1 – 3) is obtained at the soil surface to the depth of 25 m which show agreement to the shear wave velocity profile from MASW test. According to the UBC soil classification (Table 1), Kangkar Merlimau site possess average shear wave velocity at 30 m depth, $V_{s30}$ lower than 180 m/s, and hence they are classified as Class E. The $V_{s30}$ for both sites are summarized in Table 4. Basically, low $V_{s30}$ (Class E) or soft unconsolidated sedimentary formation have higher amplification on the ground motion than stiffer soils (Class B or higher) [39, 45]. This especially when an earthquake wave travels from a high (consolidated soil) to low velocity medium (unconsolidated soil), a velocity-decrease is observed. A part of the energy is transformed at the media boundary and leads to an amplification of the wave amplitudes due to energy conservation. The earthquake wave amplification is proportional to $\frac{1}{\sqrt{V_S.\rho}}$ .

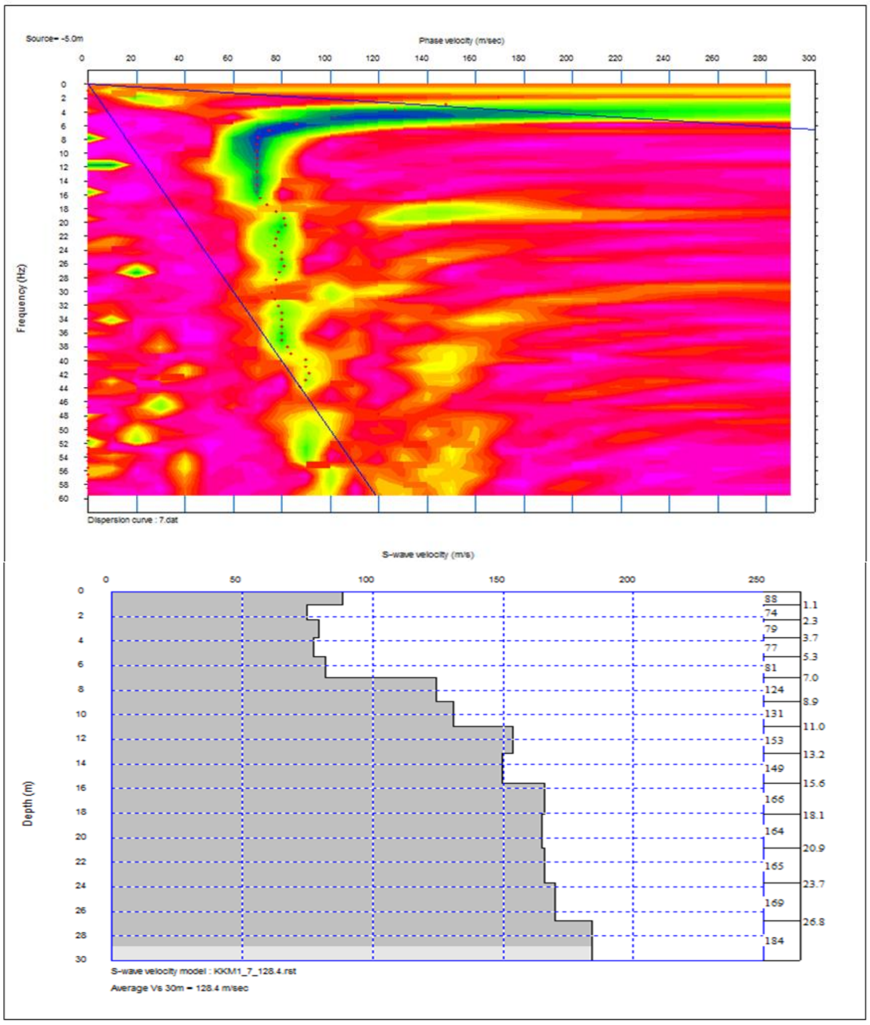


**Figure 2 Dispersion curve and Vs profile for at Kangkar Merlimau**

## V.CONCLUSION

MASW test was carried out for the RC bridges at Kangkar Merlimau. Sites are showing very low $V_{s30}$ ranging from 127.0 m/s to 128.4 m/s. The soil is classified as Class E which can be considered soft soil according to Uniform Building Code (UBC).

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