Prediction of Soil Settlement using Numerical Modelling Based on Shear Wave Velocity Measurement

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Abstract. The method of Spectral Analysis of Surface Wave (SASW) is a seismic method that consider as a non-destructive geotechnical technique to determine the soil profile based on the shear wave velocity profile by utilizing the dispersive characteristic of Rayleigh wave through the soil medium. The shear wave velocity was found to be directly proportional to the strength of the soil. In this research, SASW measurement had been proposed to predict the soil settlements using numerical modelling. The frequency responses from SASW were acquired for shear wave profile analysis using WinSASW software. Thus, the borehole information which near to the conventional pile method and SASW were taken as the reference of the study. In obtaining the correlated N-value, equation that developed from previous research was used with the reference of N-SPT value. Hence, the correlated N-values were carried forward to obtaining the bearing capacity of foundation. Meanwhile, the numerical modelling has been developed in PLAXIS software in obtaining the soil settlement. The prediction of soil settlements of Site 1, Site 2 and Site 3 that calculated by conventional equation and modelled using PLAXIS were 0.003mm and 0.001mm, 0.002mm and 0.004mm, 0.003mm and 0.004mm respectively. Based on the result obtained, this research has shown the potential used of shear wave velocity in the prediction of soil settlement.

1. Introduction

The prediction of soil settlements based on the seismic techniques such as Spectral Analysis of Surface Waves (SASW), Multi-channel Analysis of Surface Wave (MASW) and resistivity measurement is highlighting the problems and concerns faced nowadays by the engineer, geologists and professional. Generally, the soil settlements are a great concern to consider before the development of the construction projects. In the pre-construction stage, the site investigation needs to be performed to obtain the information relating to the soil physical properties or geotechnical parameters. Therefore, a proper and suitable foundation or soil treatment could be proposed to treat the current soil conditions if necessary. Previously, the conventional ground explorations had been well developed to overcome the issue, involving drilling, boring, sampling, in-situ test and laboratory test. However, these conventional methods are considered as localized and time consuming. The cost also can be very expensive if more of these tests were used to characterize the ground in detail. In recent decades, the potential of the geophysical seismic techniques has been exposed by many researchers in
various studies such as: application of SASW method in rock mass characterization [1], application of SASW in soil compaction assessment [2] and etc. These seismic studies were established to prove and promote the efficiency and reliability of the seismic techniques. The common place of seismic investigation is the Spectral Analysis of Surface Waves (SASW). It established geophysical exploration techniques explore the rapid evaluation of subsoil characteristic. It is also permitting the rapid coverage of large areas, and comparatively less expensive than conventional exploration. Even though SASW consists of those benefits, the usage of SASW is still rare as the definitive interpretation of the seismic results are complicated and difficult. This research aims to explore the prediction of soil settlement on the pile foundation using numerical modelling, PLAXIS software based on SASW data measurement. SASW measurement is chosen as it consists of high research value and it is readily available in the interval of research time.

2. Application of Shear Wave Velocity
Currently, the geophysical seismic method is a proven techniques as the result obtained more stable and reliable when compared with those of the conventional method [3, 4, 5]. It is a common practice to investigate the soil properties of site based on the geophysical seismic method. Nowadays, the use of geophysical seismic techniques has found an increasing application in geotechnical engineering practice. The shear wave velocity ($V_s$) obtained from the SASW test able to represent the soil profile and used to determine the dynamic shear modulus of the soil and an overburden stress correction used for penetration resistance [6, 7].

3. Research methods
In this research, the field measurements were conducted using a seismograph and 2nos vertical geophones with 1Hz natural frequency and 400V/m/s calibration factor. The configuration of field measurements was set up using Common Array Profiling (CAP) [8]. Four different seismic impact sources were used to generate energy over a broad frequency range; geology, rubber, steel and steel sledge hammer. The SASW test has been performed at 3 different site locations which are located in Damansara, Kuala Lumpur and Nilai. The determination of shear wave velocity is based on 3 stages categorized in data interpretation and analysis using WinSASW software, which were interactive masking, the determination of the representative experimental dispersion curve and the inversion process of dispersion curve [9]. With the reference of bore hole reports, equation was adopted for the correlation of $V_s$ and N value to determine correlated N value, by substituting the $V_s$ value from the shear wave profile [10]. The correlated N-value was the parameter to determine of the bearing capacity of pile foundation. The reasonable bearing values would be selected with the reference of conventional test for the further analysis of soil settlement value. Keçeli method was applied to compute the soil bearing capacity [11]. The empirical equations were adopted to calculate the ultimate bearing capacity of the pile foundation [12, 13]. In order to determine the soil settlement, Vesic, Poulos, Bowles and Keçeli were adopted in the research. The end result of the values would be compared with settlement value based on simulation modelling using PLAXIS software for validation.

4. Results and discussion
This research was focused on three compartments, which were data interpretation and analysis in WinSASW, empirical computation of soil settlement value and the numerical modelling performed by PLAXIS software.

4.1. Correlation of shear wave velocity and N-value
As shown in Figure 1, it represented the relationship between N-value and correlated N-value. Based on pattern profile in Site 1, there were a few interception points between both data which was exhibiting a high similarity between both data, especially at depth 1m, 3m, and 6m as shown in Figure 1(a). For the graph of Figure 1(b) and Figure 1(c), both graphs were shown the increasing trendline
which the N-values were increasing with depth. However, the correlated N-values proposed by Jafari were seemed to be slightly overestimated compared to N-values.

![Graph showing N-value vs Depth for Site 1, Site 2, and Site 3](image)

**Figure 1.** The relationship between N-value and correlated N-value

4.2. **Determination of soil settlement based on empirical equation**

In this research, the prediction of soil settlement was determined by an equation that developed by several researchers based on bearing capacity [11, 14, 15, 16]. As tabulated in Table 1, the values of soil settlements computed vary with different equation that has been used researchers. The results shows that the settlement that calculated based on bearing capacity are much greater than the results that obtained from shear wave velocity considerations where Vesic method had the highest, followed by Poulos, Bowles, and Keçeli for all sites.

| Considerations       | Researchers          | Site 1 | Site 2 | Site 3 |
|----------------------|----------------------|--------|--------|--------|
| Bearing capacity     | Vesic (1977)         | 0.088  | 0.098  | 0.046  |
|                      | Poulus (1989)        | 0.050  | 0.078  | 0.030  |
|                      | Bowles (1997)        | 0.070  | 0.048  | 0.058  |
| Shear wave velocity  | Keceli (2012)        | 0.003  | 0.001  | 0.002  |

4.3. **Comparison of Soil Settlement between Bowles and PLAXIS**

The comparison of soil settlement between empirical calculation and numerical modelling using PLAXIS software in Figure 2. The results of Keceli method are the nearest to PLAXIS software, where the percentage different between these two methods less than 25% difference. By comparing soil settlement value calculated based on consideration of bearing capacity and shear wave velocity, the soil settlement value was relatively large. In general, this condition is due to the concept of seismic techniques, which involves the spread of geometry of Rayleigh waves in vertical soil strata, while the
conventional techniques conducted is focussed on one point based on the selected borehole. The soil settlement value was quite reasonable and conservative when compared to the PLAXIS settlement value. Based on the results, empirical equation proposed by Keceli appeared to be the most suitable equation to predict the soil settlement. However, Bowles method is comparatively more conservative to PLAXIS value.

![Figure 2. The comparison of soil settlement value between empirical equation and PLAXIS modelling](image)

The calculated soil settlement using equations proposed by Vesic, Poulus, Bowles and Keceli for these three sites were given in Table 1. Significantly shows that the soil settlement that obtained from the bearing capacity is larger than the shear wave velocity. It is because, in general, this condition is due to the concept of seismic techniques, which involves the spread of geometry of Rayleigh waves in vertical soil strata, while the conventional techniques conducted is focussed on one point based on the selected borehole. It’s proven by the soil settlement value from Keceli was quite reasonable and conservative when compared to the PLAXIS settlement value as shown in Figure 2 where Keceli and PLAXIS modelling considered the shear wave velocity measurements. Correspondingly the percentage error of the ultimate pile bearing capacity for the alluvial soil at Collierville site was found to be less than 25% that follow the standard that geotechnical practitioners applied in the construction field.

5. Conclusion
The shear wave velocity profile had a close relationship with the N-value. Shear wave velocity would be affected by the stiffness and properties of soil with the depth increasing as N-value performed. The correlation of N-value and shear wave velocity could be used for the prediction of soil settlement. The prediction of soil settlement based on SASW measurement by Keceli was more conservative than conventional method. In conclusion, the SASW is valuable for further researching towards the prediction of soil settlements in the geotechnical engineering.

Acknowledgement
The author would like to acknowledge Universiti Malaysia Perlis for the sponsor and financial support under RESMATE grant.
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