TUGAS PENULISAN MAKALAH ILMIAH

MATA KULIAH	:	PRASARANA TRANSPORTASI
KODE	:	CEC 611
UNIT	:	3 SKS
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SISTEMATIK PENULISAN TUGAS MAKALAH ILMIAH

A. PENDAHULUAN

Tugas ini merupakan salah satu bagian dari penilaian tugas mandiri yang diberikan kepada mahasiswa peserta kuliah Prasarana Transportasi (CEC 611) Jurusan Teknik Sipil Universitas Muhammadiyah Yogyakarta. Tugas ini bertujuan untuk membekali mahasiswa dalam ketrampilan menulis ilmiah dan memberikan kepekaan mahasiswa untuk mengamati dan mengikuti isu-isu mutakhir dan permasalahan yang dihadapi dalam perencanaan dan penyediaan transportasi angkutan kereta api dan angkutan udara.

Makalah merupakan media penyampaian ide, gagasan, pemikiran, hasil studi, kajian referensi dan hasil-hasil penelitian. Dengan demikian, makalah mempunyai fungsi yang sangat signifikan bagi kalangan akademisi sebagai media untuk saling bertukar pikiran dan

B. ATURAN DAN PENGUMPULAN TUGAS

Tugas makalah ilmiah ini merupakan tugas individu yang harus dikerjakan selama setengah semester perkuliahan efektif (2 bulan). Tugas ini terdiri dari penulisan outline and makalah, dimana harus dikerjakan oleh mahasiswa pada awal perkuliahan hingga menjelang Ujian Tengah Semester (UTS).

Makalah ini disusun megikuti beberapa tahapan yang pelaksanaannya setiap tahapan dilakukan pada rentang minggu pertemuan kelas efektif yang dijelaskan sebagai berikut :

Pertemuan Kuliah	Tugas Mahasiswa	Keterangan
Minggu ke-1	Mencari topik dan judul untuk tugas makalah	Judul makalah **tidak boleh** ada yang sama. Mahasiswa yang terlebih dahulu mendaftar akan mendapatkan kesempatan dalam penentuan judul makalah.
Minggu ke-2	Mendaftarkan judul kepada dosen dan memulai penulisan outline makalah. (Bagi mahasiswa yang kebetulan memiliki judul yang sama diberikan kesempatan dalam minggu ini untuk mencari topik atau judul baru lainnya).	Outline berisi urutan penulisan makalah secara sistematis. Memulai untuk mencari bahan untuk menulis outline makalah.
Minggu ke-3	Mengumpulkan outline makalah dan memulai mencari bahan untuk penulisan	Outline dikumpulkan kepada dosen pada waktu perkuliahan, dan akan diberikan komentar

		untuk dilakukan perbaikan dalam penulisan makalah.
Minggu ke-4 s.d. Minggu-5	Penulisan makalah	
Minggu ke-6	Mengumpulkan tugas makalah	Pengumpulan dilakukan pada jam perkuliahan.

C. SISTEMATIKA PENULISAN OUTLINE

Makalah ditulis berdasarkan susunan outline makalah berikut ini :

Bagian Pertama : ---

a. **Judul Makalah** : Judul makalah harus ditulis dengan susunan kalimat secara ringkas dan jelas, serta mencerminkan isi makalah yang ditulis dengan baik.
b. **Penulis** : Nama penulis ditulis di bawah judul makalah secara lengkap, dan di bawah nama penulis dituliskan status dan alamat penulis yang merupakan status penulis dalam suatu institusi dan alamat institusi, misal : alamat universitas.
c. **Abstrak** : Abstrak berisi ringkasan makalah yang akan ditulis yang terdiri dari 3 bagian utama yaitu : pendahuluan (latar belakanG dan tujuan makalah), metodologi (cara dan metode yang digunakan untuk mendapatkan data, kajian literatur atau analisis suatu fenomena, yang mendasari isi dan pembahasan yang sampaikan dalam makalah) dan hasil (komentar umum dari suatu hasil atau kesimpulan dari sebuah review). Abstrak ditulis maksimal dalam 250 kata.

Bagian Kedua : **PENDAHULUAN**

a. **Latar Belakang** : Dalam bagian ini dituliskan latar belakang yang mendasari pemasalahan atau fenomena yang diangkat sebagai topik dan judul penulisan. Latar belakang ini bisa berupa pernyataan yang berisi " kenapa " masalah ini diangkat dan " apa " menjadi landasan makalah ini ditulis.
b. **Tujuan** : Bagian ini berisi tujuan dari ditulisnya makalah ini atau studi/penelitian yang dilakukan yang mendasari ditulisnya makalah ini. Tujuan diturunkan dari signifikasi permasalahan yang akan diselesaikan melalui studi yang dilakukan. Pernyataan tujuan sebaiknya ditulis dalam kata kerja yang terukur, minimal pernyataan yang dapat dituangkan dalam konsep yang jelas, dan dituliskan dengan kalimat-kalimat yang padat dan terarah.

Bagian Ketiga : **TINJAUAN LITERATUR** atau **STUDI PUSTAKA** dan **LANDASAN TEORI**

Tinjauan Literatur atau **Studi Pustaka** : (1). Bagian ini berisi rangkuman dari studi atau penelitian atau bentuk-bentuk kajian yang telah dilakukan oleh peneliti atau penulis sebelumnya yang terkait dengan judul/topik makalah, atau (2). Bagian ini dapat juga **Landasan Teori** yang berupa rangkuman teori-teori yang digunakan untuk mendasari studi yang dilakukan yang dituliskan dalam makalah.

Bagian Keempat : **METODOLOGI PENELITIAN**

Dalam bagian ini, metodologi penelitian hanya digunakan untuk makalah yang berisi kajian studi atau presentasi hasil penelitian yang memerlukan penjelasan yang terperinci mengenai langkah-langkah kerja, cara pengambilan data, cara analisis, metode penafsiran dan presentasi hasil yang diharapkan tertuang secara lengkap dalam naskah atau makalah publikasi. Jika makalah disajikan dalam bentuk kerangka ide dan rangkuman kajian literatur saja maka bagian ini dapat diabaikan dengan menggantikan bagian ini menjadi **Konsep Ide** atau **Kerangka Berfikir** dari makalah yang disajikan.

Bagian Kelima : **HASIL PENELITIAN DAN PEMBAHASAN**

Dalam bagian ini, dijelaskan secara rinci hasil-hasil kajian yang diperoleh atau hasil-hasil studi yang didapatkan. Konsep penulisan bagian ini adalah berurutan sesuai dengan tahapan-tahapan yang digunakan dalam pencapaian tujuan penelitian atau studi. Untuk makalah dalam bentuk kajian literatur, maka hasil penelitian dan pembahasan merupakan hasil kajian literatur yang disajikan atau idea yang diusulkan atau pokok penulisan dari suatu makalah yang disampaikan.

Bagian Keenam : **KESIMPULAN** atau **PENUTUP**

Pada bagian ini, penulis menyatakan suatu pernyataan singkap dan lugas, mengenai isi makalah yang ditulisnya. Pernyataan dapat berupa jawaban dari permasalahan yang melatarbelakangi makalah ini yang tertuang dalam bagian tujuan, yang selanjutnya disebut sebagai Kesimpulan. Jika pernyataan yang disampaikan bersifat umum maka bagian ini lebih sesuai disebut sebagai Penutup.

Bagian Ketujuh : **DAFTAR PUSTAKA**

Pada bagian ini, dituliskan buku teks, jurnal, artikel, koran, halaman web site, makalah seminar atau konferensi yang menjadi rujukan dalam penulisan makalah ini. Setiap referensi yang digunakan harus dituliskan secara jelas, nama pengarang, tahun penerbitan, judul buku/makalah, nama penerbit dan tempat penerbitan (kota dan negara). Makalah minimal disusun dari sumber pustaka berupa 2 buah buku teks dan 2 makalah jurnal atau proseding mengenai prasarana transportasi jalan rel.

CONTOH OUTLINES MAKALAH :

IN SITU DETERMINATION OF LAYER THICKNESS AND ELASTIC MODULI OF ASPHALT PAVEMENT SYSTEMS BY SPECTRAL ANALYSIS OF SURFACE WAVES (SASW) METHOD

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Abstract

Spectral analysis of surface waves (SASW) is a non-destructive and *in situ* method for determining the stiffness profile of soil and pavement sites. The method consists of generation, measurement, and processing of dispersive elastic waves in layered systems. The test is performed on the pavement surface at strain level below 0.001%, where the elastic properties are considered independent of strain amplitude. During an SASW test, the surface of the medium under investigation is subject to an impact to generate energy at various frequencies. Two vertical acceleration transducers are set up near the impact source to detect the energy transmitted through the testing media. By recording signals in digitised form using a data acquisition system and processing them, surface wave velocities can be determined by constructing a dispersion curve. Through forward modeling, the shear wave velocities can be obtained, which can be related to the variation of stiffness with depth. This paper presents the results of two case studies for near-surface profiling of two different asphalt pavement sites.

Key words: non-destructive method, pavement, layered media, Rayleigh waves, spectral analysis, shear wave velocity, wave propagation, elastic modulus.

1. INTRODUCTION

- There are more than 60,000 kilometers of expressways and roads in Malaysia, of which more than one half are either flexible or rigid pavements.
- Most of the expressways, federal roads, state roads and council roads are more than 20 years old.
- Owing to aging roads and increasing traffic loads and volumes, the responsibility for maintenance, rehabilitation and management of pavement structures is becoming more and more critical.
- Therefore, the need for accurate, fast, cost effective and non-destructive evaluation of the pavement structure is becoming ever more important.

- The SASW technique successfully reduces the field-testing time and improves the accuracy of the original steady-state method. It also overcomes many of the limitations of the well-known deflection-basin-based method, e.g., the falling weight deflectometer or dynaflect.
- The purpose of this paper is to describe the role of the SASW technique in assisting pavement engineers in evaluation and management of highways. The first part of the paper discusses the fundamentals of the SASW method and properties of pavement that can be detected by the method. The second section illustrates the results of the SASW tests in pavement investigations.

2. LITERATURES STUDY : Propagation of Rayleigh Waves

- The SASW is a non-destructive method for *in situ* evaluation of elastic moduli and layer thickness of layered systems, such as soils and pavements (Stokoe *et al*. 1994).
- The method is based on the phenomenon of Rayleigh wave dispersion in layered systems, i.e. the phenomenon that the velocity of propagation is frequency dependent.
- The energy of Rayleigh waves propagates mechanically from the source along the surface of a media and their amplitude decrease exponentially with depth.
- Particle motions associated with Rayleigh wave are composed of both vertical and horizontal components, which when combined, form a retrogressive ellipse close to the surface ary with frequency. However, in the layered medium where there is a variation of stiffness with depth, Rayleigh wave velocity is frequency dependent. This phenomenon is termed dispersion where Rayleigh wave refers to the variation of phase velocity as a function of wavelength.
- Rayleigh wave propagation technique may be used to determine the parameters of the elastic moduli of pavement and soil layers.
- These parameters represent the material behaviour at small shearing strain, of less than of 0.001 %.

3. RESEARCH METHODOLOGY

3.1 Field Procedure

- Elastic waves are generated (by means of impacts), on the surface of pavement and are detected by a pair or an array of receivers.
- A portable 4-channel dynamic spectrum analyser (OROS OR25 PC-Pack II) was utilized for recording and analysing the data. The common receiver midpoint (CRMP) array geometry was used (see Nazarian 1984 for detail).
- The spacing between receivers was 0.1, 0.2, 0.4, 0.8, 1.6, and 3.2 m. Piezoelectric accelerometers were used to pick up the surface wave signal.
- The accelerometers were glued to the pavement surface to ensure good coupling. The dynamic signal is generated in the pavement using a variety of impact sources depending on the frequency range of interest, which in turn influence the sampling depth.

3.2 Construction of Dispersion Curve

- When displaying the phase spectra, the analyser may not use full-scale display, instead it may display the phase in the range of ±180º and hence cause it to wrap.
- The step to find the actual phase of a frequency is to count the number of full 360º cycles preceding the frequency and to add that to the fraction of the last cycle or the frequency. The process is called unwrapping of the phase (Nazarian 1984).
- Data points that did not satisfy the following two criteria were discarded: (i) a coherence magnitude of 0.95, and (ii) a wavelength greater than ½*D* and less than 3*D* (Heisey *et al*. 1982). This operation is called 'masking'.
- It should be noted that velocities obtained from an experimental dispersion curve are not the actual Rayleigh wave velocities, but rather apparent or phase velocities. The existence of layers with higher or lower velocities at the surface of a medium, such as a pavement structure, affects the measurement of the velocities of the underlying layers.
- Thus, a method for evaluating the actual Rayleigh wave velocities from apparent Rayleigh wave velocities is necessary in the SASW test.

3.3 Inversion of Dispersion Curve

- The process of converting the dispersion curve into the shear wave velocity profile is called inversion or forward modeling.
- Data points of the experimental dispersion curve are usually compressed into a smaller number of data points by averaging a certain range of experimental data points into one data point.
- There are basically two inversion processes, a simple and a refined one.

4. RESULT AND DISCUSSION

CASE STUDY 1: LANDED-ZONE 4-B, PRECINT 11, PUTRAJAYA

- The SASW testing was carried out on a pavement surface at Landed-Zone 4-B, Precint 11, Putrajaya construction project (SASW array PREC11-JP1).
- The pavement profile consists of an asphalt layer (100 mm thick), a base of crushed aggregates (300 mm thick), and a sub base of sand (200 mm thick) over a metasediment sub grade.
- Material properties and thickness of the four layers are shown in Figure 6(a). In this study, the receiver spacing of 10, 20, 40, 80, 160 and 320 cm were used.
- The modulus and depths determined by the SASW measurements from the inversion are in good agreement with each layer of the pavement profile. A zone with higher modulus is interpreted from 0 to 10 cm for the asphalt concrete surface layer that has the highest stiffness properties (100 – 1000 MPa). An abrupt decrease of the modulus then occurs at the transition layer of the base followed by a gradual increase of the modulus for the sub base and sub grade with elastic modulus of around 10 MPa.

CASE STUDY 2: KM 296, NORTH – SOUTH EXPRESSWAY

- the SASW testing was carried out on a pavement surface at Km 296 (North Bound), Seremban – Bangi section of the North – South Expressway (SASW array LRSB-ApJ) during rehabilitation works. The pavement structure consists of an asphalt layer (180 - 200 mm thick), a sub base of crushed aggregates and fine sand (2000 - 2500 mm thick), over a metasediment sub grade.
- The sources for the Rayleigh wave employed were slightly different from those in the case study 1. For high frequency signals, 2-inch nail and small hammers were used, while geological hammer was used for receiver spacing higher than 100 cm.
- The profiles determined by the SASW measurements show good agreement with the pavement profile. A zone with higher modulus is interpreted from 0 to 20 cm for the asphalt concrete surface layer that has the highest stiffness properties (100 – 1500 MPa). This surface layer is slightly stiffer than the PREC11-JP1 site as a more stringent specification was applied to the former. Similarly, an abrupt decrease of the modulus occurs at the transition layer of the sub base followed by a gradual increase of the modulus for the sub grade.

5. CONCLUDING REMARKS

- Samples of the asphalt pavement structure for laboratory analysis were not available during the study. The thickness of layering obtained from the inversion analysis compared well with the existing profile obtained from the construction record.
- The shear wave velocities and dynamic Young's modulus profiles from this study were compared with SASW testing that had been carried out by other workers, such as Nazarian (1984) and Al Hunaidi (1998) (Table 1). In general, there is a reasonable agreement between the results from this study and their results.

Table 1 Comparison of shear wave velocity from this study to that of Nazarian (1984) and Al-Hunaidi (1998).

Profile	Shear wave velocity (m/s)		
	This study	Nazarian (1984)	Al Hunaidi (1998)
Surface course	900 – 2000	2425	1000 – 2500
Sub base course	195 – 270	301.95	100 – 500
Sub grade	200 – 400	271.45	80 – 300

- The SASW method has managed to characterise all the layers of the pavement profile in terms of shear wave velocity and dynamic shear and elastic modulus satisfactory. The method can be applied in the early stages of pavement evaluation for detecting the dynamic properties and thickness of the profile.

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CONTOH MAKALAH STUDI LITERATUR :

CIVIL ENGINEERING APPLICATIONS OF THE SPECTRAL ANALYSIS OF SURFACE WAVE (SASW) METHOD

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ABSTRACT

Civil engineering works covers a wide spectrum of applications that include projects that are small and huge in scale. The applications from a single wave form have never been so successful and widely applied in Civil engineering as the Spectral Analysis of Surface Wave. Its ability to define depths and dynamics of materials properties in both profiling and imaging has been rapidly utilized to address engineering structures of a few millimetres of depths to bedrock as deep as 50 meters has been widely reported. The direct involvement of civil engineers themselves in this method of geophysical test has been more intensive than the other geophysical method. Their applications include various layers of pavement evaluations, concrete testings, landfills and various applications in geotechnical evaluations and design. SASW is more practical in the field as the source is reasonably simple as compared to the other geophysical methods. In this paper the various methods of the SASW applications in civil engineering are highlighted so that geophysicist are able to appreciates the needs and accuracies that are required by civil engineers.

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1. INTRODUCTION

The SASW method is based on the analysis of the dispersive characteristic of surface waves in a non-homogeneous medium. The method is a non-destructive test in which both the source and the receivers are located on the ground surface. No requirement for expensive boreholes, repeatability of the test, and a simple set-up and test procedure are among the advantages of this technique.

The surface waves have been utilized by researchers in a number of applications. In geotechnical engineering, for instance, the use of surface waves is not new. Geotechnical engineers like Terzaghi (1943) and Hvorslev (1949) were among the pioneers of the surface wave geophysics. Jones (1958), on the other hand, used surface wave to assess materials under road pavements but his work was unsuccessful because of the insensitive recorders and signal receivers being used at that time. With the advent of spectral analysis and the computer technology, the traditional Rayleigh wave method based on the steady state method has been revolutionised to the SASW method. This method was developed by changing the source to the impact hammer position until the appropriate frequency for the field measurement was obtained (Heisey 1982, William 1981). Latter it was improved to the spectral analysis of surface wave (SASW) method with the generation of the dispersion curve with the factors affecting the calculation of the elastic moduli, thicknesses of pavement and soil profile were studied (Nazarian & Stokoe 1984).

2 THEORETICAL DEVELOPMENT

The stress strain behaviour of cyclically loaded soils is complex and geotechnical engineers are challenged by the need to characterize this behaviour with accurate and simple models. The balance between accuracy and simplicity depends on many factors and several combinations have been proposed. For geophysical methods that induce low-strain (<10^{-3} %) the soil models are based on equivalent linear model. These models are the simplest and most commonly used in dynamics, but they have a limited ability to represent many aspects of soil behaviour under cyclic loading conditions. Most seismic geophysical methods or tests induce shear strains lower that 10^{-4} % and the shear wave velocity (V_s) can be used to compute the G_{max} using the expression $G_{max} = \rho \times V_s^2$, where ρ is the mass density of the soil. The measured shear wave velocity is generally considered the most reliable means to obtain the G_{max} for a soil deposit. Therefore, the maximum shear modulus is developed at low shear strain where geophysical tests are used. If the strain increases the secant shear modulus will decrease where this shear modulus degradation with cyclic strain is by means of the modulus reduction curve. The modulus reduction curve normalizes the shear modulus (G) with respect of the maximum shear modulus (G_{max}) and is commonly referred to as the modulus ratio. Figure 1 shows a schematic of the typical cyclic behaviour of soils.

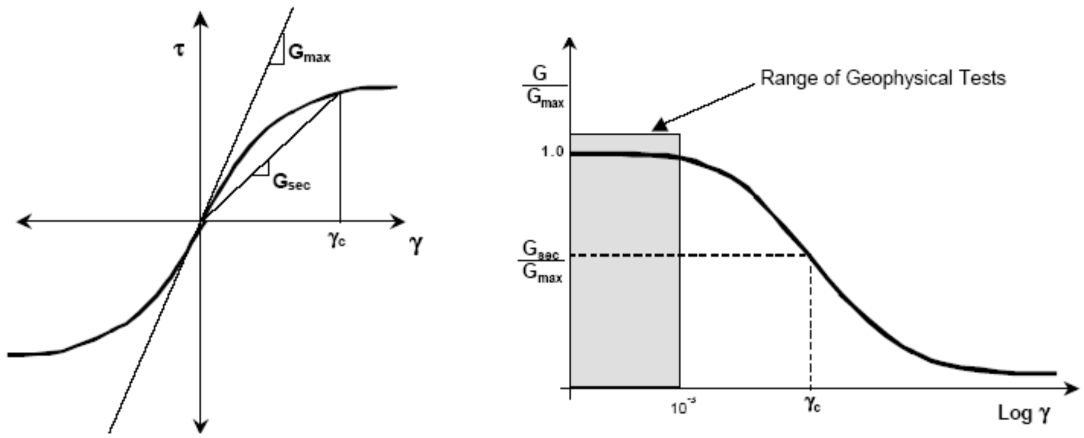

Figure1 Stress-strain curve with variation of shear modulus and modulus reduction curve

Shear wave velocity (Vs) is the most commonly used measured parameter used in shallow soil geophysics for soil characterization. It is used to calculate the following parameters in the elastic range of soil behaviour. The importance in its utility is that the particle of motion travels perpendicular to the direction of wave propagation being able to measure the shear properties of the soil skeleton and not the fluids that cannot take shear.

Shear Modulus (G) is a calculated parameter based on the Vs using the simple elastic relationship $G_{max} = \rho \times Vs^2$. The mass density is often estimated or measured by a nearby subsurface sampling or using correlations. Advanced correlations to estimate the value of the dynamic shear modulus are available based on the standard penetration test, *Atterberg* Limits (plasticity index) and grain size distributions (Vucetic & Dobry 1991, Idriss et al. 1980). The shear modulus is used to perform more advanced soil modelling, and dynamic response of the soil-structure interactions. Shear modulus at low strain levels as measured by geophysical techniques will provide the elastic parameter for machine foundation analysis or earthquake engineering. The important utility of this parameter is that it can be used as a varying parameter with respect to strain making the soil response represents the real modulus degradation in soil behaviour. This parameter is used in defining the stiffness matrices for finite element analysis of earth structures and foundation soils.

Maximum Shear Modulus (G_{max}) is used to normalize the shear modulus (G) vs. shear strain relationships. These normalized relationships allow the engineer to use well-established degradation curves and scale them to the measured in-situ value of G_{max}. For example, the classic relationships of the shear moduli for cohesionless and cohesive soils are provided in Seed et al. (1984) and Sun et al. (1988). In the absence of extensive dynamic soil testing at all ranges of shear strain these curves are used and G_{max} is used as the scaling parameter.

Damping Ratio (D) is used in several dynamic analysis procedures to provide a realistic motion attenuation. This ratio is based on the material damping properties. The damping ratio and shear strain relationships for cohesionless and cohesive soils are provided in Seed et al. (1984) and Sun et al. (1988). Since damping ratio is also shear strain dependent, it is required to have several values with strain. Dynamic analysis results are also influenced by the damping ratio for single and multi degree modal systems. The effects of soil-structure interaction also influence the damping of the system making it an area where recent research has focused. The utility of this parameter is based on the ability of the system to absorb dynamic energy and how this will affect the duration and modes of vibration.

The SASW method is based on the particles motion of Rayleigh wave in heterogeneous media. The energy of Rayleigh waves from the source propagate mechanically along the surface of media and their amplitude decrease rapidly with depth. Particle motions associated with Rayleigh wave are composed of both vertical and horizontal components, which when combined, formed a retrogressive ellipse close to the surface. In homogenous, isotropic, elastic half-space, Rayleigh wave velocity does not vary with frequency. However, Rayleigh wave velocity varies with frequency in the layered medium where there is a variation of stiffness with depth. This phenomenon is termed dispersion where the frequency is dependent with the Rayleigh wave velocity. The ability for detecting and evaluating of the depth of the medium is influenced by the wavelength and the frequency generated. The shorter wavelength of higher frequency penetrates the shallow zone of the near surface and the longer wavelength of lower frequency penetrates deeper into the medium.

To derive a theoretical dispersion of Rayleigh motions, the mathematical formulation of wave propagation in layered system was generated. There are several modeling approaches available for SASW applications. Among them are: (1) the transfer matrix method (Thomson 1950 & Haskell 1953); the dynamic stiffness matrix method (Kausel & Röesset 1981) and the finite difference method (Hossain & Drnevich 1989). The transfer and stiffness matrix methods provide exact formulation as compared to the other methods (Ganji et al 1998). Although the approach of the inversion methods can be different, however, all the methods assume that the profile consists of a set of homogeneous layers extending to infinity in the horizontal direction. The last layer is usually considered as a homogeneous half-space.

3 METHODOLOGY

3.1 Steady-State Surface Wave Method

The steady state surface wave technique does not require boreholes and is another in-situ method used to measure the shear modulus (G) of all types of soils. In this test, an electromagnetic oscillator at high frequency (30 to 1000 cycles/second, cps) or a rotating mass type oscillator to produce low frequency vibrations (less than 30 cps) are used. These surface vibrators generate Rayleigh R-waves, which at low strains have nearly the same velocity as the shear waves. The ground surface can be deformed as shown in Figure 2. The shear wave velocity is computed from the Rayleigh wave-length measured with receivers placed along the ground surface, and the frequency of vibration at the source using the following equation (Gazetas, 1991):

$$V_S \sim V_R = f \lambda_R \quad (1)$$

where, f = frequency of vibration and λ_R = Rayleigh wave length.

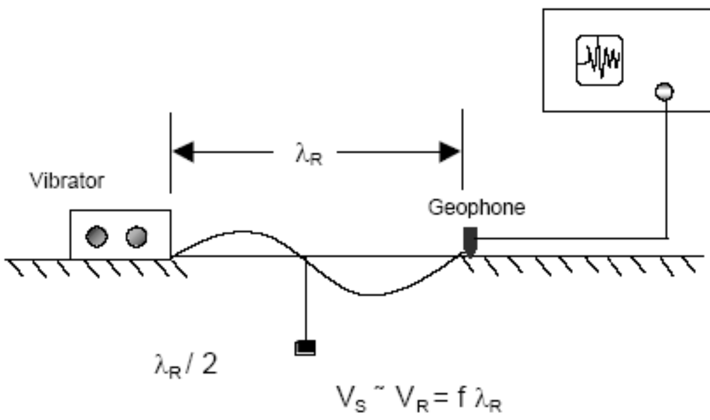

Figure 2 Steady-State Surface Wave Test

The effective depth of the R-wave has been empirically related to the soil layer at a depth equal to one half the wavelength, λ_R (Heukelom and Foster 1960). The variation of shear wave velocity with depth is obtained by changing the frequency of the source and thus changing the wave-length λ_R. This technique requires however, large force-generating equipment that can operate at low frequencies (i.e., rotating mass oscillators) to explore deep soil profiles.

3.2 Spectral Analysis of Surface Wave

The SASW method evolved from the steady-state vibration test discussed in the previous section. The purpose of the SASW test is to determine a detailed shear wave velocity profile working entirely from the ground surface. The method involves using a series of successively longer source-receiver arrays to measure the propagation of Rayleigh waves over a wide range in wavelengths. A vertical impact is applied at the ground surface generating transient Rayleigh waves. The sources used in SASW measurements include solenoid-operated impactors, hammer and V-meters (high frequency sources) and large drop weights and bulldozers (low-frequency sources).Two or more receivers placed at the surface, at known distances a part monitor the passage of these waves (Stokoe et. al. 1994; Gazetas 1991). Several sets of test with different receivers spacing are required to sample different depths. Shot receiver spacing with high frequencies (short wavelength) are used to sample shallow layers while long receiver spacing with low frequencies (long wavelengths) are used in sampling deeper layers. Figure 3 shows a schematic of the field setup of this test. The receivers or vibration transducers produce signals that are digitized and recorded by a dynamic signal analyzer, and each recorded time signal is transformed to the frequency domain using a fast Fourier transform algorithm.

The phase difference ($\phi(f)$) between two signals is then determined for each frequency, and the travel time ($t(f)$) between receivers is obtained for each frequency as follows:

$$t(f) = \phi(f) / 2\pi f \qquad (2)$$

where, $f(f)$ = phase difference for a given frequency in radians and f = frequency in cycles per seconds (cps). The velocity of R-waves is determined as:

$$V_R = \Delta d / t(f) = \lambda_R f \qquad (3)$$

where, Δd = distance between receivers and λ_R = surface wavelength.

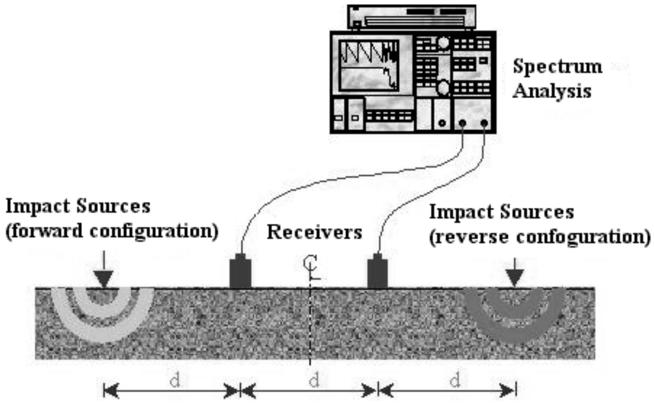

Figure 3 Spectral Analysis of Surface Wave

The calculations of V_R and λ_R are performed for each applied frequency, and the results plotted in the form of a dispersion curve. The dispersion curve is the characteristic or "signature" of a site. Using forward modeling or "inversion" analysis, the dispersion curves are used to determine the shear wave velocity profile of the site. Forward modeling is an iterative process involving assumption of a velocity profile and a theoretical dispersion curve for a given site using the two-dimensional solution for waves propagating along the surface of an elastic medium. The theoretical dispersion curve is then compared to the experimental curve measured at the site. The assumed profile is then modified and the process repeated until a match is achieved between theoretical and experimental dispersion curves. Shear moduli and shear wave velocity of the soil profile are then determined (Stokoe, et. al., 1994). It is to note that, in a deep, homogeneous subsoil profile where the subsurface can be represented by a half-space, the signals of the transducers would have the same shape. However, in a layered soil profile, the various frequency components generated by the source propagate at different speeds, thus arriving at different times at the two receiver locations, and the signals would then have different shapes (Gazetas 1991).

4 APPLICATIONS

4.1 Soil Profile

The study of the SASW method on the soil profile was pioneered by Heisey (1982) and Nazarian & Stokoe (1984) where layered soil profile and their corresponding stiffness were accurately determined. Svensson & Möller (2001) also compared the dynamic shear modulus from the SASW method and the Seismic Cone Penetration Test (SCPT) and were found to be in good agreement. Matthews et al (1996) had shown that the SASW was able to measure stiffness at small strain level of less than 0.001 % where values of the small strain stiffness are required to predict ground deformation under dynamic loading. The comparison between laboratory measurement of the resonant column and the SASW for residual soil profile was also tested by James et al (1999). The result shows that both testings were found to be in good agreement.

4.2. Pavement Profile

In pavement investigation, Nazarian (1984), Heisey et al (1982) and Nazarian & Stokoe (1984) started to conduct the measurement of the moduli and thickness using SASW. Thus, a considerable amount of theoretical and experimental research work has been successfully conducted at the University of Texas at Austin (Shao 1985, Sanchez Salinero 1987, Sheu 1987, Rix 1988 Röesset et al. 1990, Kang 1990 etc.). The modelling study had been also carried out as well as the experimental study. Röesset et al (1991) studied the 3 D model was implemented in pavement investigation using SASW analysis. From their result had shown that the 3 D model of SASW analysis was successful to be used for complicated profile in the pavement system. From their verified study that was conducted at Texas road, the 3 D model reproduced very well fitting with the experimental data. Tawfiq et al. (2000) combined the SASW and the FWD test for material investigation in the base and subgrade layer. From their study had shown that the comparison moduli between both tests were in good agreement which was calculated based on the deflection. In Malaysia, Rosyidi et al. (2002) implemented the SASW measurement on the new constructed road at Putrajaya. From their study, the comparison between thickness of pavement layer from the SASW result and the road profile was found to be in good agreement.

4.3. Liquefaction potential

The use of Vs as an index of liquefaction potential is justified since both Vs and liquefaction potential are influenced by many of the same factors (e.g. void ratio, effective confining pressure, stress history and geologic age). The study of liquefaction using the SASW method was successfully demonstrated Stokoe & Nazarian (1983). Their result had shown the shear wave velocities of the liquefiable layer were less than 450 fps. Andrus et al (1998) measured the liquefaction potential in the improved and unimproved soil area at Treasure Island, California where were used the two procedures with the following equation:

$$\tau/\sigma'_v = a\left(V_{S1}/100\right)^2 + b[1/\left(V_{S1c} - V_{S1}\right) - 1/V_{S1}] \tag{4}$$

$$a_{\max}\big/g = f_1\left\{a\left(f_2 V_S/100\right)^2 + b\left[1/\left(V_{S1c} - f_2 V_S\right) - 1/V_{S1c}\right]\right\} \tag{5}$$

where, τ is cyclic shear stress resisting liquefaction, a_{max} is peak horizontal ground surface acceleration, σ'_v is initial effective stress, g is acceleration of gravity and V_s is shear wave velocity. From their result had shown that two liquefaction assessment procedures based on V_s correctly predicted no liquefaction fro the improved area and marginal liquefaction for the unimproved area. This study further could support the usefulness in situ Vs for predicting liquefaction potential and demonstrated the potential of SASW method for rapid delineation of weak layers.

4.4. Attenuation properties for earthquake evaluation

The attenuation property is an important parameter to evaluate the vibration propagation in the material affected by earthquake. The SASW method can simultaneously measure the dispersion of motion and attenuation curves from the surface of the ground. Rix et al (2001) demonstrated the technique for obtaining attenuation using SASW. From their result, the material attenuation was easily obtained from the displacement transfer function.

4.5. Control of fill materials

Ismail et al (2002) conducted the SASW testing on compacted fill at Block A, College H, UKM, Malaysia. The result showed that the SASW was able to determine the depth of the fill material at the site. Moxhay et al (2000) also demonstrated the potential use of the SASW method for the monitoring of soil stiffness. Their result shows that the range of surface wave testing is a viable and economic technique for effectively monitoring ground improvement work. Their results had shown that the method can be applied to both cohesive as well as granular soils. Kim et al (2001) carried out the SASW test to evaluate the density in compaction works. Their study has proposed the combined method of SASW and Free-Free Resonant Column test to evaluate the in situ density of compacted soil layer with following equation:

$$V_s = 15.9 \times \gamma_d - 139.2 \tag{6}$$

where, the unit of Vs and γ_d were m/sec and kN/m^3. The field verification study performed at Hoengsung road construction site in Korea had shown the great potential of applying the proposed method.

4.6. Structural evaluation of concrete

The SASW is also useful for the structural evaluation of concrete. Cho & Lin (2001) conducted the experimental study to examine the dispersive characteristics of Rayleigh wave in the multi-layer cement mortar slab. The result shows that the SASW method is a reasonable tool to detect the dispersive characteristics of multi-layer cement mortar system with a finite thickness. Using forward modelling, the shear wave velocity of each layer in the multi-layer system can be obtained and the material properties of each layer can then derived using the shear wave velocity result. From their study the SASW method can be utilized in examining the structural elements of the general concrete the structural structures.

4.7. Obstacle detection method

Gucunski et al (2000) implemented this method in the field for detection of a cavity under a highway. The result had presented the potential of SASW technique in detection of cavities and other anomalies under roads and highways in a karts terrain. The SASW was implemented on the section of interstate expressway I-80 in the New Jersey. The result showed the significant fluctuations in the dispersion curve were clearly observed where represented as the cavities in the road material.

4.8. Offshore method

Rosenblad (2000) developed the SASW methodology for implementing in the underwater environment. Each sets of SASW tests performed in his study yielded insight into various approaches of effectively implementing the SASW method offshore. The result from testing offshore Vancouver demonstrated that small explosives can be used effectively as a source for SASW underwater. The results from the tests in 40 ft of water demonstrated that the traditional SASW methodology applied at this location yielded a consistent and interpretable dispersion curve. From the tests performed along the Galveston shoreline had shown that the application of the SASW methodology for saturated soil conditions is suited to the underwater environment.

5 CONCLUSIONS

The SASW method is a seismic technique employing Rayleigh waves to determine in situ shear waves velocity profiles. This method is a valuable tool to characterizing the materials and is very useful for many civil engineering applications.

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