Application of MASW Method for Evaluating Dynamic Properties of Lu-Liao-His Earth Dam

Pei-hsun Tsai\textsuperscript{1,a} and Kang-nan Chen\textsuperscript{2,b}

\textsuperscript{1} Department of Construction Engineering, Chaoyang University of Technology, 168 Jifong E. Rd., Wufong District, Taichung, 41349, Taiwan

\textsuperscript{2} Liming Engineering Consultants, 3F, 137 Dadun 17\textsuperscript{th} St., Nantun District, Taichung, 40848, Taiwan

\textsuperscript{a} phtsai@cyut.edu.tw, \textsuperscript{b}kun@li-mi.com.tw

**Keywords:** MASW, Slant stacking, Genetic algorithm, Dispersion curve.

**Abstract.** In the paper the shear wave velocity and Poisson’s ratio profile are studied using the MASW test. Slant stacking was adopted in experimental dispersion curve constructing. Theoretical dispersion curve can be constructed by thin layer stiffness matrix method. A real-parameter genetic algorithm is required to minimize the error between the theoretical and experimental dispersion curves. Test results show that spectrum using slant stacking shows the fundamental mode of Rayleigh wave in the frequency range from 15 Hz to 50Hz. To reduce the error of experimental and theoretical dispersion curve using real-parameter genetic algorithm is feasible. The results also show that the strata of Lu-Liao-His Earth Dam can be modeled as 3 soil layers with an underlying half space.

**Introduction**

The Lu-Liao-His Dam, located in Tainan, Taiwan, is a roller compacted earth dam with 30 m high and 270.4 m long. In order to analyze the safety of the dam under earthquake loading, dynamic properties of the dam need to be studied. Among the various seismic methods, surface wave seismic method is deemed as one of the best solutions. The Rayleigh waves travel on ground surface and they are easily detected using some receivers placed on ground surface. They contain plentiful dynamic information and they are useful for identification the soil strata in situ. From the phase spectra of the recorded data, the Rayleigh wave phase velocity can be calculated using spectral analysis of surface waves (SASW). However, only a pair of receivers is required repeated measurements in order to cover a certain depth range and to reduce the influence of body wave and noise. The multichannel analysis of surface wave method (MASW) method based on multiple channel records is used to construct the dispersion curve of Rayleigh wave. There are some analysis methods to evaluate the dispersion curve, such as frequency-wavenumber (f-k) analysis and τ-p transform. The dispersion curve is traced along higher energy spectra in the dispersion image, and the random noise will be masked. Park et al. [1], Foti [2], Lu and Zhang [3], Lin. et al. [4] were studied the Rayleigh wave dispersion curve using MASW.

To obtain the shear wave velocity profile based on the experimental dispersion curves, the process involves three steps: measuring the vibration data along a survey line on ground surface, construction of dispersion curve, and back-calculation of the shear wave velocity profile from the measured dispersion curve. The surface wave experimental data were collected using multiple receivers along a survey line. Slant stacking (or τ-p transform) was adopted in experimental dispersion curve constructing. To obtain the shear wave velocity profile based on the experimental dispersion curves, a back-calculation will be performed. Theoretical dispersion curve can be constructed by thin layer stiffness matrix method [5]. In this study, a real-parameter genetic algorithm is required to minimize the error between the theoretical and experimental dispersion curves.

**MASW Experiment and Procedure**

The test setup used is shown in Fig. 1. The impulsive source is used by weight drop (weight =125kg, falling height=1.7m). A linear array of 12 receivers 1 m apart aligned acquires the vertical velocity time history on ground surface. Receivers were 4.5Hz geophones mounted on 10 cm spikes. The
receivers were fixed on ground surface, and the spread length is 11m. A 16 channel seismograph records the seismic data of each receiver. The distance between the source and the closest receiver is 4 m, 15 m, 26 m, respectively. The duration used for measurement is only 1 sec with sampling interval of 0.2 msec. The spread was moved forward along the line by one spread length, but the location of impulsive source was fixed during the entire measurement process.

Fig. 1. MASW method field configuration

Analysis of Experimental Dispersion Curve

The procedure consists of two linear transformations: slant stacking (or τ-p transform) and Fourier transform. The traveltimes and source-receiver offsets were recorded. The τ-p transformation is a mapping of 2-D data defined by coordinates (t, x) onto a domain defined by the intercept and slope (τ, p) of lines present in the data. The slope of line represents the phase slowness. Slant stacking was performed using Radon transform with the Matlab image processing toolbox. Calculating one–dimensional Fourier transform of the τ-p domain, the wave field present by phase slowness-frequency (p-f) is given. Thus, the experimental dispersion curve can be obtained.

The frequency-phase velocity spectrum in Lu-Liao-His Dam is shown in Fig. 2. The experimental dispersion curve can be obtained from the maximum of the frequency-phase velocity spectrum. The spectrum shows the fundamental mode of Rayleigh wave in the frequency range from 15 Hz to 50Hz in this study.

Back-Calculation of Shear Wave velocity and Poisson’s Ratio Profile

Back-calculation is a common method to identify mechanical parameters of strata using experiment data. In this study, thin layer stiffness matrix method was used to calculate the theoretical dispersion curve. And then, a real-parameter genetic algorithm is required to minimize the error between the theoretical and experimental dispersion curves.
The soil strata are divided into some “thin” layers, firstly. Thin layers means that the layer thickness is smaller than the wavelength of interest. Assembling these layer matrices individually the stiffness matrix of the entire strata is setup. The stiffness matrix can be expressed as a function of wave number. Hence the eigenvalue problem for wave propagation is algebraic. And then, for the each frequency, the corresponding eigenvalue and eigenvector are obtained from these algebraic, they are wavenumber and modal shape for the individual frequency, respectively [5]. The theoretical dispersion curve can be obtained with the relation of frequency and phase velocity of surface wave.

**Theoretical Dispersion Curve.** The soil strata are divided into some “thin” layers, firstly. Thin layers means that the layer thickness is smaller than the wavelength of interest. Assembling these layer matrices individually the stiffness matrix of the entire strata is setup. The stiffness matrix can be expressed as a function of wave number. Hence the eigenvalue problem for wave propagation is algebraic. And then, for the each frequency, the corresponding eigenvalue and eigenvector are obtained from these algebraic, they are wavenumber and modal shape for the individual frequency, respectively [5]. The theoretical dispersion curve can be obtained with the relation of frequency and phase velocity of surface wave.

**Minimize the Error between Theoretical and Experimental Dispersion Curves.** How to obtain a global optimal solution in nonlinear multimodal domain is a key point in back-calculation procedure. Genetic algorithm is a technique that searches an approximate solution for an optimization problem. Such a solution is achieved based on an evolving process of numerical calculation. The solutions are selected through a fitness-based process in this study. The fitness of 50 sets of geo-material parameters is evaluated in each generation. There are three geo-material parameters of thin layer stiffness matrix method in a soil layer, such as layer thickness, shear wave velocity and Poisson’s ratio. To save time of calculation, densities of soils are fixed as 1800 kg/m$^3$ in this study. The process is terminated after ten generations because the maximum of the fitness function has reached a steady value. The error of experimental curve and theoretical curve is within 5%.

**Results of Back-Calculation.** The optimal parameters based on genetic algorithm are listed in Table 1. The shear wave velocity and Poisson’s ratio profiles is plotted as a function of shear wave velocity and Poisson’s ratio with depth, as shown in Fig. 3. The results shows that 3 soil layers with an underlying half space can be modeled in Lu-Liao-His Earth Dam.

Table 1. Values of shear wave velocity and Poisson’s ratio with depth

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Shear wave velocity (m/sec)</th>
<th>Poisson's ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0~1m</td>
<td>177</td>
<td>0.3</td>
</tr>
<tr>
<td>1~3m</td>
<td>187</td>
<td>0.3</td>
</tr>
<tr>
<td>3~10m</td>
<td>360</td>
<td>0.25</td>
</tr>
<tr>
<td>10~17m</td>
<td>380</td>
<td>0.21</td>
</tr>
<tr>
<td>&gt;17m</td>
<td>380</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Conclusions

The article introduces the process of shear wave velocity and Poisson’s ratio profile in Lu-Liao-His Earth Dam obtained using MASW. The results are summarized as follows:

1. The spectrum using slant stacking shows the fundamental mode of Rayleigh wave in the frequency range from 15 Hz to 50Hz in this study.
2. It is feasible using the real-parameter genetic algorithm to reduce the error of experimental and theoretical dispersion curve.
3. The strata of Lu-Liao-His Earth Dam can be modeled as 3 soil layers with an underlying half space.

Acknowledgements

This study funding supported from Liming Engineering Consultants Co. is highly appreciated.

References