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<td>Author(s)</td>
<td>Safdar, Muhammad; Kim, Jin Man; Mahmood, Khalid</td>
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Dynamic Properties of Marine Silty Sand

Muhammad Safdar
Research Associate, School of Civil and Environmental Engineering
Nanyang Technological University, Singapore
e-mail: safdar.pnu@gmail.com

Jin Man Kim*
Professor, School of Civil and Environmental Engineering
Pusan National University, Pusan, South Korea
* Corresponding Author; e-mail: jmkim@pusan.ac.kr

Khalid Mahmood
Assistant Professor, Department of Civil and Environmental Engineering
COMSATS Institute of Information Technology, Abbottabad, Pakistan
e-mail: mkhalid@ciit.net.pk

ABSTRACT
The dynamic properties of west coast marine silty sand are investigated between 1%–4% cyclic double amplitude shear strain using cyclic direct simple shear test apparatus. The dynamic properties are expressed in terms of secant shear modulus (Gs) and damping ratio (D). This study systematically investigates the effect of relative density, cyclic double amplitude shear strain, cyclic stress ratio, frequency, vertical effective stress and number of loading cycles on the dynamic properties of soil samples. All the tests are performed with frequency of 0.1 Hz with different relative densities 65 % and 70 %. Shear modulus decreases with increase in number of loading cycles and damping ratio increases. Shear modulus decreases with increase in cyclic double amplitude shear strain (1–4%) and damping ratio increases.

KEYWORDS: Dynamic properties; Shear modulus, Damping ratio, CDSS.

INTRODUCTION
Dynamic properties of soils are strongly affected by the magnitude of shear strain amplitude induced in the soil deposits during strong earthquakes motions. The dynamic properties of marine silty sand such as shear modulus and damping ratio are very vital in the design of geotechnical engineering problems such as cyclic loading.

Nonlinear hysteretic soil behavior observed during cyclic loading test in laboratory is usually summarized by plotting degradation in secant shear modulus and variation in damping ratio as functions of amplitude of cyclic shear strain ( Seed and Idriss, 1970; Hardin and Drnevich, 1972; Hashash and Park, 2001). Darendeli, (2001) explained the development of new family of normalized modulus reduction and material damping curves. The stiffness-strain relationship can be plotted by variation of calculated secant shear modulus ($G_{sec}$) with cyclic shear strain amplitude ($\gamma_c$).
CYCLIC DIRECT SIMPLE SHEAR APPARATUS

Cyclic simple shear tests are used to determine the cyclic shear strength of a soil specimen under constant volume or undrained conditions. Constant volume direct simple shear (DSS) test is a reliable method for measuring undrained shear strength of undisturbed or compacted soil samples. The DSS test is most similar to the CU triaxial test in that samples are consolidated prior to shearing.

The CDSS test procedure is based on that of a constant-volume direct simple shear testing of soils, which has been studied extensively for half a century and is described in the standard test ASTM D6528-07. The sample is consolidated under a normal load within a wire-reinforced membrane or a stack of thin rings that provide lateral confinement (Safdar et al., 2013). Once consolidation is complete, a horizontal shear force is applied to the end of the sample.

The sample height is continuously maintained during shear to ensure constant volume. Rather than measuring pore pressures, which would require complete saturation of the sample, the pore pressure response is inferred from the change in vertical stress which is monitored throughout the test (Baxter et al, 2010).

In this way changes in applied vertical stress ($\Delta \sigma_v$), which are required to keep the sample height constant, are assumed to be equal to the excess pore water pressure ($\Delta u$) that would develop if the test were truly undrained with pore pressure measurements (Dyvik et al. 1987).

Concept of effective stress was clarified by Terzaghi in the early 1920s, many soil laboratory testing apparatuses such as direct shear, direct simple shear, triaxial, and torsional shear apparatus, etc were invented to measure the shear strength of soil. Among them, the direct shear apparatus has been widely used both in research and application due to the ease of operation, the low cost of expense, and the little time expenditure. However, the direct shear test consists of the disadvantages in terms of the deformation and stress distribution during shear.

Deformation of the specimen in direct shear apparatus is non-uniform; it varies from one point to another point. This leads to the innovation of the direct simple shear apparatus which can overcome the deficiency in direct shear device. In direct simple shear machine, the deformation is approximately equal at all points and form an angle, called as “shear strain”. The distribution of stress is fairly good and certainly better than direct shear device.
EXPERIMENTAL INVESTIGATION

8 CDSS Tests are performed at a frequency of 0.1 Hz. 4 tests are performed at relative density of 65% and 4 tests are performed at 70% relative density. The failure criterion of 4% cyclic double amplitude shear strain is selected for all the tests. The relative density (65%, 70%) is the initial relative density before consolidation step.

To produce in-situ (Ko) stress conditions, a vertical consolidation stress must be applied to the sample prior to shearing. Applied vertical stresses simulate the loads from overburden material located over the soil sample. For marine silty sand, a normal consolidation stress of 100 kPa is applied in one step for all specimens (Safdar et al., 2013).

The laboratory testing program for this study is designed to analyze the cyclic behavior of marine silty sand when subjected to cyclic loads for different combinations of parameters such as cyclic shear stress, no. of loading cycles, and relative density. Cyclic loading from traffic and earthquakes have lower cyclic load periods (~1 s) than wave loading (~10–20 s) and this needs to be taken into account (Andersen, 2009). Hence, the frequency of 0.1 Hz is taken into account and all the tests are performed with this frequency.

SAMPLE PREPARATION

In this study marine silty sand is obtained from the West coast of South Korea. Specific gravity of material tested is $G_s = 2.65$. Marine silty sand has minimum voids ratio of 0.745 and maximum voids ratio of 1.183. Details of properties of soil tested are given in Table 1.

In Swedish Geotechnical Institute (SGI) direct simple shear apparatus, the cylindrical sample is used and completely surrounded by stack ring. Later, this apparatus design was modified by Bjerrum and Landva (1966) at the Norwegian Geotechnical Institute (NGI) using cylindrical sample confined by a wire-reinforced membrane. In this paper, Geocomp cyclic direct simple shear apparatus using wire-reinforced membrane is employed to investigate the marine silty sand behavior. During this study, dry tamping approach or dry deposition approach is used. A sample weight of 100 g is used and laid in 3~5 layers in wire-reinforced membrane (diameter = 63.5 mm) to obtain the required relative density.

Table 1: Properties of marine silty sand

<table>
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<tr>
<th>Properties of Soil Tested</th>
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<tr>
<td>Min. Voids Ratio</td>
<td>0.74</td>
</tr>
<tr>
<td>Max. Voids Ratio</td>
<td>1.18</td>
</tr>
<tr>
<td>Coefficient of Uniformity</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>$D_{10}$</td>
<td>0.08 mm</td>
</tr>
<tr>
<td>$D_{30}$</td>
<td>0.09 mm</td>
</tr>
<tr>
<td>$D_{60}$</td>
<td>0.14</td>
</tr>
<tr>
<td>USCS</td>
<td>Silty Sand (SM)</td>
</tr>
<tr>
<td>Specific Gravity ($G_s$)</td>
<td>2.652</td>
</tr>
</tbody>
</table>
TEST RESULTS AND DISCUSSION

Figure 1 and 2 shows the typical behavior of soil subjected to symmetrical cyclic loading. Equivalent viscous damping ratio (D) is the ratio of dissipated energy to maximum retained energy in a single load cycle (Kramer, 1996; Darendeli, 2001). Figure 3, 4, 5, and 6 shows normalized shear modulus versus $(G/G_{\text{max}})$ shear strain curve. $(G_{\text{max}})$ is the initial maximum shear modulus at 2nd loading cycle. Figure 7, 8, 9 and 10 shows damping ratio versus shear strain curves.

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**Figure 1:** Typical Stress strain behavior of marine silty sand

- $\sigma'_v = 100$ kPa
- $\text{CSR} = 0.16$
- Dr($%$) = 70
- $e_c = 0.847$
Figure 2: Typical Stress strain behavior of marine silty sand

Figure 3: Normalized shear modulus versus Shear strain curve
**Figure 4:** Normalized shear modulus versus Shear strain curve

![Normalized shear modulus versus Shear strain curve](image1.png)

- $\sigma'_{vc} = 100$ kPa
- CSR = 0.16
- Frequency = 0.1 Hz
- $D_r = 65$
- $e_c = 0.898$

**Figure 5:** Normalized shear Modulus versus Shear strain curve

![Normalized shear Modulus versus Shear strain curve](image2.png)

- $\sigma'_{vc} = 100$ kPa
- CSR = 0.10
- Frequency = 0.1 Hz
- $D_r = 70$
- $e_c = 0.847$
Figure 6: Normalized shear modulus versus Shear strain curve

Figure 7: Damping ratio versus Shear strain curve
Figure 8: Damping ratio versus Shear strain curve

Figure 9: Damping ratio versus Shear strain curve
Figure 3 and 4 shows the normalized shear modulus versus shear strain curve for 65% relative density samples. Figure 4 and 5 shows the shear modulus versus shear strain curve for 70% relative density samples.

The effect or dependency of relative density (void ratio) on shear modulus is more prominent in the small range of shear strain and there is very little or almost no effect in case of large shear strain.

As obvious from the above figures, there is very little dependency of relative density on the shear modulus degradation. Generally, shear modulus decreases with increase in cyclic double amplitude shear strain in the range of (1~4%).

Figure 7 and 8 shows the damping ratio versus shear strain curve for specimens having relative density of 65%. Figure 9 and 10 shows the damping ratio versus shear strain curve for specimens having relative density of 70%.

The effect or dependency of relative density (void ratio) on damping ratio is more prominent in the small range of shear strain and there is very little or almost no effect in case of large shear strain.

As obvious from the above figures, there is very little dependency of relative density on the damping ratio. Generally, shear modulus increases with increase in cyclic double amplitude shear strain.

**CONCLUSION**

The following conclusions can be drawn from series of laboratory cyclic direct simple shear tests.

Shear modulus decreases with increase in cyclic double amplitude shear strain (1~4%) and damping ratio increases.
The effect of relative density on shear modulus of marine silty sand is usually significant in small strain levels hence the effect of relative density on shear modulus with increase in shear strain is not significant in large strain levels.

Although, we can easily summarize that shear modulus decreases with increase in shear strain, number of loading cycles.

Degradation of shear modulus is more prominent in case of higher cyclic stress ratios and lower relative density samples.

In case of lower relative density samples, damping ratio increases quickly but reached to smaller values of damping ratios.

However, in case of higher relative density, damping ratio increases slowly but the initial values of damping ratios are higher than the lower relative density samples.

The reduction in shear modulus and increase in damping are significant in range of 1.5% ~ 4%. The effect of various parameters should be studied in depth in the future.

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REFERENCES


