Characteristics of Shear Waves in Frozen Soils

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1. Introduction
Soils are frozen when the temperature falls below the freezing point. This phenomenon affects on the behavior of soils. The purpose of this study is to investigate the characteristics of shear waves in soils due to temperature change. Experiments are carried out in a nylon cell designed to fix the shear wave transducers. The sand-silt mixture specimens are frozen in the TRRL refrigerator. The velocities, resonant frequencies and amplitudes of the shear waves are measured during freezing. Experimental results show that the shear wave velocities and resonant frequencies increase rapidly and the amplitudes of shear waves decrease rapidly around at the temperature of 0℃. It is important that this study provides basic information about shear waves during soil freezing.

2. Experimental setup
2.1 Materials
In this study, specimen was prepared by using sand and silt. Jumunjin 30/50 sand, which passed through sieve no.30 and remained on the sieve no.50, are used (D=0.3-0.6mm) to minimize the size effect. The properties of the sand are summarized in Table 1.

<table>
<thead>
<tr>
<th>Property</th>
<th>G_s</th>
<th>D_{50}</th>
<th>e_{max}</th>
<th>e_{min}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>2.59</td>
<td>0.45</td>
<td>0.82</td>
<td>0.56</td>
</tr>
</tbody>
</table>

2.2 Specimen preparation
The specimen was prepared by mixing the sand and silt. The relative density of sand before being mixed with silt is 70% (W_sand =3040g). The weight fraction of silt (W_silt/W_sand × 100%) is 10% and water fraction (W_water/W_sand × 100%) is 10%. The specimen was placed into the freezing cell in five layer and was compacted by applying the same tamping energy to each layer.

2.3 Freezing cell
A nylon cell for freezing specimen is shown in Fig. 1 below. The cell consists of four pieces to remove the vibration propagating through nylon cell. Fig. 2 shows the top view of the cell.

2.4 Measurement system
Shear wave measurement system is shown in Fig. 3. Input signals is generated by a signal generator. Filtered signals are captured by oscilloscope and saved in computer.

2.5 Test procedure
A pair of bender elements (Lee and Santamarina, 2005) combined with soils was installed at the side walls of freezing cell at the depth of 6cm from the top. The cell was fixed in refrigerator designed by TRRL (Transportation and Road Research Laboratory). The temperature inside refrigerator was maintained at -20℃. Shear waves are continuously measured while the temperatures of specimen drop from 10℃ to -10℃.

3. Test results
3.1 Shear wave velocities
The shear waves measured from 10℃ to -10℃ are illustrated in Fig. 4. Fig 4 shows that the lower temperature are, the faster first arrival time are. It is clear that the first arrival time dramatically decrease and the wave signature changes dramatically at the temperature of around 0℃.

3.2 Amplitude
Fig 4 illustrates the amplitudes of shear waves. Amplitudes decrease when the temperature changes from 2℃ to 0℃. It means that the shear waves are reflected because of the different impedance caused by phase change of water in void.

3.3 Resonant frequencies
Resonant frequencies versus temperatures are presented in Fig 5. The greatest frequency is measured at 0℃. Fig 5 shows that phase change which water in void turn into ice have an influence on the resonant frequency of shear wave.

References