Effect of the confining method on the cyclic undrained behaviours of sand

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Abstract. Cyclic Simple Shear (CSS) test is widely considered to best simulate vertically propagating shear waves and in-situ stress conditions. CSS test is always performed to generate reliable laboratory data for development and calibration of models in Geotechnical Earthquake Engineering design. Soil sample is laterally confined to simulate in-situ stress condition (k0). Stacked rings (SR) and Wire-reinforced membranes (WR) are the two widely used confining methods. Studies have been conducted on the effect of the two confinement methods on the static behavior of soil. In this paper, the effect of the SR and WR confinement methods on the dynamic soil behavior is studied. Undrained cyclic stress controlled tests were performed on loose and medium dense samples of Ottawa sand laterally confined by SR and WR. The comparison of the tests results showed that the dynamic behavior of the two confinement methods is mostly similar.

Keywords: Cyclic simple shear test, stacked rings, wire-reinforced membranes, stress, strain.

1. Introduction
The Cyclic Simple Shear (CSS) test and Cyclic Triaxial (CTX) test have been extensively performed to determine the behavior of soil under cyclic loading condition, [1-3]. CSS test can best simulate the vertically propagating shear wave induced by earthquake loading than the CTX test [4]. In the CSS test, k0 (in-situ) consolidation is provided by confining the sample against lateral deformation. The lateral confinement is provided by using the stacked rings or NGI type wire-reinforced membrane, as shown in Figure 1. Both the stacked rings and wire-reinforced membrane methods have been used in the early development of the Simple Shear apparatus [1, 5].

Studies have been conducted on the effect of the two confinement methods on the drained behavior of soil under static loading. Baxter, Bradshaw [6] and McGuire [7] conducted undrained simple shear tests on cohesive soil and reported that the results with the two confinement methods are comparable. Kwan and El Mohtar [8] tested cohesionless soil under drained condition using the two confinement methods and showed an overall agreement between the measured shear strength and volumetric response with the two confinement methods. However, no studies have been conducted to compare the
effect of the two confining systems on the cyclic behavior of soil. This paper presents undrained cyclic simple shear test results conducted on sample of clean Ottawa sand using both stacked rings (Teflon-coated aluminum rings) and wire-reinforced membranes, as shown in Figure 1.

![Image of stack rings and wire-reinforced membrane](image)

**Figure 1.** (a) stack rings (b) NGI type wire-reinforced membrane [9]

2. Material and Testing
The Simple Shear equipment used in this study is “Geocomp Shear Trac-II”, an automated device capable of performing consolidation, drained and undrained, static and cyclic simple shear tests. The system is of the type developed at NGI in the mid 1960's. The constant volume condition during the shearing is maintained by adjusting the vertical load through a closed loop computer control with the vertical displacement sensor as the feedback. The change in vertical stress is essentially equal to the developed excess pore water pressure in a constant volume SS test. Cyclic undrained tests were performed on clean Ottawa sand designated as ASTM C 778 [10] (also known as ASTM C 109). The particle size distribution curve of Ottawa sand is shown in Figure 2 and properties are presented in Table 1.

![Image of grain size distribution](image)

**Figure 2.** Grain size distribution of Ottawa sand
Table 1. Index properties of Ottawa sand

| Soil         | $e_{max}$ | $e_{min}$ | $G_s$ | $D_{50}$ (mm) | $C_u$ |
|--------------|-----------|-----------|-------|---------------|-------|
| Ottawa sand  | 0.764     | 0.49      | 2.65  | 0.31          | 1.89  |

2.1 Sample preparation
Two types of confinement methods SR and WR were used in this study. The installation of the two confinements are shown in Figure 3 and Figure 4. The membrane was installed on the bottom platen and Stack of rings was put around the membrane, as shown in Figure 3 a and b. Split mould shown in Figure 3 c was applied over the stack of rings, as shown in Figure 3 d. The suction was then applied to stretch the membrane tightly against the inner wall of the stack rings. While the wire-reinforced membrane was simply installed on the bottom platen, which do not need the suction to be applied, as shown in Figure 4. The reconstituted samples were made with moist by applying the under compaction method as described by Ladd [11]. The specimen diameter was 6.37 cm and height was 2.4 cm, which fulfils the ASTM D6528-07 [12] requirements. Sand was oven dried and weighted the required amount for the targeted density. The weighted sand was divided into 3 equal parts, mixing each part with 5% of water by weight. The moist soil was directly placed inside the membrane in three layers of equal thickness. Each layer was gently compacted. Top layer was leveled and cape was placed. Split-mould was removed in case the staked of rings was used. The whole assembly was than putted in the shear box for consolidation and shearing, as shown in Figure 5.

![Figure 3](image.png)

(a) (b) (c) (d)

Figure 3 (a) Membrane installed on the bottom cap (b) stack of rings are placed around membrane (c) One half of split-mould (d) Suction mould is applied

2.2 Consolidation and cyclic shearing
Vertical stress of 100 kPa was applied and the samples were anisotropically consolidate for 20 to 30 minutes. The consolidation was followed by undrained stress controlled cyclic shearing. Uniform sinusoidal loading was applied in the horizontal direction at the rate of 0.1 Hz. The cyclic loading was applied to the samples till failure. The tests were performed at different cyclic stress ratios (CSR).

$$CSR = \frac{\tau_{cyc}}{\sigma'_o}$$

(1)

where $\tau_{cyc}$ is cyclic shear stress and $\sigma'_o$ normal effective stress.
3. Results and discussion

The undrained cyclic behavior of loose and dense Ottawa sand, accomplished with the two confinement methods SR and WM, are shown in Figure 6, Figure 7 and Figure 8, respectively. Where Figure 6 and Figure 7 shows the results of the loose sample subjected to CSR = 0.08 and 0.1 respectively, and the results of dense sample subjected to CSR = 0.3 are shown in Figure 8 for both SR and WM. The effect of the two confinement are analyzed by comparing (a) shear strain versus number of cycles; (b) stress-strain response; (c) excess pore-water pressure versus number of cycles; and (d) Undrained stress path. It can be seen by comparing Figure 6, Figure 7 and Figure 8 that the number of cycles to liquefaction are larger for smaller CSR and vice versa. However, the number of cycles to liquefaction in the two confinement systems are similar. Insignificant discrepancies consists in the stress-strain response, excess pore pressure development and stress path between SR and WR. The overall comparison of the two confinement methods show comparable results.

Figure 6. Comparison of test results obtained with wire-reinforced membrane and stack ring. (Loose Ottawa sand, \(\sigma_\text{vo} = 100 \text{kPa}, \text{CSR} = 0.08\)
Figure 7. Comparison of test results obtained with wire-reinforced membrane and stack ring, (Loose Ottawa sand, $\sigma'_v = 100$ kPa, CSR = 0.1)

Figure 8. Comparison of test results obtained with wire-reinforced membrane and stack ring, (Dense Ottawa sand, $\sigma'_v = 100$ kPa, CSR = 0.3)

4. Conclusion
In this paper, the comparison between the two widely used lateral confining systems, stacked rings and
wire-reinforced membrane, in undrained stress control cyclic simple shear testing is presented. Undrained cyclic simple shear tests with the two confinement systems were performed on loose and dense samples, laterally confined by stack of rings and wire-reinforced membrane, of clean Ottawa sand. The comparison of test results shows that the two confinement systems provide comparable results with minor inconsistencies in terms of excess pore pressure generation and stress-strain behavior.

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