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Simple Shear Versus Direct Shear Tests on Interfaces during Cyclic Loading

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Simple Shear Versus Direct Shear Tests on Interfaces during Cyclic Loading

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SYNOPSIS An apparatus capable of direct shear type and simple shear type testing of interfaces between soil and structural materials is developed. A series of monotonic and cyclic tests are conducted at the interfaces between dry sand and a rough surface under constant normal stress conditions with both methods. The test results indicate that the peak and residual shear strengths obtained from direct shear and simple shear are approximately the same. However, the simple shear box permits separate measurements of shear deformation of the sand mass and also sliding at the contact surface.

INTRODUCTION

In many geotechnical engineering problems soil-structure interaction takes place under cyclic loading conditions. For example, offshore structures are subjected to cyclic lateral loading from wind, ice sheet movements, earthquakes, and waves. The load is transferred from the structural elements to soil thorough the contact zone which is normally called ***interface***. The load-deformation characteristics of the interface during cyclic loading play an important role in the behaviour of such structures.

Desai *et al.* (1985) employed a direct shear type device for displacement controlled cyclic testing of interfaces between dry Ottawa sand and concrete. They observed that the mobilized shear stress increases with number of cycles for both loose and dense sands such that the rate of increase in the mobilized shear stress is higher for loose sand. Uesugi and Kishida (1989, 1991) used a simple shear box, instead of the direct shear box, in a series of cyclic tests on interfaces between dry sand and steel. The simple shear box distinguishes the sliding at the interface from shear deformation of soil. They observed that the cyclic behaviour of the interface with a small shear displacement amplitude is divided in three stages. In the first stage, the peak shear is not yet reached. The mobilized maximum shear stress increases with the increase in the number of loading cycles. However, after the peak shear stress is attained, the maximum shear stress starts decreasing with the number of loading cycles. Eventually, the hysteresis curves converge to a loop.

An apparatus for monotonic and cyclic testing of interfaces was developed by Fakharian and Evgin (1993) which used a direct shear box as the soil container. In the present work, this apparatus is modified by using a simple shear box in addition to the direct shear box. This additional feature allowed comparisons to be made between the results of experiments using the two different types of soil containers.

EXPERIMENTS

Soil containers and sample preparation

The schematic diagram of the soil containers and the measured tangential displacements are shown in Fig. 1. The direct shear type soil container is a 25 *mm* thick, hollow aluminium box, with an inside area of 100 *mm* × 100 *mm*. It is placed on the steel plate which has an area of 300 *mm* × 300 *mm*. Since the steel plate is longer than the sand surface, the area of contact surface remains constant during sliding. The sand is rained into the box to a height of 20 *mm*.

The simple shear type soil container is similar to that of the friction testing apparatus employed by Uesugi and Kishida (1986). A stack of 10 anodized, Teflon coated, square aluminium plates with an inside area of 100 *mm* × 100 *mm* is placed on the steel plate. The thickness of each plate is 2 *mm*. The sand is rained into the container at desired density. Then the surface of sand is leveled by means of suction.

For the case of direct shear tests (Fig. 1*a*), the tangential displacement in *x*-direction, U_{xa}, is measured by an LVDT transducer, a_x. In the simple shear type tests, however, two sets of tangential displacements are measured to distinguish between slip at interface and shear deformation of the soil mass (Fig. 1*b*). The total displacement, U_{xa}, between the top aluminium plate and the steel specimen is measured by LVDT, a_x. The shear deformation of sand, U_{bx}, is measured by LVDT, b_x, which reads the relative tangential displacement between the top and bottom aluminium plates. Therefore, the slip at the sand-steel interface, U_x, is obtained from $U_x = U_{xa} - U_{xb}$ (Uesugi and Kishida, 1986).

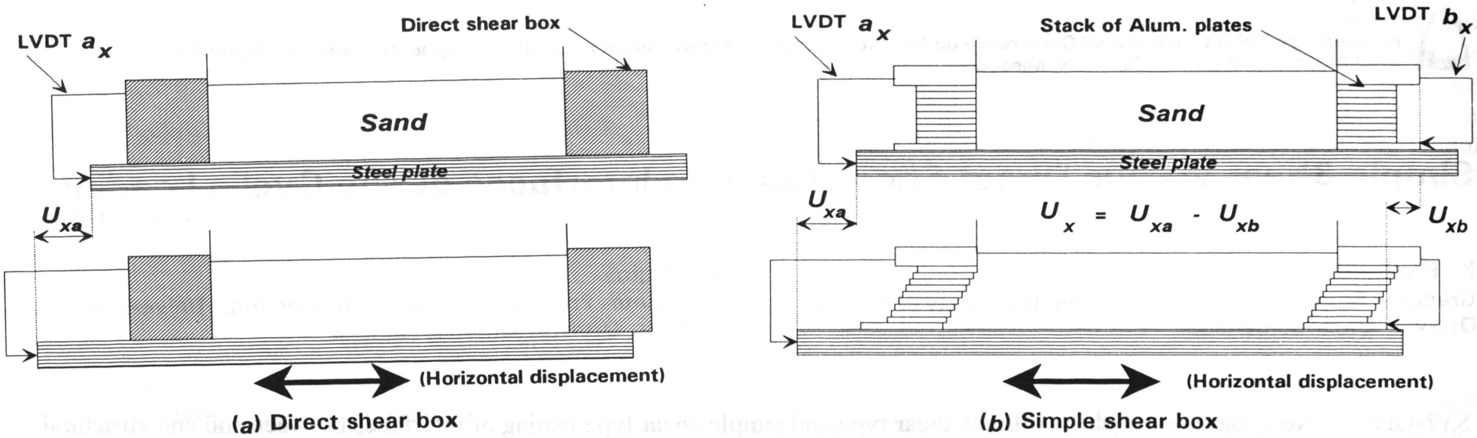


FIG. 1. Direct shear and simple shear type soil containers and corresponding shear displacement measurements (Modified after Uesugi and Kishida, 1986)

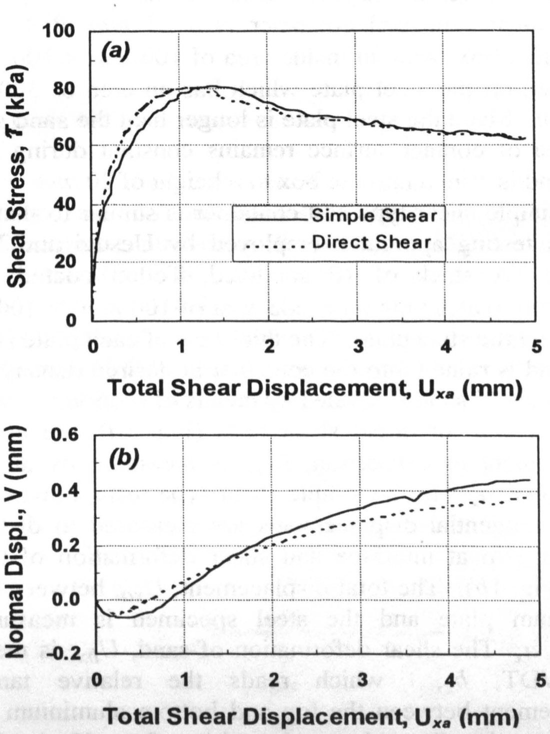
Materials

An air-dried medium crushed quartz sand is used as the soil material in this study. The mean grain size, minimum void ratio, and maximum void ratio, are 0.6 *mm*, 0.651, and 1.024, respectively. The sand is deposited with an initial relative density of 84% by using the Multiple-Sieving-Pluviation Method described by Miura and Toki (1982).

The structural material is a steel plate with an area of 300 × 300 *mm*. A rough surface is obtained by pasting Aluminium Oxide (ALO) cloth (a type of sand paper) on the steel plate. In this case, the steel specimen does not have a direct contact with the soil sample. However, the use of ALO cloth provides a uniformly distributed roughness.

TEST RESULTS

Some typical test results are presented to show the difference between using the direct shear box and the simple shear box



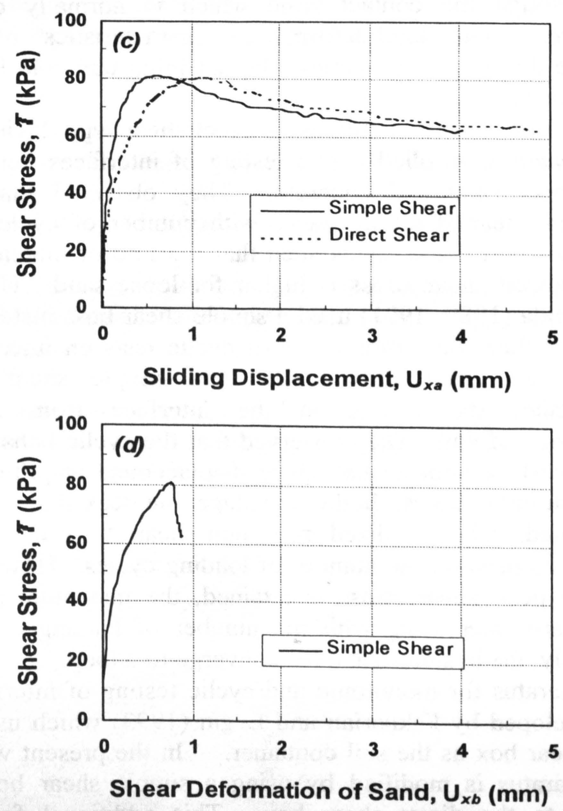


FIG. 2. Direct and simple shear results, Monotonic, $\sigma_n = 100\ kPa$, Initial $D_r = 84\%$

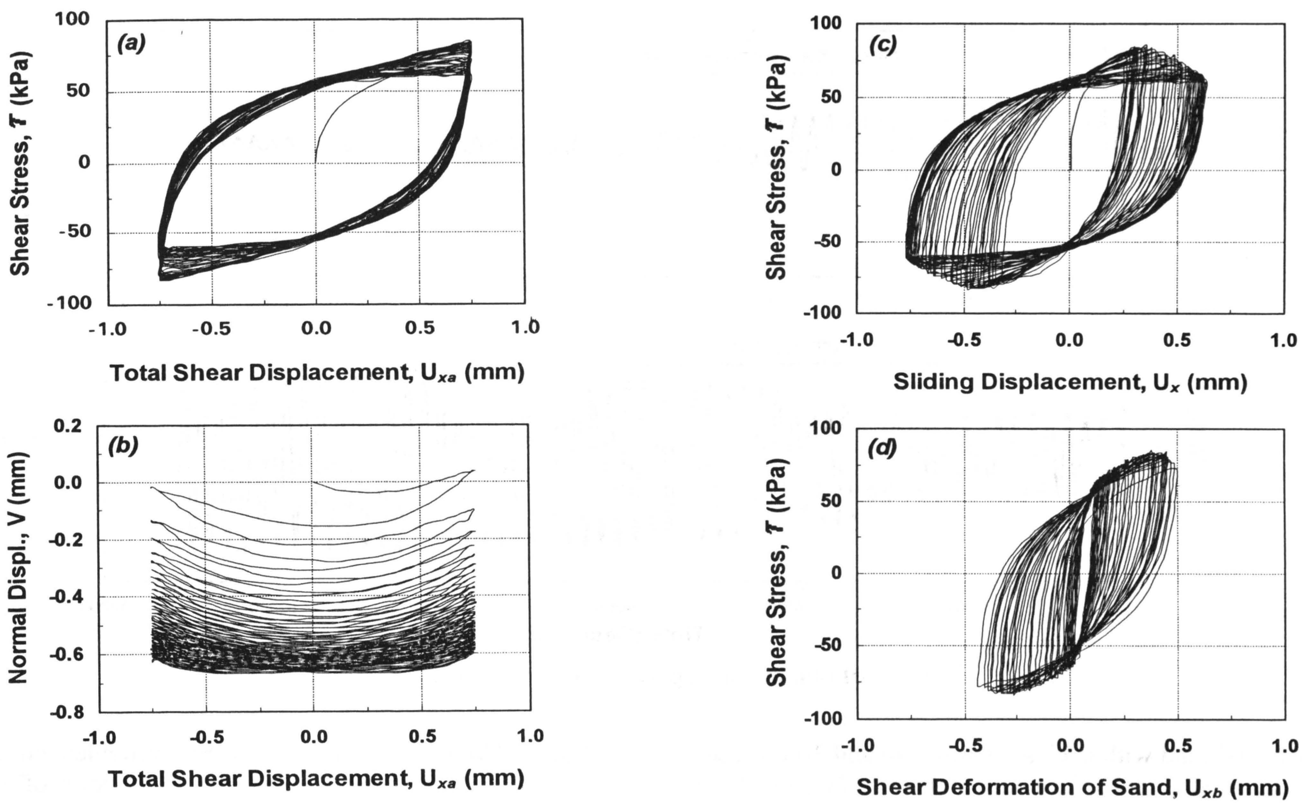


FIG. 3. Simple shear results, Cyclic, $\sigma_n = 100$ *kPa*, Initial $D_r = 84\%$

as soil container. First, the results of monotonic tests between the medium dense sand and the ALO cloth #600 are presented in Fig. 2 for both direct shear and simple shear types. The tests are conducted under a constant normal stress, σ_n, of 100 *kPa* with shear displacement rate at 1 *mm/min* up to a total shear displacement of 5 *mm*. The shear stress, shear displacement(s), and normal displacement, are recorded during the process of shearing. Normal displacement (or volume change) includes the normal compression or dilation for both soil mass and the contact surface. Figure 2*a* illustrates the shear stress, τ, versus total shear displacement, U_{xa}, for both methods. The peak and residual shear stresses are 80.3 *kPa* and 62.8 *kPa*, respectively. The peak is reached at a total shear displacement of 1.14 *mm* for direct shear and 1.3 *mm* for simple shear boxes. The variation of normal displacement, shown in Fig. 2*b*, indicates a small amount of compression at first followed by dilation which is typical for an interface between a rough surface and dense sand.

Total tangential displacement, U_{xa}, for simple shear box, includes the sliding displacement, U_x, and displacement due to the shear deformation of sand, U_{xb}. It is observed that the shear deformation of sand prevails before peak (Fig. 2*d*). Thereafter, the shear deformation is negligibly small as sliding at the contact surface continues (Fig. 2*c*). The sliding displacement at peak stress is about 0.6 *mm* which is roughly one half of that observed in the test using the direct shear box. However, the peak and residual shear stresses obtained in both type of tests are the same. These results indicate that both methods are alike for determining the strength parameters of the interface.

For the comparison of cyclic test results, two tests were conducted between the medium dense sand and ALO cloth #600. These tests were displacement controlled under a constant normal stress of 100 *kPa* with a period of 200 seconds. The first test was carried out using the direct shear box. Shear stress-shear displacement results for tests conducted under displacement amplitude of 0.5 *mm* indicated that the shear stress increased with increasing number of cycles up to a maximum of 83.6 *kPa* at cycle 4, after which shear stress decreased and eventually stabilized at 70 *kPa*. For displacement amplitude of 0.75 *mm*, maximum shear stress of 80.3 *kPa* was reached during the first cycle after which it decreased and finally stabilized at 62 *kPa*. Complete test data for this test is provided in Fakharian (1994).

In the second test, the behaviour of the same interface is examined using the simple shear box under cyclic loading conditions up to 55 cycles. The results are shown in Figs. 3*a-d*. Figure 3*a* shows the shear stress-total displacement, U_{xa}, relationship. The amplitude of total displacement is set at 0.75 *mm*, therefore, no change is observed in U_{xa} during cycles. The normal displacement is shown in Fig. 3*b* indicating a gradual decrease in volume which is due to

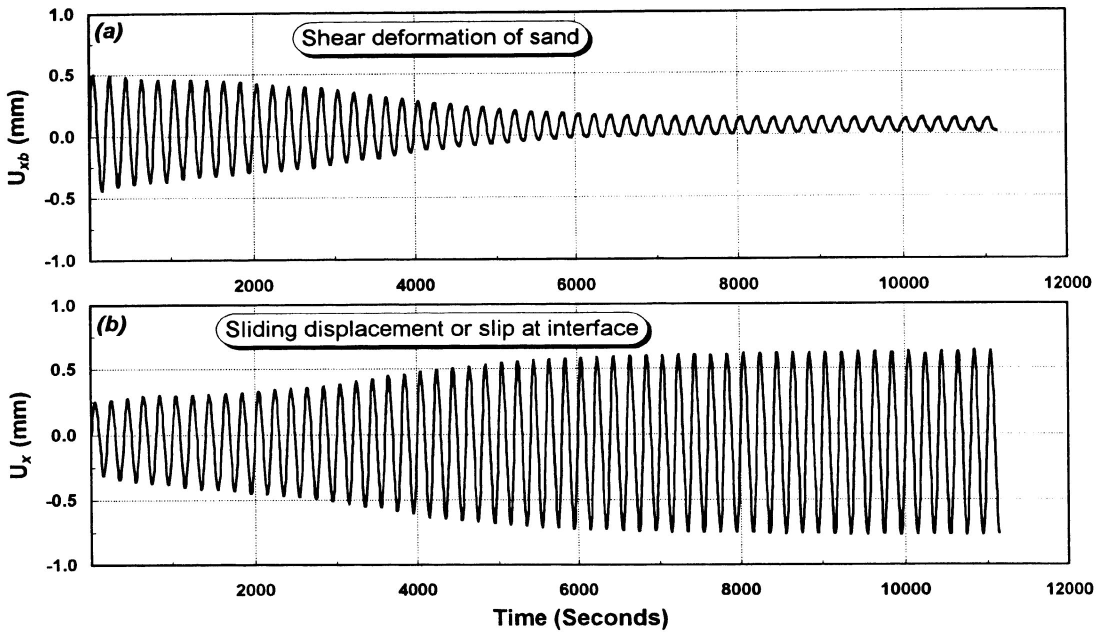


FIG. 4. Variation of tangential displacements with cycles for results of Fig. 3

compression of sand with cycles. Figures 3*c* and 3*d* represent the shear stress-sliding displacement at the interface and shear stress-shear deformation of soil mass, respectively. It is observed that the shear stress, which is 72.9 *kPa* at the end of the first cycle, reaches a peak of 83 *kPa* at cycle 12 after which the shear stress decreases and stabilizes at 60 *kPa*.

Figures 4*a* and 4*b* show the shear deformation of sand mass and sliding displacement versus time for the same cyclic simple shear test. During the first cycle, the maximum shear deformation of sand is 0.5 *mm*, i.e. 2/3 of the total displacement amplitude of 0.75 *mm*. As number of cycles increases, the shear deformation amplitude reduces and the sliding displacement amplitude increases. The shear deformation amplitude reduces to a value of 0.15 *mm* and sliding displacement amplitude increases to 0.6 *mm*, thereafter they remain at this value. The stabilization takes place after about 30 cycles equivalent to 6000 seconds. These observations agree qualitatively well with the results reported by Uesugi *et al.* (1989).

CONCLUSIONS

A comparison between the results of direct shear type and simple shear type interface testing has indicated that for both monotonic and shear displacement controlled cyclic loading, no major difference exists between the two types of testing as far as peak and residual strengths are concerned. The shear displacement controlled cyclic test results, with amplitudes less than that required to fail the interface in monotonic shearing, indicated that the peak and post-peak behaviour may occur with increase in the number of loading cycles in both methods. However, Simple shear box provides information separately on both load-deformation behaviour of the soil mass and the sliding at the contact surface.

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