A "SIMPLIFIED" DIRECT BOX SHEAR TEST ON GRANULAR MATERIALS INCLUDING ROCKFILL MATERIALS

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ABSTRACT

This paper gives a description of a new "simplified" direct box shear test apparatus in a large size, and the test results by the new apparatus. In the new apparatus, there is no upper shear box as used in the standard direct box shear test. A loading plate is directly placed on the sample in the lower shear box and pulled horizontally by a flexible chain. By doing this, the effect of frictional forces between the sample and the internal surfaces of the upper shear box induced in the standard direct box shear test during dilatancy is naturally eliminated. The test by the new apparatus is similar to a frictional test on usual materials such as metals. A lot of tests are performed on three kinds of granular materials including rockfill materials(the maximum grain size:150mm) using the new large-sized apparatus. The test results by the new apparatus agree well with those by the triaxial compression tests. It takes only about 30 minutes to test even the rockfill materials by the new apparatus, including the time to set the specimen.

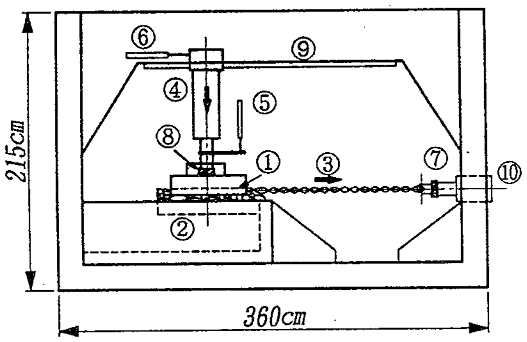
INTRODUCTION

Large-sized triaxial compression tests are mainly used to determine the strength and deformation parameters of rockfill materials at present. As the diameter of the specimen in the triaxial compression test is limited, it is impossible to test rockfill materials with large grains. It is necessary to adjust the grain size in the specimen on the conditions that (1)the specimen has such a similar grain size distribution as that of the real material and (2)the part of large grains is removed from the real material. In this paper, we introduce a new "simplified" direct box shear test apparatus and the test results by it. This new apparatus can easily test real rockfill materials even with large grains in a very short time(about 30 minutes including the time to set the specimen for every test).

The characteristic of the new apparatus is that no upper shear box exists, in other words, a loading plate is directly placed on the sample in the lower shear box. It is well known that the standard direct box shear test apparatus has both an upper shear box and a lower shear box, and the sample is sheared along the surface between the upper and the lower shear boxes. In the standard direct box shear test , the upper shear box induces pretty large frictional forces between the sample and the internal surfaces of the upper shear box during dilatancy, which might be one of the reasons that the shear strength obtained by the standard direct box shear test is higher than that measured by other tests such as the triaxial compression test. However, in this new apparatus , as the loading plate directly set on the sample in the lower shear box is pulled by a flexible chain, and no extra-external vertical force to transmit the frictional force exists except the own weight of the loading plate, the above-mentioned shortcoming in the standard direct box shear test is overcome. In fact, the shear test by the new apparatus is similar to a frictional test on usual materials such as metals.

"SIMPLIFIED" DIRECT BOX SHEAR TEST APPARATUS IN A LARGE SIZE

Fig.1 presents the schematic view of this new large-sized direct box shear test apparatus and the whole equipment is illustrated by Photo. 1. The vertical force (normal load) is transferred to the loading plate through a reaction force from the upper beam applied by an oil cylinder, and the oil cylinder can slide smoothly along the upper beam in the horizontal direction. The horizontal(shear) force is applied by pulling the loading plate with a flexible chain horizontally at a certain velocity (0.14mm/sec.) through another oil cylinder. The vertical and horizontal forces are measured by means of two load cells, and the



① Loading plate, ② Lower shear box, ③ Horizontal(shear) force, pulling by chain connected to oil cylinder, ④ Vertical (normal) force, applying by oil cylinder, ⑤ Vertical displacement transducer, ⑥ Horizontal displacement transducer, ⑦ Load cell to measure horizontal(shear) force, ⑧ Load cell to measure vertical(normal) force, ⑨ Upper beam, ⑩ Oil cylinder, connecting to oil unit.

Fig. 1. Schematic diagram of "simplified" direct box shear test apparatus in a large size

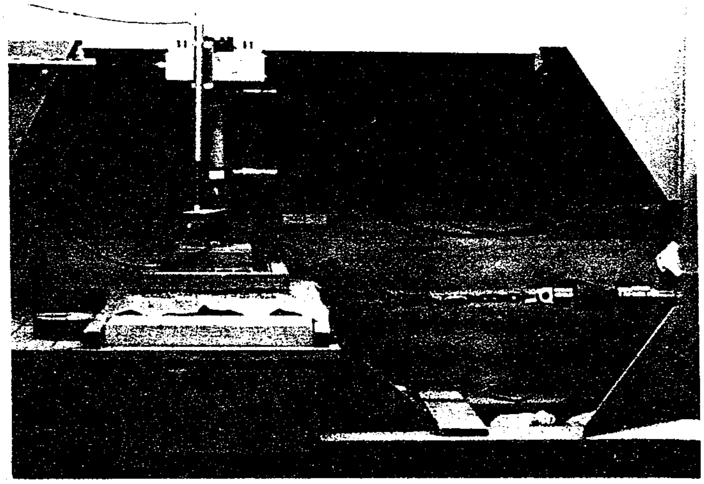


Photo. 1. New "simplified" direct box shear test apparatus in a large size

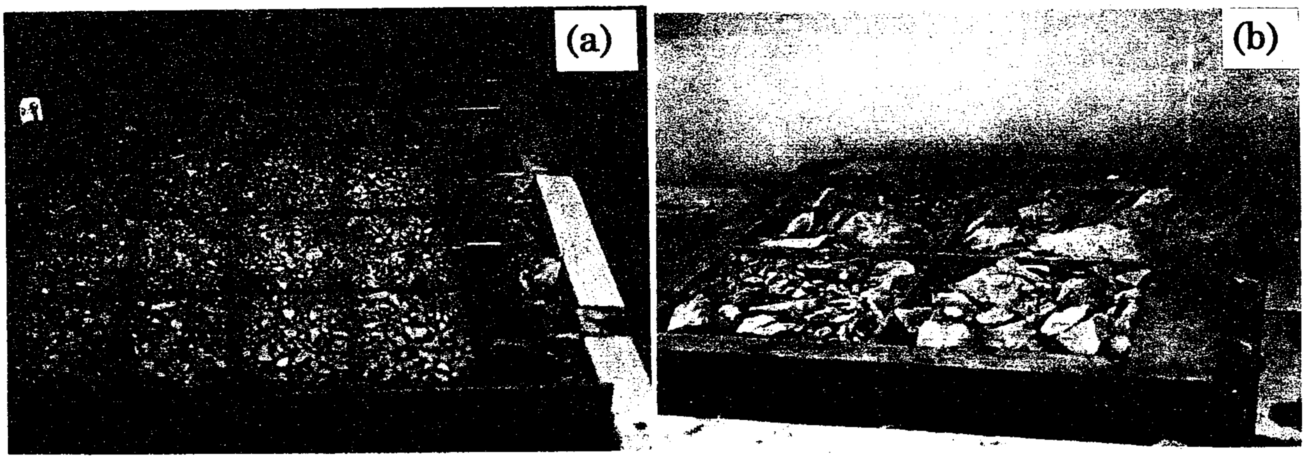


Photo. 2. Two kinds of loading plates used in new large-sized apparatus and their engagement with samples tested: (a) loading plate Ⅰ used to test sample A and sample B, and (b) loading plate Ⅱ used to test sample C

vertical and horizontal displacements are measured by means of two displacement transducers, respectively, all of which are connected to a personal computer through an interface board so that test data are recorded automatically. In this new large-sized direct box shear test apparatus, the loading plate is made of steel ribs with a shape of mesh and the same granular materials as the sample are engaged among the ribs to make the loading plate have sufficient frictional resistance on its base. Granular materials with any grain size from sands to rockfill materials can be tested by use of the new apparatus if the dimensions of the loading plate and the lower shear box are changed. In this paper, two kinds of the loading plate dimensions and correspondingly two kinds of the lower shear box dimensions are used for different samples to be tested. One is 60cm×60cm×4cm for the loading plate with twelve meshes(called loading plate Ⅰ, see Photo.2(a)) and 80cm×80cm×10.5cm for the lower shear box, and the other is 60cm×60cm×10cm for the loading plate with four meshes(called loading plate Ⅱ, see Photo.2(b)) and 80cm×80cm×21cm for the lower shear box.

MATERIALS TESTED

Three kinds of materials have been tested by the "simplified" direct box shear test apparatus in a large size, which are called sample A, sample B and sample C , respectively. Sample A was manufactured artificially with the average grain size of 8mm and the maximum grain size of 20mm; sample B and sample C were obtained from a rock-fill dam construction site. Sample B has the average grain size of 5.5mm and the maximum grain size of 50mm, and sample C has the average grain size of 18mm and the maximum grain size of 150mm The specific gravity Gs is 2.67 for sample A and 2.69 for sample B and sample C. Their grain size distributions are shown in Fig.2. Sample B and sample C have a similar grain size distribution .

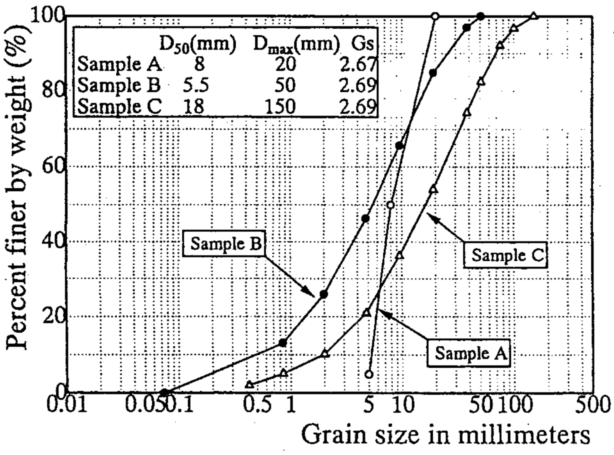


Fig. 2. Grain size distribution curves of samples tested by new large-sized direct box shear test apparatus

TEST PROCEDURES

In testing sample A and sample B, loading plate I (see Photo.2(a)) and the lower shear box of 80cm × 80cm × 10.5cm(length × width × depth) were used; whereas in testing sample C, loading plate II (see Photo.2(b)) and the lower shear box of 80cm × 80cm × 21cm(length × width × depth) were used. Herein, we take testing sample A as an example to explain the test procedures in the new large-sized direct box shear test. Firstly, prepare the sample in the lower shear box (10.5cm thick) in accordance with an initial void ratio being tested. Then, place the loading plate on the sample in the lower shear box and put the sample with the same initial void ratio as that in the lower shear box inside the meshes of the loading plate. After that, place a piece of vinyl sheet on the sample and some other materials on the vinyl sheet. The materials on the vinyl sheet are purposely raised with a shape like a little hill among meshes of the loading plate and careful attention should be paid to assure that there are no grains just on the ribs of the loading plate. The purpose to do these are to make the normal load be transmitted uniformly into the sample in the lower shear box. After every test, the vinyl sheet and materials on it are taken away. Finally, put a piece of steel plate on the hill-like materials, apply a normal load on the steel plate and pull the loading plate horizontally. The dense state of specimens was achieved by fully compacting the sample with a small vibrator . On the other hand, the loose state of specimens was made by putting the sample into the lower shear box and into meshes of the loading plate little by little with a spoon . It takes only about 30 minutes for every test.

TEST RESULTS

Three different initial void ratios e_0 have been selected for sample A and sample B . They are 0.68～0.69, 0.75 and 0.80～0.83 for sample A, and 0.37,0.42 and 0.56 for sample B, which represent dense, medium dense and loose states, respectively. Sample C was tested with initial void ratios e_0 of 0.42 and 0.56, respectively. Figs.3~9 present the test results of sample A ,sample B and sample C by the "simplified" direct box shear test apparatus in a large size. Figs.3, 5 and 7 show the relationships among the shear-normal stress ratio τ/σ, the horizontal displacement D and the vertical displacement h. Figs.4,6 and 8 show the relationships between the shear strength τ_f and the normal stress σ. Fig.9 shows the representative relationship between the shear-normal stress ratio τ/σ and the displacement increment ratio (-dh/dD) up to the peak strength. In the figures of this paper, the plots represent the test results and the lines are drawn by fitting the experimental plots using the least square method. For each kind of samples, the following observations can be made from these figures: (1) The shear-normal

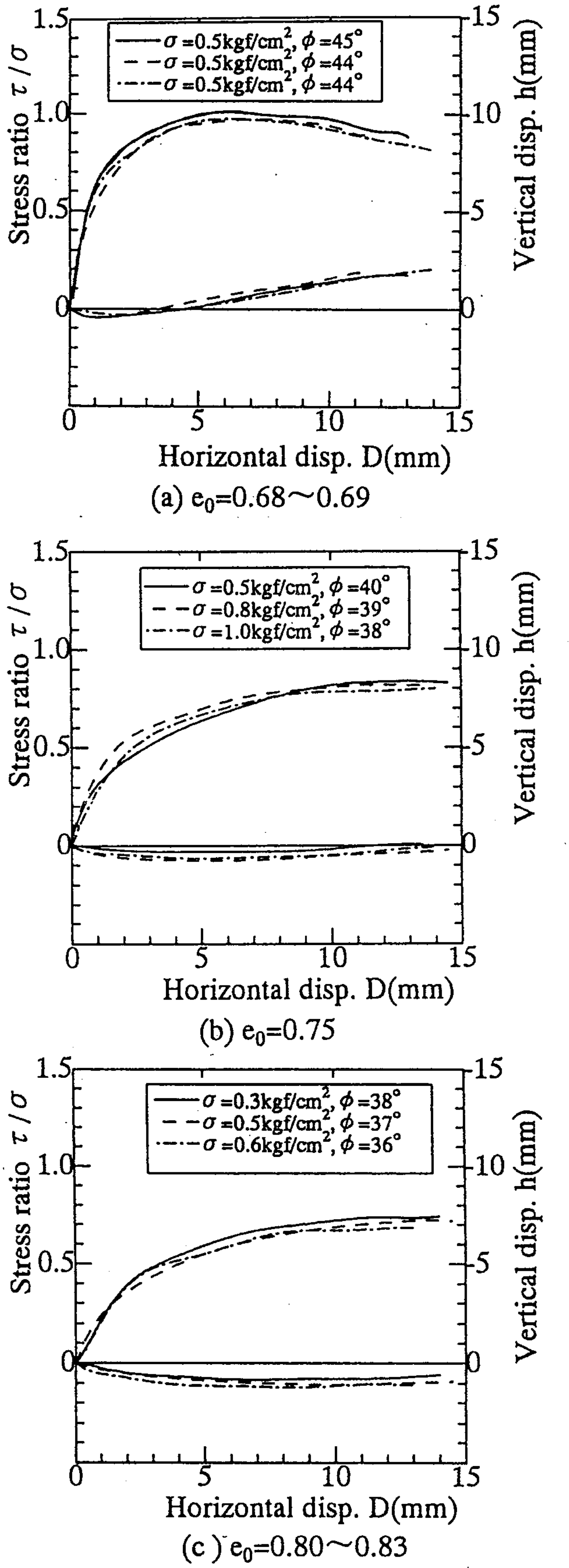


Fig.3. Relationship among stress ratio, horizontal displacement and vertical displacement of sample A under different initial void ratios by new large -sized direct box shear test ($1kgf/cm^2$=98kPa)

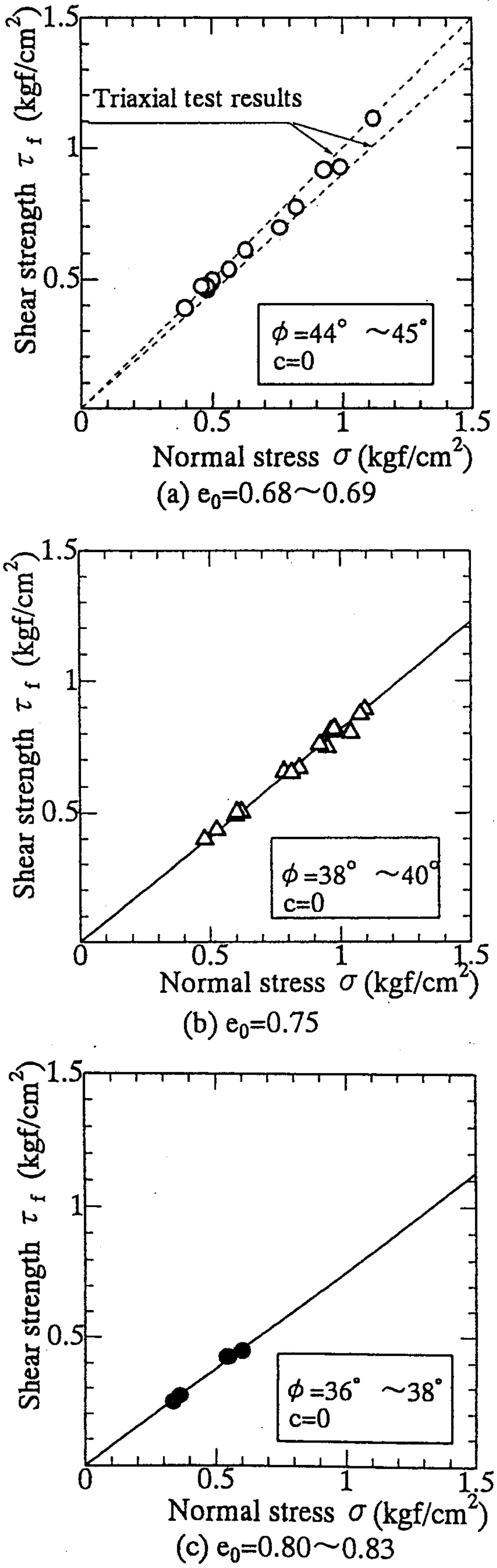


Fig. 4. Relationship between shear strength and normal stress of sample A under different initial void ratios by new large-sized direct box shear test($1kgf/cm^2$=98kPa)

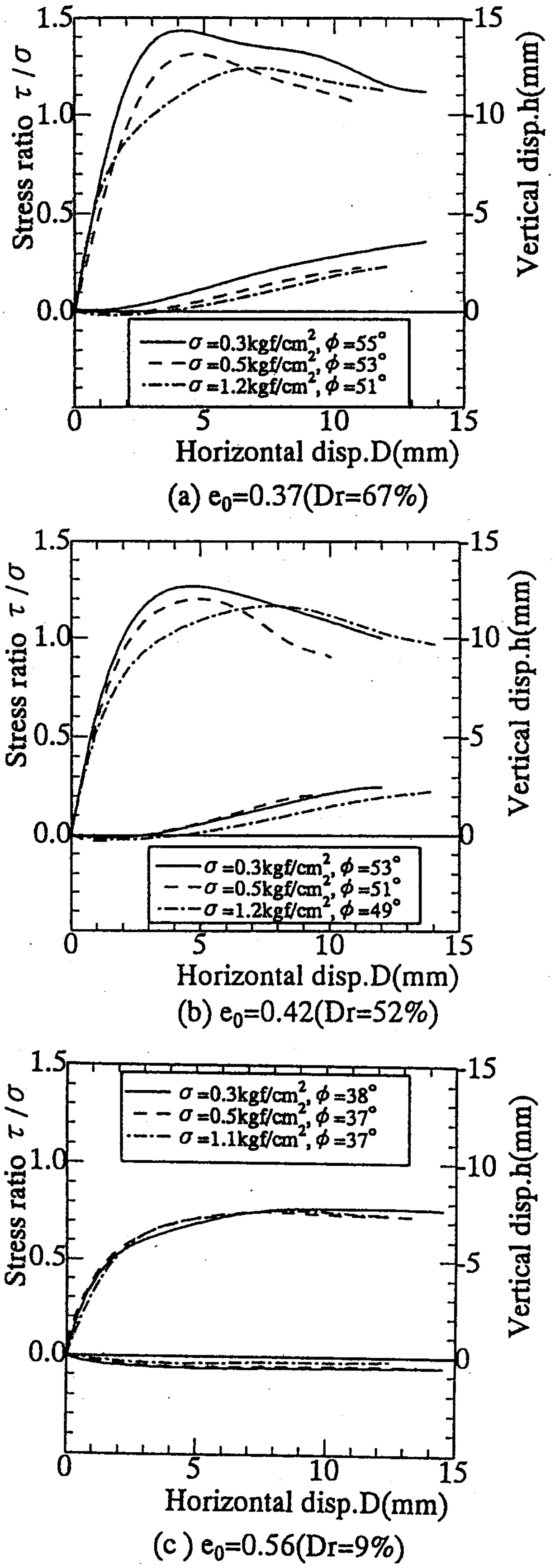


Fig. 5. Relationship among stress ratio, horizontal displacement and vertical displacement of sample B under different initial void ratios by new large -sized direct box shear test ($1kgf/cm^2$=98kPa)

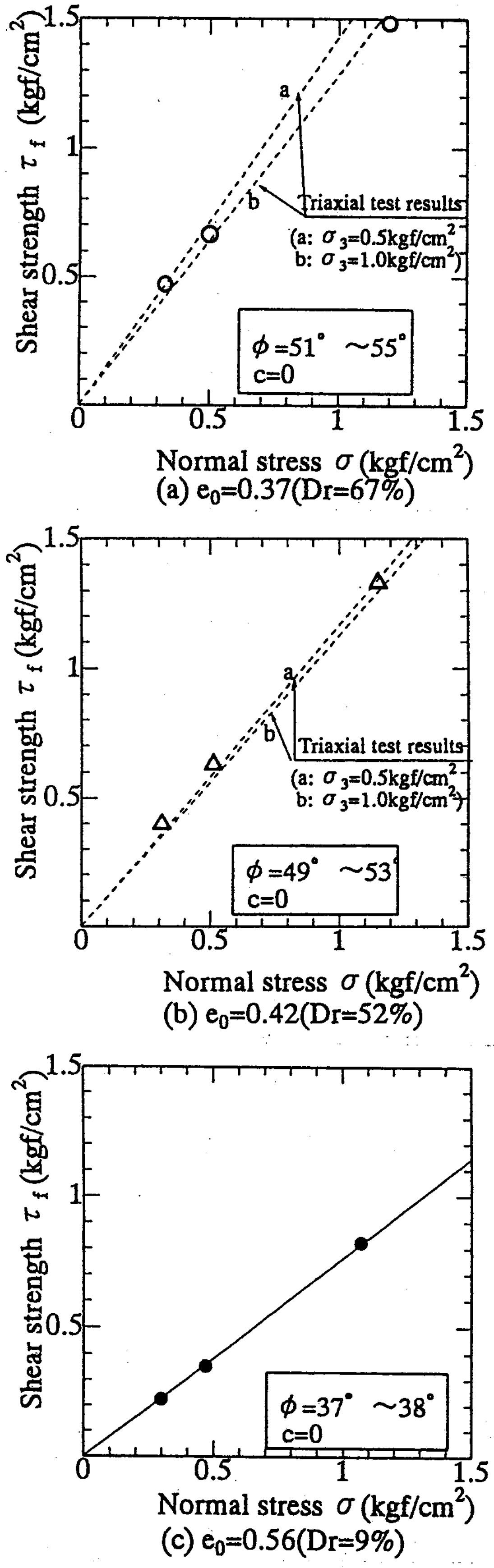


Fig. 6. Relationship between shear strength and normal stress of sample B under different initial void ratios by new large-sized direct box shear test ($1kgf/cm^2$=98kPa)

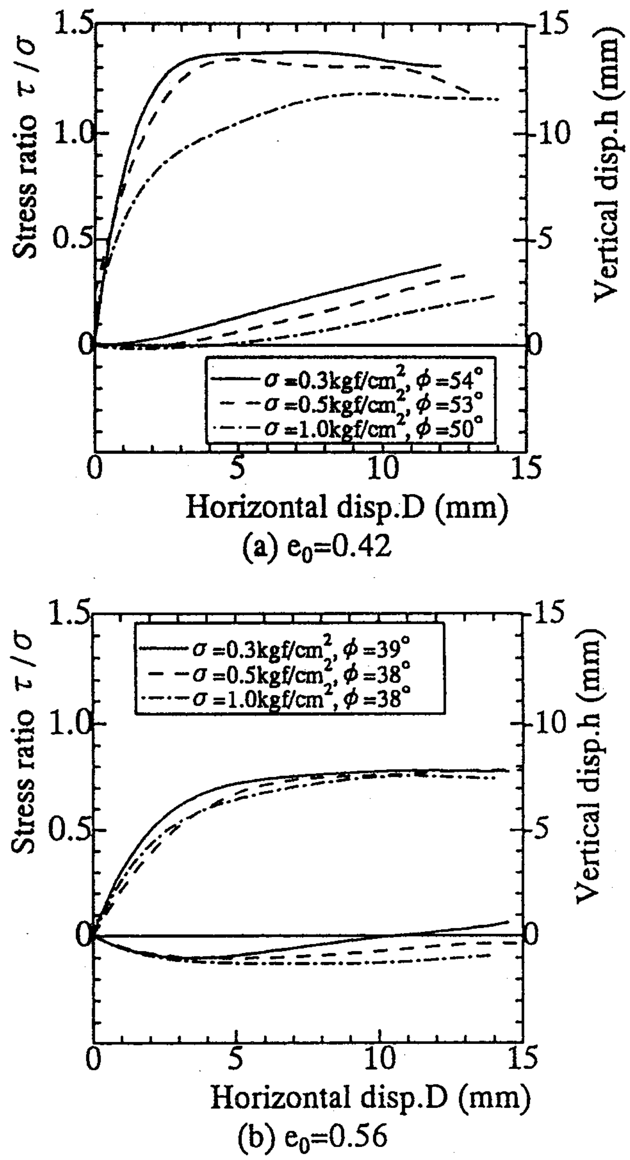


Fig. 7. Relationship among stress ratio, horizontal displacement and vertical displacement of sample C under different initial void ratios by new large -sized direct box shear test (1kgf/cm^2=98kPa)

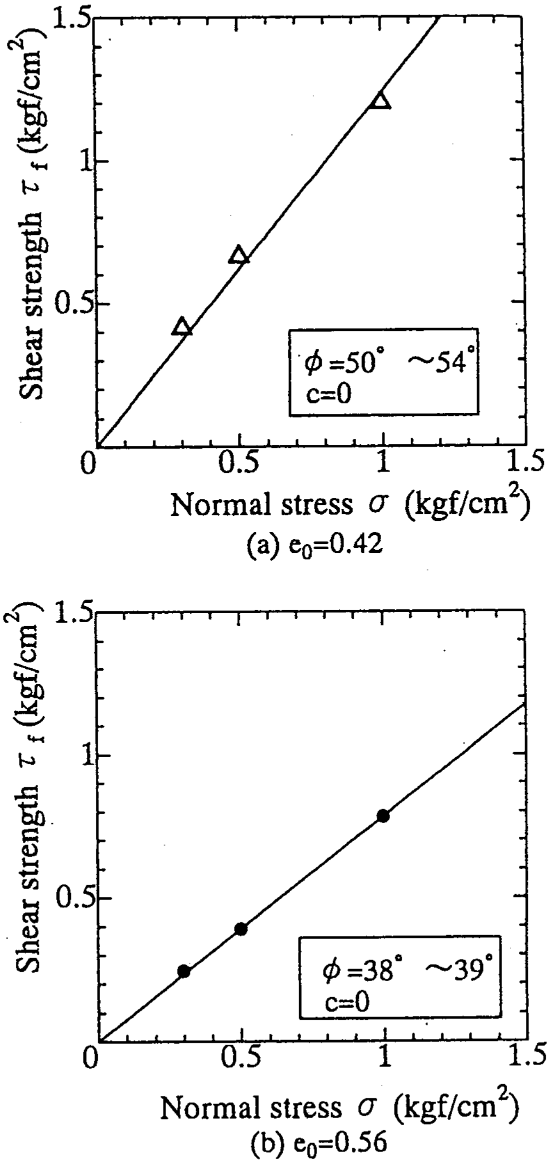


Fig. 8. Relationship between shear strength and normal stress of sample C under different initial void ratios by new large-sized direct box shear test (1kgf/cm^2=98kPa)

stress ratio at failure τ_f/σ decreases with the increase in the initial void ratio e_0(see Figs. 3, 5 and 7), i.e., the internal friction angle ϕ decreases with the increase in the initial void ratio e_0(see Figs. 4, 6 and 8); (2) The plots of the shear-normal stress ratio τ/σ against the displacement increment ratio(-dh/dD) are almost arranged on a straight line, independent of initial void ratios e_0(see Fig.9); (3)The internal friction angle ϕ tends to decrease with the increase in the normal stress σ even if the initial void ratio e_0 is the same(see Figs.3, 5 and 7). Next, we consider the reason of the phenomenon (3) using the test result of sample B at the initial void ratio e_0=0.37, as shown in Fig.10. It is seen from Figs. 9and 10(c) that the unique straight relationship between τ/σ and (-dh/dD) holds for the same sample under different initial void ratios e_0 and different normal stresses σ. As the sample dilates well under a low normal stress, (-dh/dD) at failure becomes large and consequently τ_f/σ at failure also becomes large, as understood from Fig.10(c). Thus, it can be easily understood that the internal friction angle ϕ (=$\tan^{-1}\tau_f/\sigma$) of the sample under a low normal stress is larger than that under a high normal stress,

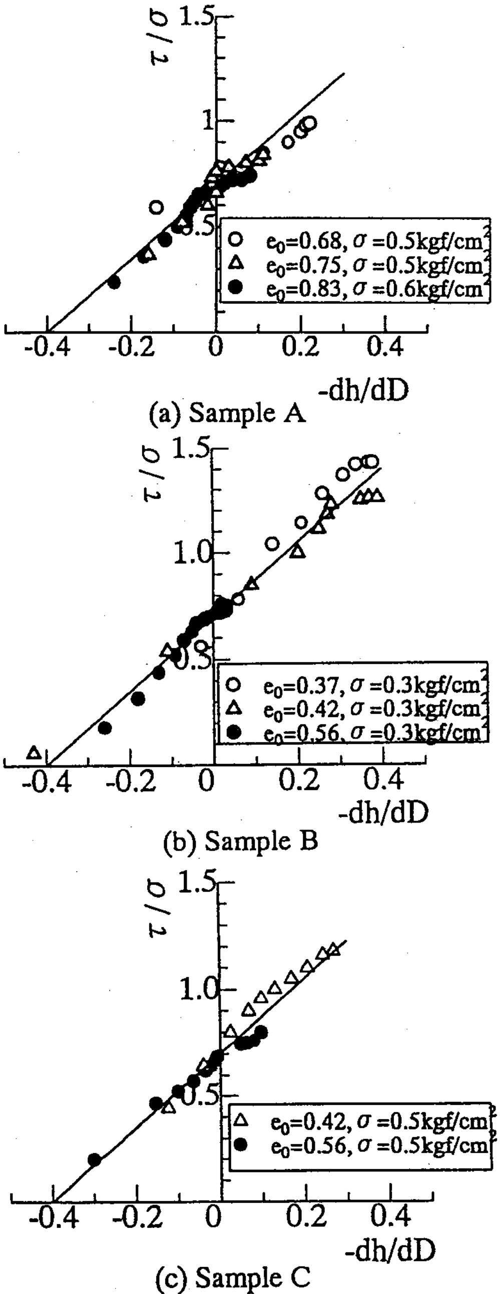


Fig. 9. Representative relationship between stress ratio and displacement increment ratio of three kinds of samples by new large-sized direct box shear test ($1kgf/cm^2$=98kPa)

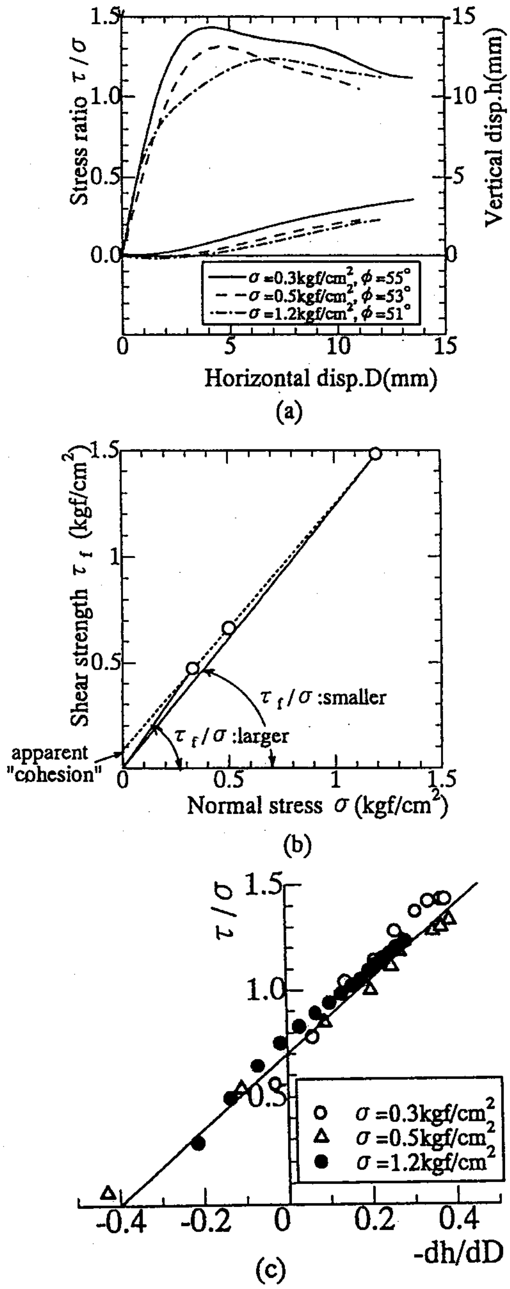


Fig. 10. An example to explain effect of normal stresses on internal friction angle (sample B, e_0=0.37, $1kgf/cm^2$=98kPa)

which means that an apparent "cohesion" appears if the plots of the shear strength τ_f against the normal stress σ are connected with a straight line, as shown in Fig.10(b).

For reference, some internal friction angles measured by the large-sized triaxial compression tests are also indicated in Figs.4(a), 6(a) and 6(b) by broken lines. The confining stresses σ_3 in large-sized triaxial compression tests on sample B are 0.5 and 1.0kgf/cm²(49 and 98kPa), as shown in Fig.6(a) and (b), which are approximately the same stress levels as used in the new direct box shear tests. It is seen from Figs.4(a), 6(a) and 6(b) that the internal friction angles measured by the new large-sized direct box shear tests for samples A and B agree nearly with those found by the triaxial compression tests at the same initial void ratio. A triaxial compression test is a test in axi-symmetrical stress condition, while a direct box shear test is considered to be a test in plane strain condition. Therefore, strictly speaking, the internal friction angle ϕ by a direct box shear test is a little higher than that by a triaxial compression test. However, the difference in ϕ is considered to be at most a few degrees, so the internal friction angle ϕ by the triaxial compression test and the direct box shear test may be comparable. Through the comparisons of the internal friction angles of samples A and B measured by the new apparatus with those measured by the larged-sized triaxial compression tests, it is concluded that the new large-sized direct box shear test can measure the internal friction angles of granular materials including rockfill materials with high accuracy. There are no test results from any other tests for sample C to be compared, because the grain size of sample C is too large(D_{max}=150mm). However, by considering that sample C and sample B are similar in the grain size distribution(see Fig.2) and the internal friction angles of sample C and sample B found by the new large-sized direct box shear tests are almost the same, it can be deduced that the internal friction angles of sample C found by the new large-sized direct box shear tests are also credible .

CONCLUSIONS

The main results of this paper are summarized as follows:

(1) A new "simplified" direct box shear test apparatus in a large size has been developed. The main feature of this new apparatus is replacing the upper shear box in the standard direct box shear test apparatus with a loading plate. A lot of efforts have been made to make the loading plate have sufficient frictional resistance on its base. The loading plate is directly put on the sample in the lower shear box . The test by this new apparatus is performed only by pulling the loading plate with a flexible chain under the application of the vertical force on the loading plate.

(2) Three kinds of granular materials including rockfill materials(the maximum grain size:150mm) have been tested by the new apparatus. The test results are compared with those measured by the triaxial compression tests. Through these comparisons, the validity of the new apparatus is demonstrated.

(3) In the new direct box shear test apparatus, there is no extra-external vertical force to transmit the frictional force except the own weight of the loading plate, because the loading plate directly placed on the sample in the lower shear box is pulled by a flexible chain .

(4) The greatest advantage of this new "simplified" direct box shear test is that it is able to test granular materials consisting of either small grains or large grains in the same way only by changing the size of the loading plate. Furthermore, the testing technique by the new apparatus is very easy and the time required for the test is very short. It takes only about 30 minutes to test even the rockfill materials, including the time to set the specimen. In the near future, we'll use this new apparatus to test rockfill materials in a real rockfill dam site.

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