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Strength and deformation characteristics of SLB sand from two types of plane strain compression tests

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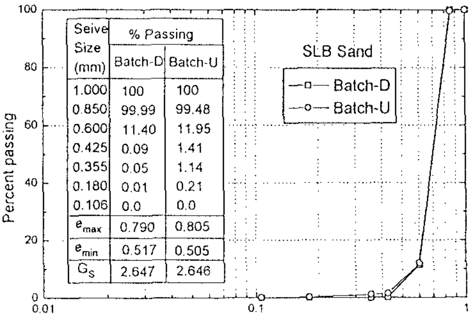
Introduction: Stress-strain and strength characteristics of dense Silver Leighton Buzzard (SLB) sand under plane strain condition obtained by using two types of apparatus; (i) a conventional Plane Strain Compression (PSC) apparatus (Park and Tatsuoka, 1994) and (ii) a Biaxial Tester (BT) (Ogunbekun, 1988) are compared. Results of two different batches of SLB sand are also compared.

Apparatuses, test methods and materials: In BT the σ_1 and σ_3 surfaces are flexible, made of membranes and the σ_2 surface is rigid, whereas in PSC the σ_1 and σ_2 surfaces are rigid and the σ_3 surface is flexible. Other comparisons are shown in Table 1. For both types of tests specimens were prepared by pluviating air-dried sand particles through air into a mold. In PSC tests, suction was then applied to the specimens through top and bottom platen and the specimens were sheared at an axial strain rate of 0.125% per minute. In BT tests, specimens were then moistened and frozen, and after placing in the apparatus the frozen specimens were thawed for 5-6 hours, saturated and sheared in a stress-controlled manner. Both axial and lateral deformations were measured by dial gauge in BT tests. In PSC tests axial deformations reported here are those measured externally by dial gauge and lateral strains were obtained from the average of the lateral displacements of the σ_3 surfaces measured by four pairs of proximity transducers. Although no lubrication was used between the sample membrane and air bag(s) in σ_1 and σ_3 directions in BT, the air bag(s) frame expanded and contracted according to specimen deformations so as not to exert any membrane force on the specimen.

Table 1: Differences in test conditions for the two apparatuses

Description	PSC	BT
Specimen size	8cm(Width)X20cm (Length)X10cm(Hight)	10cmX10cmX10cm
σ_3 (kgf/cm^2)	0.15	0.15
δ (Angle of loading direction relative to bedding plane)	90^0	90^0
Loading direction w.r.t. gravity	In the direction of gravity	Perpendicular to the direction of gravity
Saturation	Air dried	Saturated
Drainage condition	Drained	Drained
Membrane thickness	0.3 mm	0.3mm
Lubrication of σ_1 loading surface	Lubricated by Dow Corning Grease	Not lubricated
Lubrication of σ_2 plates	Lubricated by Dow Corning Grease	Lubricated by Silicon grease
Confiing pressure application	By suction	By pressure bag



Seive Size (mm)	% Passing	
	Batch-D	Batch-U
1.000	100	100
0.850	99.99	99.48
0.600	11.40	11.95
0.425	0.09	1.41
0.355	0.05	1.14
0.180	0.01	0.21
0.106	0.0	0.0
e_{max}	0.790	0.805
e_{min}	0.517	0.505
G_S	2.647	2.646

Fig.1 Grain size distribution of two batch of SLB sand

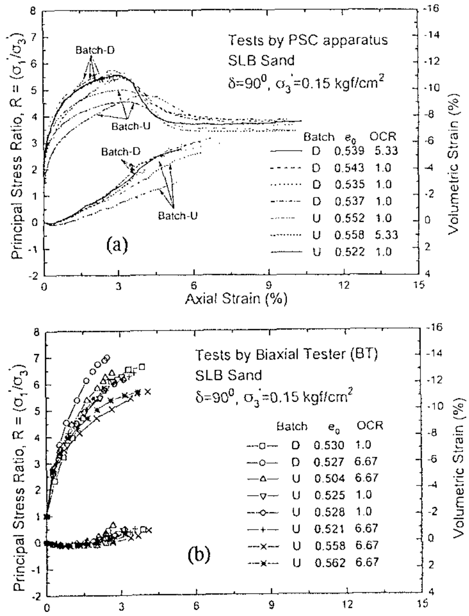


Fig.2 Stress-strain relationship for tests by (a) PSC apparatus and (b) BT

Two batches of SLB sand were tested, which are designated here as batch-D and batch-U. No appreciable difference was found in the gradation, maximum and minimum void ratios and sp.gr. between these batches (Fig.1), except that batch-U contains a slightly larger amount of particles finer than 0.600mm. Both batches were reused.

Test results and discussion: Stress-strain relations from the PSC and BT tests are shown in Fig.2(a) and (b) respectively. No correction is made for the membrane forces for the tests using the two apparatuses, considering that they can be ignored. The BT tests were terminated after reaching peak state of stress. For both batches of sand at similar void ratios the PSC specimens were more dilatant exhibiting larger axial and shear strains at failure compared to the BT specimens. This point is

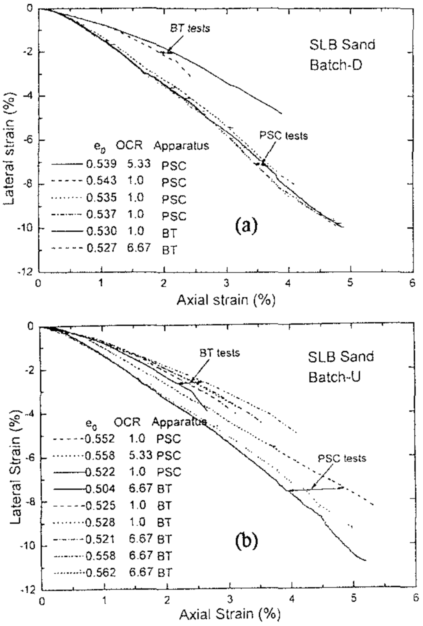


Fig.3. Relation between axial and lateral strain of SLB sand(a) Batch-D and (b) Batch-U

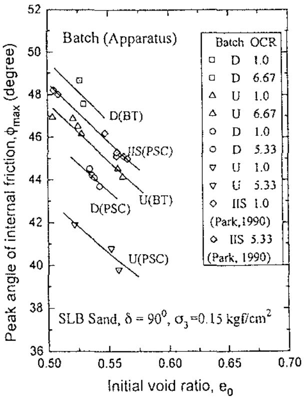


Fig.4. ϕ_{max} versus initial void ratio

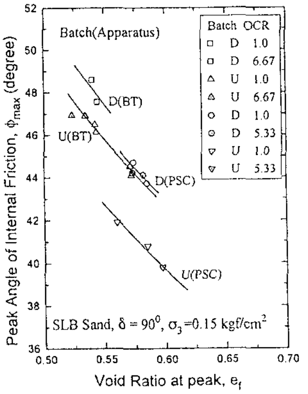


Fig.5. ϕ_{max} versus void ratio at failure

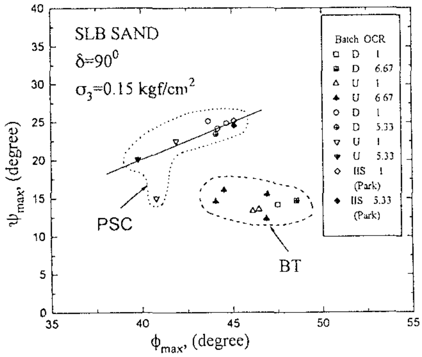


Fig.6 Relationship between ψ_{max} and ϕ_{max}

also noticeable from Figs.3(a) and 3(b); for each of batch-D and batch-U, PSC specimens underwent greater lateral strains at the same axial strain.

Fig.4 shows the angles of internal friction, ϕ_{max} [= $\arcsin\{(\sigma_1{}' - \sigma_3{}')/(\sigma_1{}' + \sigma_3{}')\}_{max}$] plotted against the initial void ratio e_0, measured at $\sigma_3{}'=0.05$ kgf/cm^2 and 0.00 kgf/cm^2 for PSC and BT tests respectively. For each batch, at the same void ratio, ϕ_{max} from the BT tests is larger than ϕ_{max} from the PSC tests by as much as 3.5^0. The difference in specimen dimensions in the tests by the two apparatuses can be assumed to have negligible effects since loading platens in the PSC tests were properly lubricated. The results on another batch (IIS) of SLB sand obtained by Park (1990) by PSC apparatus are also plotted in Fig.4. The trend of the ϕ_{max}~e_0 relationship is similar to the other batches of SLB. If, instead of initial void ratio e_0, the void ratio at failure, e_f is considered (Fig.5) the difference in ϕ_{max} between the two apparatuses reduces to about 1^0 for batch-D and 3^0 for batch-U.

Fig.6 shows the relationship between the dilatancy angle at peak, $\psi_{max}=\arcsin\{-(d\varepsilon_1+d\varepsilon_3)/(d\varepsilon_1-d\varepsilon_3)\}_{peak}$ and ϕ_{max}. The data points from BT tests are somewhat scattered whereas the data points from PSC tests show a linear relationship $\phi_{max} = \psi_{max} + 20^0$ (except one data point). Also ψ_{max} are lower for BT than for PSC. Similar differences in strength and dilation between the two apparatuses were also observed for Toyoura sand (Yasin, et.al., 1995). It is likely that in the BT tests, perturbation caused by continuous adjustment of the σ_3 surface not to induce membrane force may have restrained dilation, while some differences in the boundary conditions may have led more brittle behaviour and higher ϕ_{max} in BT (or more ductile behaviour and lower ϕ_{max} in PSC).

Another interesting point to note is the difference in strength between the two batches of SLB sand despite no discernible difference in their physical properties. At the same e_f, ϕ_{max} of batch-D is greater than that of batch-U by 2^0 by BT apparatus and 3^0 by PSC apparatus. Correspondingly, batch-U exhibits lower stiffness and larger axial strain at peak compared to batch-D (Fig.2). It also indicates that the effects of different batch are different between the two types of tests.

Conclusions: (1) At the same void ratio at failure, the peak strength of SLB sand was lower with more dilative and ductile behaviour in the conventional PSC tests than in the BT tests. (2) In both PSC and BT tests, two batch of SLB sand exhibited large differences in strength and axial strain at peak, whereas their physical properties were similar.

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