研 究 速 報

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Strength and Deformation Anisotropy of Dense Silver Leighton Buzzard Sand in Plane Strain Compression

平面ひずみ圧縮状態における密詰めSilver Leighton Buzzard砂の変形・強度異方性

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Introduction

Anisotropy in strength and deformation of air-pluvialed sands has been studied by Arthur and Menzies (1972) and Oda (1972). This aspect for Silver Leighton Buzzard (SLB) sand has been intensively investigated by the research group at University College London using their Directional Shear Cell (DSC) (e. g., Arthur and Assadi, 1977; Arthur et al., 1977; Wong and Arthur, 1985). In DSC, the specimen subjected to flexible boundaries is sheared under conditions of plane strain. The results were interpreted as ϕ_{max} at failure was continuously reduced as δ, the fixed angle of σ_1 relative to the bedding plane, decreased from 90° to zero. On the other hand, Oda and Tatuoka et al. (1986) showed that the relationship between ϕ and δ had a minimum at δ around $45-\frac{\phi_{max}}{2}$. This paper discusses the effects of δ on the stiffness and strength of SLB sand for a wide range of strain from 10^{-6} to those at the peak strength. The discussion refers to the results of drained tests obtained using a conventional plane strain compression (PSC) apparatus in which the specimen was sheared in a combination of flexible and rigid boundaries. A particular attension was also paid to anisotropy in the maximum shear modulus.

Tests performed

The SLB sand tested had the grain size distribution as shown in Fig. 1. The rectangular specimen with the dimension of 8cm wide, 16cm long and 20cm high was prepared by pluviating dry grains into a mould, and it was moistured and frozen. In tests at $\delta=90°$, the dry specimens were used. In the PSC apparatus, the specimens were defrosted under a constant suction of -0.05kgf/cm^2, at which the void ratio of $e_{0.05}$ was measured. They were isotropically consolidated by increasing (or decreasing afterwards for overconsolidated (OC) specimens) the suction to the σ_3'valve at which the specimen was sheared. Anisotropy in the soil properties was examined by having specimens with the various, but fixed angle δ, between 0 and 90 degrees. The drained shear took place at a constant σ_3' using an controlled rate of axial displacement of 0.25mm/min., through a lubrication layer in between the rigid top plate (or the pedestal) and the specimen. The deformation of specimen was measured locally on the lateral surfaces, covered with a 0.3mm thick membrane, using two Local Deformation Transducers (LDT, Goto et al., 1990) and a total of eight proximeters to define the averaged ε_1 and ε_3, respectively (Fig. 2). The overall accuracy of the strain measurements was about 1×10^{-6}.

(Shibuya et al., 1990)

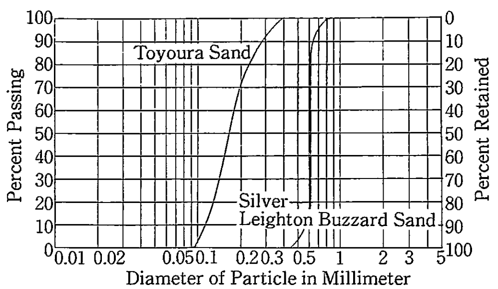

Fig. 1 Grain size distribution of Silver Leighton Buzzard sand tested.

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Discussion

(a) Anisotropy in strength

The results of the strength anisotropy are shown in Fig. 3, in which ϕ_{max}=arcsin {($\sigma_1'-\sigma_3'$)/($\sigma_1'+\sigma_3'$)} corrected to e=0.52 is plotted against δ for both NC and OC specimens. When the PSC results are compared to those of DSC tests (Arthur and Assadi, 1977), it should be noted that i) the tendency of the strength anisotropy is similar, but ii) the values of ϕ_{max} of the OC specimens were higher in the DSC by 3 to 4 degrees. In the PSC tests, the correction for the membrane force was made, albeit it reduced ϕ_{max} by only 0.03 degree. The effect of membrane force on ϕ_{max} will be more significant when a thicker membrane is used. The results of PSC tests on Toyoura sand, tested in the same apparatus, showed that the minimum of ϕ_{max} was observed at δ around 25 degrees. However, no such a kink in the relation of ϕ_{max} and δ can be seen in the SLB sand for both NC and OC specimens. This would suggest that the display of the minimum of ϕ_{max} was a characteristic of Toyoura sand, not due to the boundary effect associated with the configuration of the specimen.

(b) Anisotropy in stiffness

The relationships between the principal stress ratio and the axial strain are shown in Figs. 4 and 5 for the OC and NC specimens, respectively. The axial strain contours in a plot of the mobilized friction angle versus δ are shown in Fig. 6. In the post-peak region involving the development of the shear band(s), the area of the specimen was estimated based on an assumption of no change in the volumetric strain (Figs. 4a and 5a). Note that the anisotropy in the stress-strain relation is apparent at axial strains more than 0.01% (see Figs. 4b, 5b and 6) in that the specimen with δ=90 degrees exhibited the sfiffest response. However, the stiffness at extremely small strains was rather independent of δ. The limiting strains from which the anisotropy in stiffness appeared were somewhere in between 0.01% and 0.02% (Fig. 6), but it was obviously larger in OC specimens (Fig. 4b and 5b). Accordingly, a notion could be derived that the OC specimens were initially more stable in the structure of grain assembly than in the NC specimens. This effect of the overconsolidation seems to disappear rather quickly as the shear strain increases. Indeed no effect of the overconsolidation can be seen in the strength anisotropy (Fig. 3).

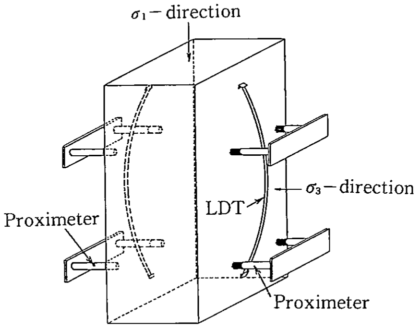

Fig. 2 Instrumentation of the plane strain specimen.

(c) Young's modulus at small strains

Examples of the stress-strain response as an unloading-reloading cycle was applied within the strains less than 0.006%, are shown in Fig. 7. Note that the value of E_{max}, which refers to the slope of the virgin loading with ε_a<0.001%, was practically the same as the Young's modulus associated with the reloading. This suggests that E_{max} is an elastic mudulus, and that it was scarcely affected by δ and the overconsolidation ratio.

Conclusions

1. The strength anisotropy of Silver Leighton Buzzard sand tested in the plane strain compresson apparatus was similar in tendency, but ϕ_{max}=arcsin {($\sigma_1'-\sigma_3'$)/($\sigma_1'+\sigma_3'$)} was smaller by about 4

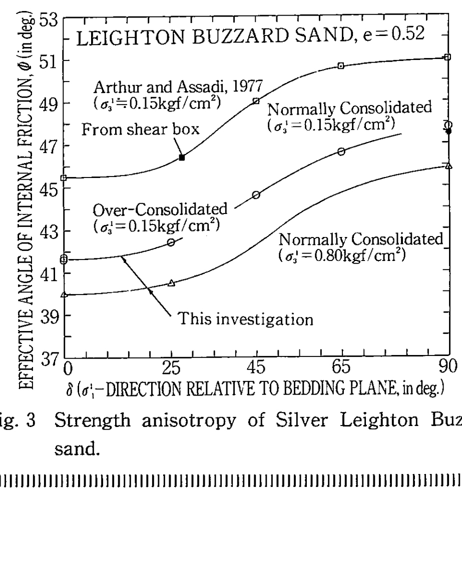

Fig. 3 Strength anisotropy of Silver Leighton Buzzard sand.

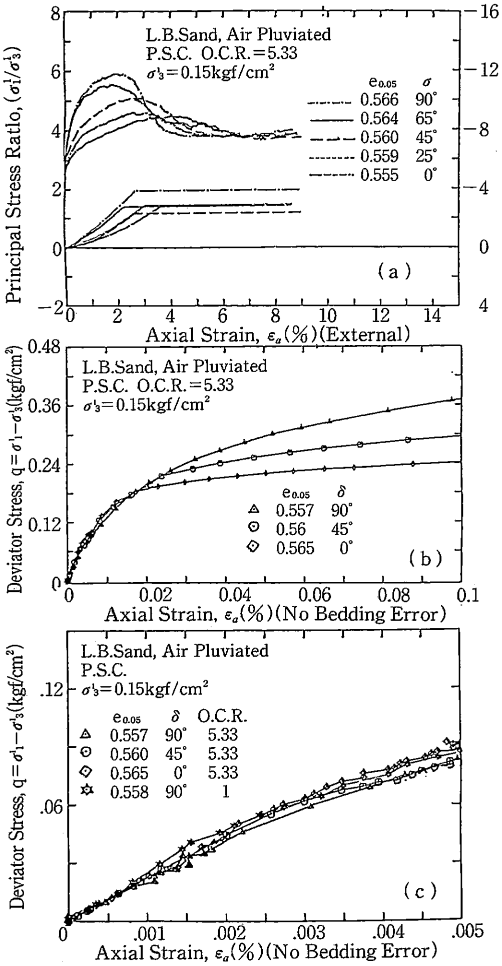

Fig. 4 Stress-strain curves for overconsolidated (OC) specimens.

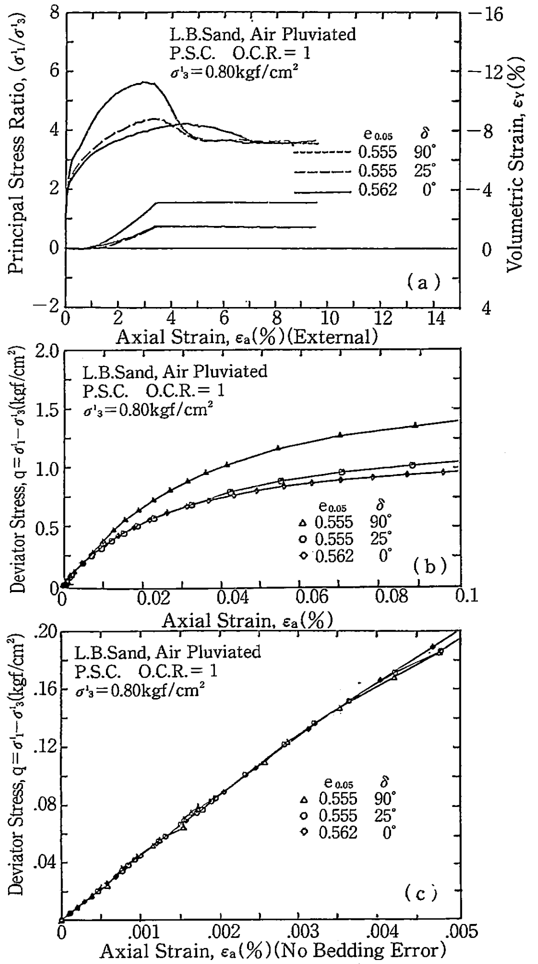

Fig. 5 Stress-strain curves for normally consolidated (NC) specimens.

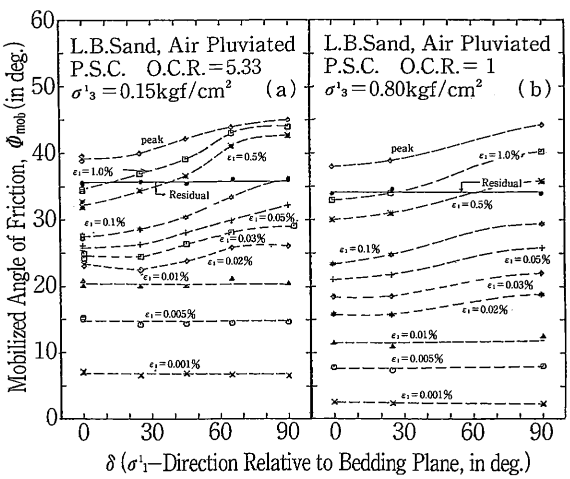

Fig. 6 Anisotropy in stiffness.

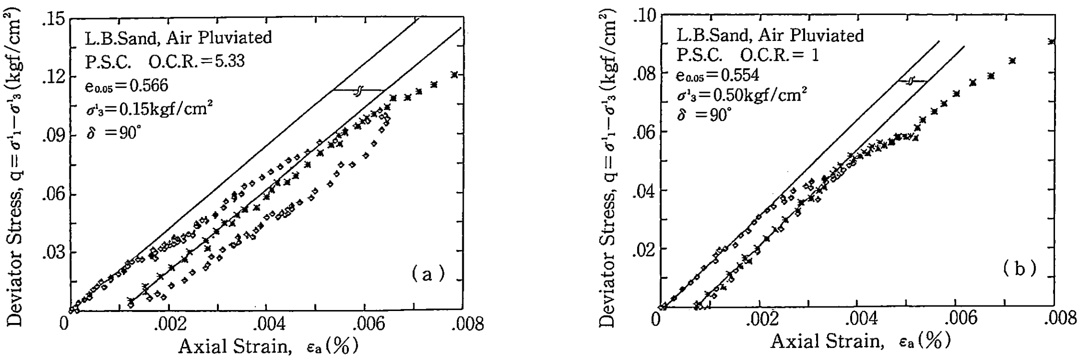

Fig. 7 Stiffnss at small strains.

degrees, compared to those of the DSC tests, irrespective of δ.

2 . The anisotropy in stiffness starts to appear at the axial strain somewhere between 0.01% and 0.02% below which the stress-strain relationship was isotropic.

3 . The maximum Yong's mudulus determined in the small strain region with the axial strain less than 0.001% was an elastic mudulus.

4 . The soil exhibited an isotropic, linear elastic response in the small strain region in which the elastic mudulus was also unaffected by the overconsolidaton ratio up to 5.33.

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