研 究 速 報
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Small Strain Behaviour of Sands in Plane Strain Compression
——Part I Development of instrumentation for small strain measurements——
平面ひずみ圧縮状態における砂の微小ひずみでの挙動
——その1　微小ひずみ測定装置の開発——

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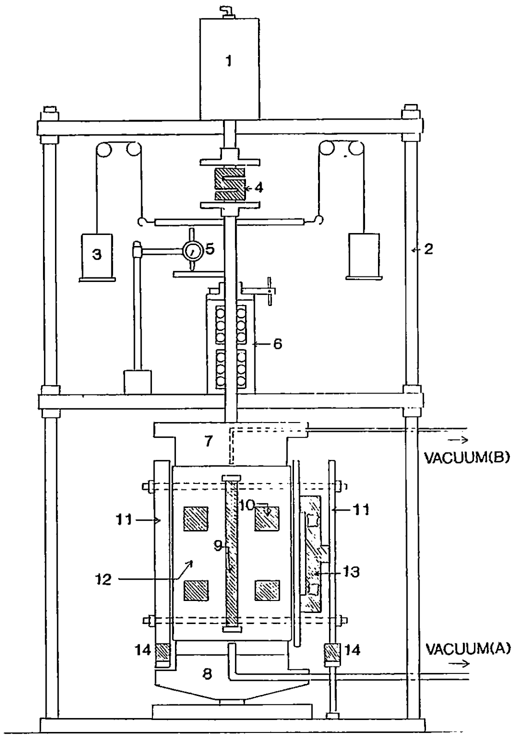
1. Introduction

A long-term research programme has been underway to study the stress-strain behaviour of soils in which the altering stiffness is investigated for a wide range of strain levels from 10^{-6} to 10^{0} (i.e; from elastic stiffness to that in shear bands). Amongst these, herein reported is the small strain behaviour of sands when subjected to shearing in plane strain compression.

2. Instrumentation for small strain measurements of plane strain specimens

The set-up of the apparatus for testing a vacuumed sample is shown in Fig. 1. Two components of principal strains, ε_1 and ε_3, of a rectangular specimen are measured using a couple of local deformation transducers (LDTs, Goto et al., 1990) and the lateral deformation measuring system (LDMS), respectively. The values of ε_1 and ε_3 are averages of each measurement.

The LDMS incorporates a total of eight proximity transducers by using which the lateral deformation is directly measured at four positions, each using two proximeters, within the central part of σ_3-planes (Figs. 2 and 3). Each set of four proximeters (①) is fixed onto a platen (③) which is in turn supported by a precise x-z stage (④). To have a wide space between these two sets of proximeters on mantling them in the proximity of the specimen, one of the two x-z stages is fixed onto a precise cross-roller way unit (⑧). Since a target of each proximeter is a thin aluminum foil stuck directly onto the membrane using a Dow grease (Fig. 3), a possible error in the measurements of ε_3 may be involved due to the indentation of the surface of specimen and to the non-



1. Bellofram cylinder for vertical load
2. Frame
3. Counter ballance
4. Load cell for vertical load
5. Dial gauge for vertical displacement
6. Bearing house for guide of loading piston
7. Cap
8. Pedestal
9. L.D.T.
10. Target for proximeter
11. Cofining plate
12. Specimen
13. Load cell for lateral force
14. Load cell for measuring friction between the confining plate and the specimen

Fig. 1　Set-up of plane strain compression apparatus used.

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coincidence in directions between the loading axis (σ_1 -axis) and the averaged specimen surface (Fig. 4). The z axis shown in Fig. 5 correspons to that of the x-z stage on which a set of four proximeters are fixed (Fig. 2). The error could be denoted as (a + b) for the averaged lateral deformation of ΔW (Fig. 4). In a correction of the error, the angle F which is the inclination between each z-axis and the direction of loading was determined using a dummy of which two planes a-d and b-c were strictly flat and parallel to

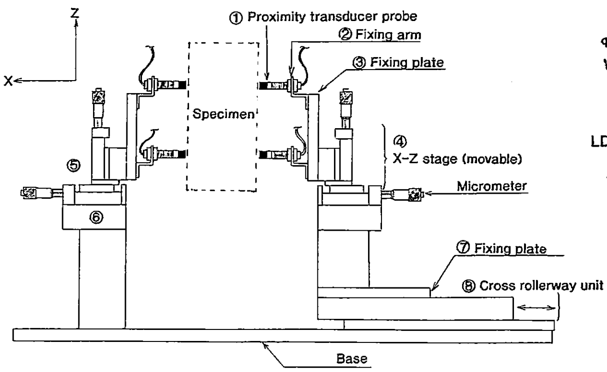


Fig. 2　Lateral deformation measuring system (LDMS).

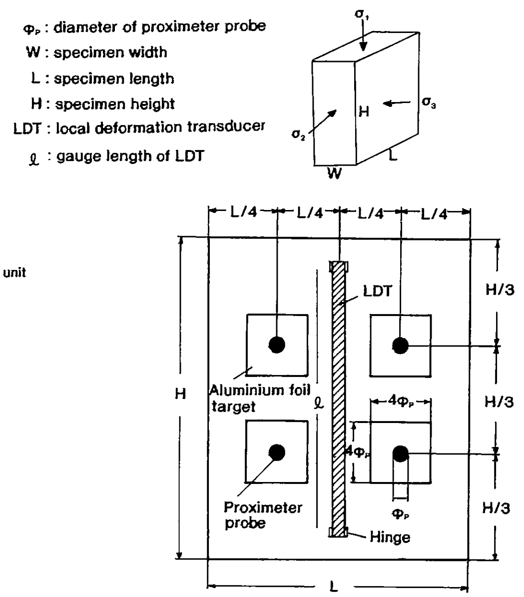


Fig. 3　Positionings of instrumentation for local strain measurements.

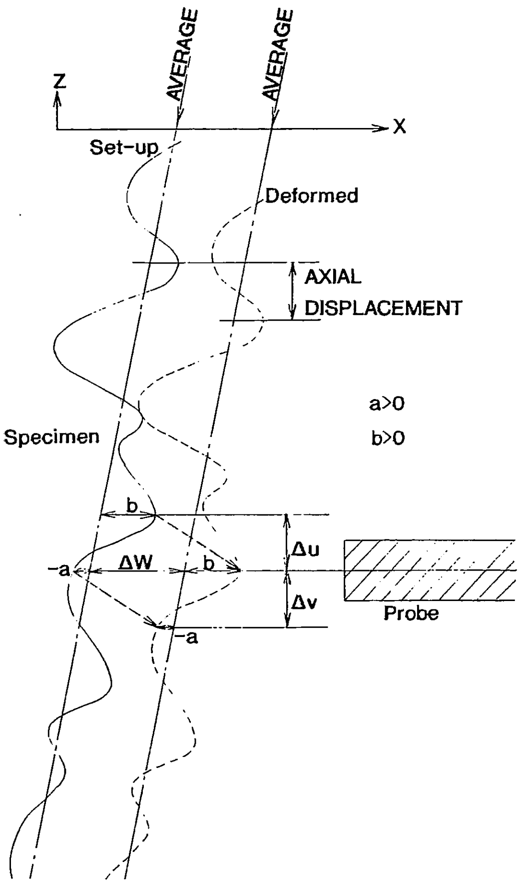


Fig. 4　Error involving the lateral strain measurement

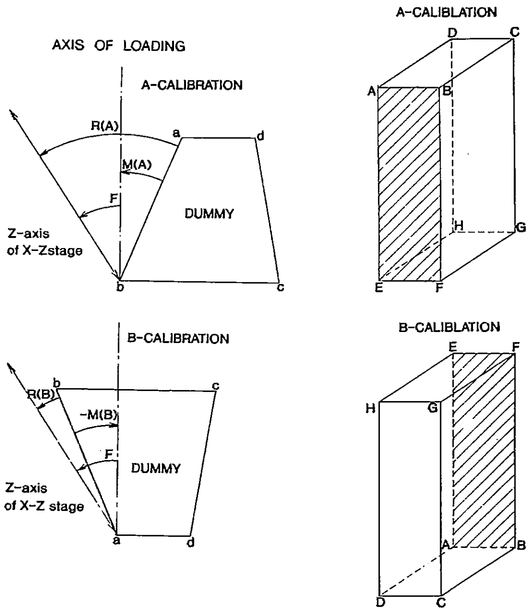


Fig. 5　Calibration to measure the angle between a z-axis of LDMS and the direction of loading.

each other (Fig. 5). By performing the calibrations as indicated in Fig. 5, the angle F can be derived as {R(A)+R(B)}/2. Prior to shearing in every test, the indentation of the specimen surface and its averaged inclination were scanned by moving a set of proximeters along the z-axis with a known value of angle F. Typical results for specimens of Toyoura sand (D_{50}=0.16mm) and Silver Leighton Buzzard (SLB) sand (D_{50}=0.62mm) are shown in Fig. 6, in which the error (i.e., the value of (a + b) for the two surfaces opposite to each other, which is to be corrected) was examined in relation to the estimated change in the average axial strain, ε_1, for the subsequent shear. Note that for both specimens, the error seems to be practically negligible and far smaller than the actual identation of the specimimen surface; i.e., 0.4μm and 0.5μm at ε_1= 1% for Toyoura and SLB sands, respectively. This could be because each proximeter sensors the distance between the probe surface and an area, not a point, of the target.

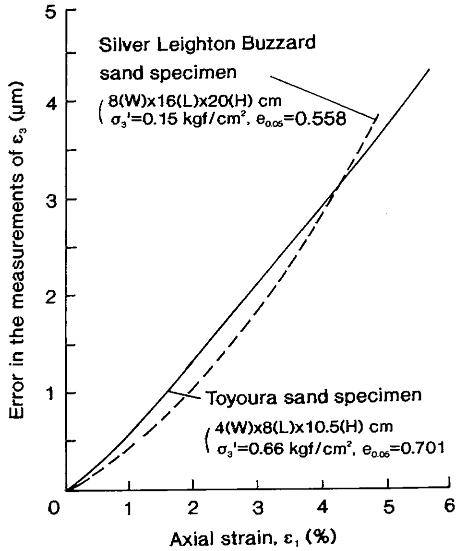
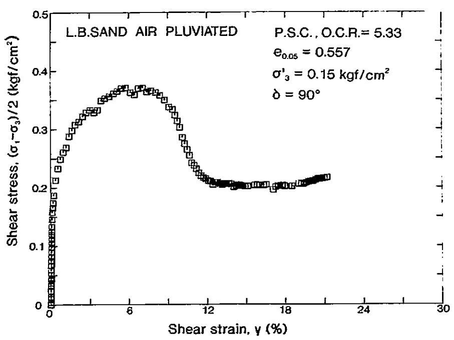
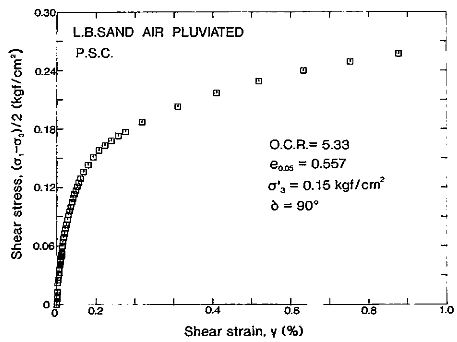


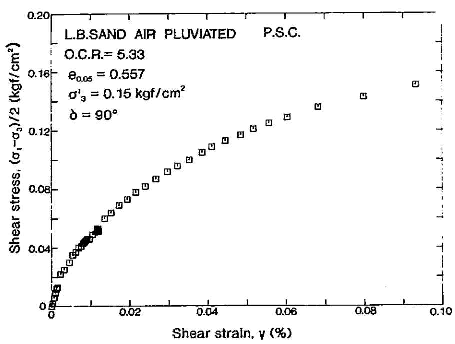
Fig. 6　Error in the measurement of displacement in the x-direction of LDMS in relation to the axial strain.



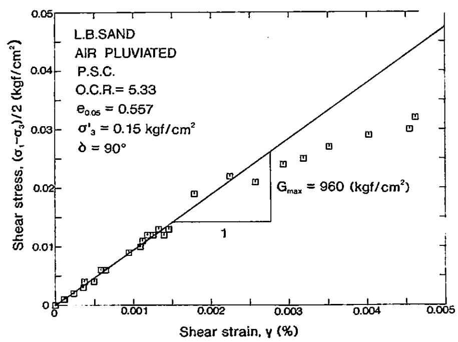
(a) maximum scale for γ equal to 30%,



(b) maximum scale for γ equal to 1%,

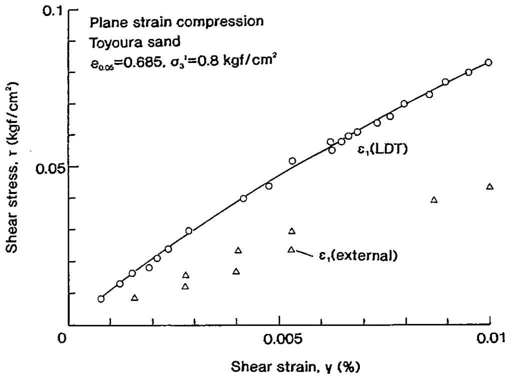


(c) maximum scale for γ equal to 0.1%,

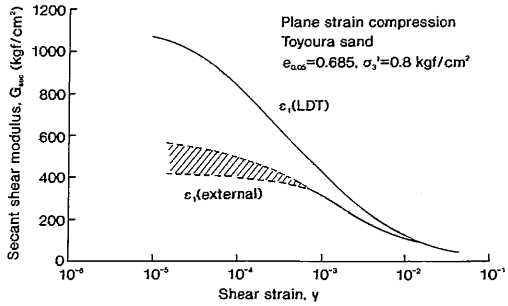


(d) maximum scale for γ equal to 0.005%.

Fig. 7　Stress-strain relatioship of a dense specimen of Silver Leighton Buzzard sand.



(a) stress-strain relationship at small strains,



(b) G_{sec} versus γ.

Fig. 8　Significance of local axial strain measurements for a loose Toyoura sand specimen,

Note that, as the confining pressure, σ_3', is kept constant, the strain measurements are utterly free from bedding error, and that, in the current system, the overall acccuracy of the strain measurements is 1×10^{-6} for both ε_1 and ε_3.

3. Typical results

Rectangular specimens of Toyoura sand (4cm in width, 8cm in length and 10.5cm in height) and of SLB sand (8cm×16cm×20cm) were monotonically sheared under drained conditions in plane strain compression by using a constant axial straining of 0.125% per minute. The air-pluviated specimens were sheared in an apparatus shown in Fig. 1, which was similar, except for the instrumentation, to that described in detail by Tatsuoka et al. (1986). A lubrication with a 0.3mm thick membrane together with a layer of 50μm thick grease was at both ends of the specimen.

The stress-strain relationship of a dense SLB sand specimen when sheared using a constant σ_3' is shown in Fig. 7. The measurements of local strains were terminated at γ equal to about 1% beyond which the condition of no increment of volumeric strain was postulated for the specimen having a shear band. It is demonstrated in Fig. 7 (d) that the maximum shear modulus, G_{max}, can be objectively determined for the initial linear portion of the stress-strain curve with γ less than about 2×10^{-5}.

A significance of the local axial strain measurement can be seen in Figs. 8 (a) and (b), in which the difference in the stiffness of a dense Toyoura sand specimen is examined in relation to shear strains, γ $(=\varepsilon_1-\varepsilon_3)$. In this test, the overall accuracy of the strain measurements was approximately 1×10^{-5}, since the LDT used incorporated only two active strain gauges (c.f., LDT with four active gauges used for the SLBS tests). Note that, due mainly to the effect of bedding error, the response based on the external axial strain, ε_1(external), was much softer than that measured using the LDTs, ε_1(LDT).

4. Concluding remarks

It has been demonstrated in plane strain compression tests performed on Toyoura sand and Silver Leighton Buzzard sand that the newly developed instrumentation for small strain measurements was capable of measuring altering stiffness of sands for a wide range of shear strain from 10^{-6} to 10^{-2}. The results of the stiffness and the stress-dilatancy relationship are described in the following paper.

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References

1) Goto, S., Tatsuoka, F., Shibuya, S. and Kim, Y-S. (1990): A simple gauge for local small strain measurements in the laboratory, submitted to Soils and Foundations.
2) Tatsuoka, F., Sakamoto, M., Kawamura, T. and Fukushima, S. (1986): Strength and deformation of sand in plane strain compression at extremely low pressures, Soils and Foundations, Vol. 26, No. 1, pp. 65-84.