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Micromechanics of Strain Localization: Effects of Boundary, Sample Size and Confining Pressure

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Introduction

The present study is an extension of the previous work on a microslip model for strain localization in sand deformation[1]. The model takes care of the interaction effects among microslips and produces the process of growth of individual microslips. It has been shown that strain localization as well as strain softening can be predicted by the microslip model. The effect of local dilatancy as an important mechanism in strain localization is also discussed. The formulation of the model however, was carried out using an infinite body to simplify the problem, neglecting the interaction effect between boundaries and microslips. Although this effect is not considered as a dominant factor, it may strongly influence the process of strain localization. In the present study, we introduce the boundary constraints of a finite specimen to microslips to study the boundary effect. The microslip model is then formulated by the method of pseudo-tractions as well as the boundary integral equation method. The obtained system of nonlinear equations are numerically solved under the boundary conditions for plane strain tests of sand.

Results and Discussion

Let us consider the response of the microslips inside the rectangular region in Fig.1, as the end displacement increases. Like those previous cases without boundary constraints, the growth of microslips is uniform throughout the whole field at the early stages of loading. After a certain load level, the growth of microslips gradually becomes localized in an inclined region in the upper corner of the specimen. Microslip softening occurs after the peak load, and strain localization proceeds rapidly under decreasing end displacement.

The shear band pattern developed with boundary constraints requires a special attention. Despite symmetry in arranging the initial defects, localization occurs in the upper corner of the specimen, and the shear band does not possess any symmetry with respect to the specimen shape. With the same arrangement of initial defects, however, localization occurs in the diagonal region without boundary constraints. The asymmetry in the shear band is thought to be caused by the fact that one of the nodes of the boundary elements must be restrained horizontally in order to prevent horizontal movement. In other words, imposing boundary constraints to microslips brings certain non-homogeneous effect on microslips through their interactions with boundary elements. Changing the position of the fixed node also affects the growth of the microslips inside the shear band. The shear bands with boundary constraints compare well with those observed in experiments, which usually are not formed in the diagonal region of the specimen; The degree of non-symmetry depends on individual experiments.

Size effect on the deformation and strength characteristics of materials is of engineering importance. In triaxial compression tests of sand, it is found that the post-peak reduction in stress is more significant in large samples than in small samples. The same trend is also found in the localization process of microslip growth. Let us consider a square-shape specimen. While the density of microslips is kept constant, the specimen size is increased and the corresponding localization process is traced. Illustrated in Fig.2 are the relationships between the stress ratio and the average microslip length inside each shear band. It shows that the post-peak decrease in stress becomes more apparent as the specimen size is increased, together with a slightly decreasing trend in the peak load. The mechanism behind this size effect is not clear at present, and a further study on the microslip interactions is considered a key point. Although it is not dealt with here, the effect of sample slenderness on strain localization can also be predicted with the present model.

The dependence of the deformation characteristics on the confining pressure has also been observed in sample tests on sand. In the microslip model, quantities with stress dimension are normalized with σ_3. The dependence of the results on the value of σ_3, in the sense that we obtain different values of $(\sigma_1/\sigma_3)_c$ for example, originates only from the normalized dilatancy coefficient $\hat{\alpha}_d = \alpha_d \cdot a_0/|\sigma_3|$. Note that $\hat{\alpha}_d$ decreases with increasing $|\sigma_3|$.

The effect of increasing the confining pressure on the response behavior of microslips is illustrated in Fig.3 for two different values of $\hat{\alpha}_d$, which correspond to two different confining pressures. With increasing confining pressure, the value of the critical stress ratio $(\sigma_1/\sigma_3)_c$ decreases and the lengths of the microslips inside the shear band increase. These features agree with the experimental observations mentioned above. This discussion on increasing confining pressure once more illustrates the important effect of local dilatancy on the main characteristics of sand deformation.

Conclusion

Through example studies the problem of strain localization and strain softening has been further discussed, with a special attention to the effect of boundary constraints. The boundary effect is found to cause the asymmetry of the shear bands, which is often observed in strain localization of sand. In addition to the above study, we have also discussed the effects of sample size and confining pressure on strain localization. It is shown that the main deformation characteristics of sand under increasing sample size and confining pressure can be predicted by the microslip model.

Reference

[1] Shi Zihai and H. Horii, Mechanics of Materials; accepted.

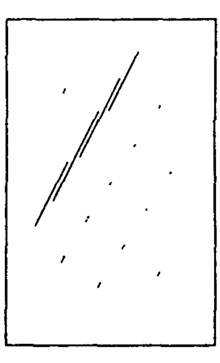

Fig.1 Formation of a Shear Band with Boundary Constraints

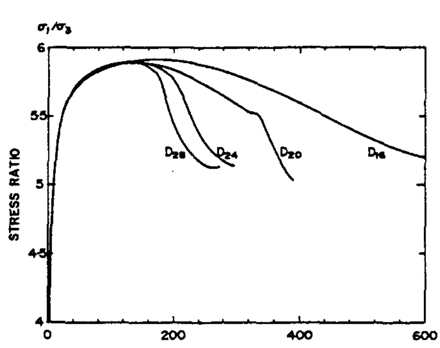

Fig.2 Size Effect on Localization of Microslip Growth(D is the non-dimensionalized sample size.)

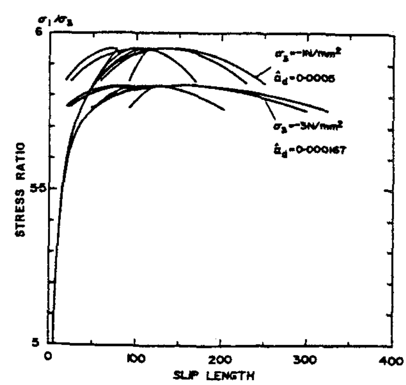

Fig.3 Effect of Confining Pressure on Strain Localization