Mechanics and Foundations Division, ASCE, Vol. 91, No. SM 4, Proc. Paper 4395, July, pp. 67-75.
17) Kovacs, W. D., Evans, J. C. and Griffith, A. H. (1974): "A comparative investigation of the Mobile Drilling Company's manually operated safety driver with the standard cathead with manila rope for the performance of the standard penetration test," Research Report, School of Civil Engineering, Purdue University (in preparation).
18) Mooney, H. M. (1974): "Seismic shear waves in engineering," Journal of the Geotechnical Engineering Division, ASCE, Vol. 100, No. GT 8, August, Proc. Paper 10745, pp. 905-933.
19) Peck, R. B., Hanson, W. E. and Thornburn, T. H. (1974): Foundation Engineering, Second edition, John Wiley & Sons Inc., New York, p. 115.
20) Schmertmann, J. H. (1974): "Penetration testing in USA," State of the Art Report, Proceedings, European Symposium on Penetration Testing, Stockholm, pp. 217-218.
21) Stokoe, K. H., II and Woods, R. D. (1972): "In situ shear wave velocity by cross-hole method," Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 98, No. SM 5, May, Proc. Paper 8904, pp. 443-460.
22) Woods, R. D. (1974): Private communication.

A MICROSCOPIC STUDY ON SHEAR MECHANISM OF GRANULAR MATERIALS*

Discussion by MASANOBU ODA**

The writer would like to comment on Matsuoka's approach to the granular mechanics under the following two headings:

Integration of Eq. (19)

By considering the microscopic mechanism of dilatancy of granular material, Matsuoka obtained the following equation (Eq. (19)):

$$\frac{\Delta L/L}{\Delta\theta} \cong \frac{d\varepsilon_N}{d\gamma} \cong \frac{d\varepsilon_N}{d\bar{\theta}} = -\tan\bar{\theta} \tag{19}$$

By integrating Eq. (19), the dilatancy $\varepsilon_N(=\varepsilon_1+\varepsilon_3)$ was represented absolutely by the change of the mean value of θ, irrespective of other experimental conditions such as void ratio and magnitude of applied shear strain. However, it seems to the present writer that the derivation of Eqs. (19) and (20) is based on some unacceptable assumptions. The reasons are summarized as follows:

1) The average angle of θ must increase from $\bar{\theta}_A$ to $\bar{\theta}_C$ with the increase of stress ratio from $(\tau/\sigma_N)_A$ to $(\tau/\sigma_N)_C$ during the strain hardening process up to the peak stress ratio (Fig. 13). The upword convex curve in Fig. 13 shows the relation given by Eq. (16) which represents the change of the total length L in the vertical direction during the progressive increase of $\bar{\theta}$ from $\bar{\theta}_A$ to $\bar{\theta}_C$. The length L extends at the earlier stage of stress-strain curve until $\bar{\theta}=0°$ and contracts at the later stage. It is obvious that Eq. (16) is inconsistent with the experimental fact that contraction occurs at the earlier stage and dilatation occurs at the later stage as shown in Fig. 14.

2) According to Eq. (13), the value of $\bar{\theta}$ used in tan $\bar{\theta}$ must be increased during the process of strain hardening at least up to the peak value of τ/σ_N; that is, monotonous increas

* By Hajime Matsuoka, Vol. 14, No. 1, Mar. 1974, pp. 29-43.

** Research Assistant, Department of Foundation Engineering, Faculty of Science and Engineering, Saitama University, Urawa, Saitama.

ing value. The value of $d\bar{\theta}\,(\cong d\gamma)$, however, must be always negative because sliding movements always result in the decrease of angle $\bar{\theta}$ as shown in Fig. 7. It is very important to understand that the monotonous increase of $\bar{\theta}$ used in Eq. (13) and in tan $\bar{\theta}$ during shear is mainly due to the progressive formation of new contacts so as to sustain the increasing stress ratio (τ/σ_N), not due to the mechanism of the decrease of $\bar{\theta}$ by climbing up or slipping down of upper particles on the lower ones. Therefore, we can conclude that $d\bar{\theta}$ in Eq. (19) which is always negative and nearly equal to $d\gamma$ has a quite different physical meaning from the differential of $\bar{\theta}$ used in Eq. (13) and also in tan θ which represents a differential increase of θ due to the progressive formation of new contacts. It is obvious that Eq. (19) can *never* be integrated.

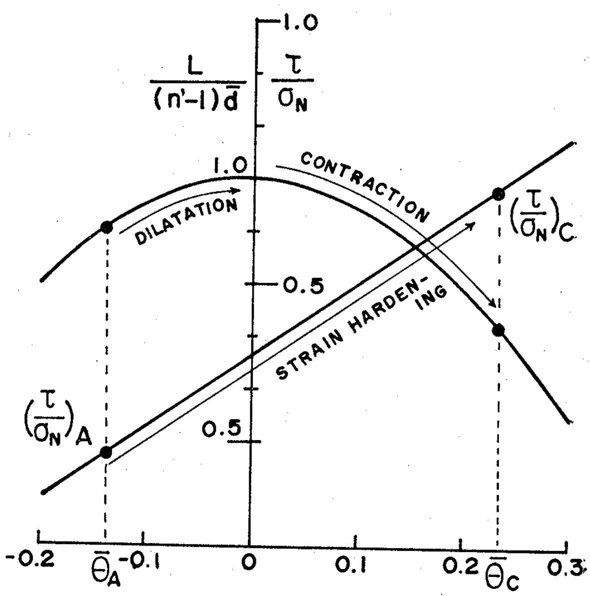

Fig. 13. Change of $\bar{\theta}$ mobilized stress ratio and length L given by Eq. (16) during the strain hardening process up to the peak stress ratio $(\tau/\sigma_N)_C$

If the differential of $\bar{\theta}$ used in Eq. (13) and in tan $\bar{\theta}$ is nearly equal to the differential of γ, some unacceptable relations are obtained. For example, since the relation of $d\bar{\theta}\cong d\gamma$ is equivalent to the relation of $\bar{\theta}\cong\gamma+c$, we get the linear relation between γ and τ/σ_N as follows:

$$\frac{\tau}{\sigma_N}\cong\lambda\gamma+(\lambda\mu+c) \tag{28}$$

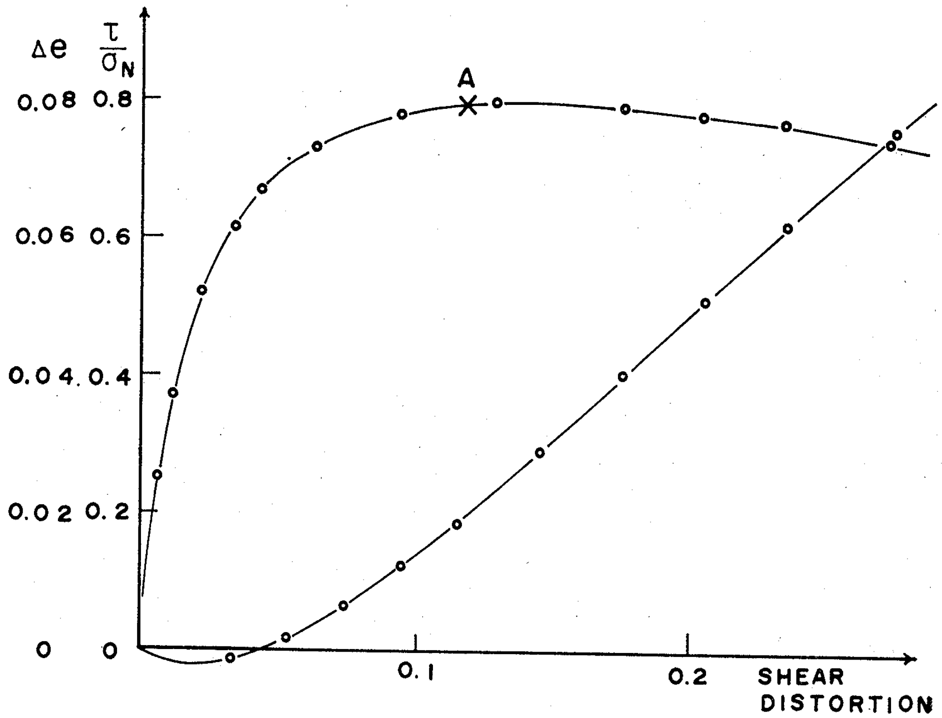

Fig. 14. Typical curves showing relations between stress ratio, shear distortion and change of void ratio in simple shear test of granular soil (Cole, 1967)

3) Eq. (20), if it is correct, means that the absolute value of dilatancy of granular material is determined only by the absolute value of $\bar{\theta}$ for a given initial value $\bar{\theta}_0$.

Now consider a usual stress-strain-volume change curve in a simple shear test of sand by Cole (1967) (Fig. 14). A point A in this figure shows the condition just prior to the peak value of τ/σ_N. At this condition, the relation $\Delta(\tau/\sigma_N)/\Delta\gamma\cong 0$ is nearly satisfied.

According to Eq. (13), we get

$$\left(\frac{\Delta\left(\frac{\tau}{\sigma_N}\right)}{\Delta\gamma}\right)_{atA}=\lambda\left(\frac{\Delta\bar{\theta}}{\Delta\gamma}\right)\cong 0 \tag{29}$$

Eq. (29) means that $\Delta\bar{\theta}/\Delta\gamma$ at the point A must be equal to zero because of $\lambda\neq 0$. This is quite incompatible with Matsuoka's assumption $d\bar{\theta}\cong d\gamma$. According to Eqs. (20) and (29), we get

$$\left(\frac{\Delta\varepsilon_N}{\Delta\gamma}\right)_{atA}=0 \tag{31}$$

Eq. (31) is inconsistent not only with Eq. (19) but also with the experimental fact that the remarkable dilatancy is usually observed at the condition of A just prior to the peak of τ/σ_N (Fig. 14).

Therefore, Matsuoka's consideration that the notation $\bar{\theta}$ used in $d\bar{\theta}$ (Eq. (19)) has the same physical meaning as the notation $\bar{\theta}$ used in tan $\bar{\theta}$ cannot be accepted.

Granular Model Accepted by Matsuoka

Matsuoka tried to explain the difference of the stress-strain characteristics between a loosely packed sand and a densely packed sand. In interpreting the reason why the loosely packed sand has no obvious peak in the stress-strain curve, he assumed progressive change of frequency distribution of θ during shear as shown in Fig. 12-(b). The granular model given by Matsuoka (Fig. 12-(b)) seems to be inadequate to show the strain hardening process of the loosely packed sand, because the progressive change of frequency distribution of θ from ① representing the initial state to ② in Fig. 12-(b), according to Eq. (13), is the same meaning as the process of strain softening. The strain softening stage cannot be detected in the stress-strain curve of the loosely packed sand.

Acknowledgement

The writer wishes to express his sincere gratitude to Prof. Y. Seki of the Saitama University for his critical reading of this manuscript.

Reference

15) Cole, E. R. L. (1967): "The behaviour of soils in the simple shear apparatus," Ph. D. Thesis, University of Cambridge.

A MICROSCOPIC STUDY ON SHEAR MECHANISM OF GRANULAR MATERIALS*

Discussion by Junichi Konishi**

The writer wishes to comment on the author's assumptions under two headings:

* By Hajime Matsuoka, Vol. 14, No. 1, Mar. 1974, pp. 29-43.
** Lecturer, Department of Civil Engineering, Shinshu University, Wakasato, Nagano.