Evolution of Fabric in the Shearing Process Based on Micromechanics

Homayoun Shaverdi[1], Mohd. Raihan Taha[1], and Farzin Kalantary[2]

[1] Department of Civil and Structure Engineering, University Kebangsaan Malaysia (UKM)
homayoun_shaverdi@yahoo.com, profraihan@gmail.com
[2] Department of geotechnical engineering, Khaje Nasir Toosi University of Technology
fz_kalantary@yahoo.co.uk

Abstract. In this paper a new formulation is presented to encompass the induced anisotropy during shear deformation in granular mass. The fabric anisotropy is affected by a number of parameters such as the mobilized stress ratio, internal friction angle, and the state of fabric. Non-coaxiality between stress and fabric tensor is included in this equation. This proposed formulation is derived by considering the interaction of particles across a potential sliding plane at micro-level. It is further developed to incorporate the initial fabric anisotropy. The changes of fabric in the presence of inherent anisotropy will be predicted by these equations. Verifying of the formulation is presented with numerical simulations and experimental tests.

Keywords: induced anisotropy, inherent anisotropy, degree of anisotropy, micromechanic, granular materials.

1 Introduction

Micromechanical characteristics (or fabric) of the granular materials have a great effect on the behavior of their shearing mechanism (e.g., [1-4]). The effect of fabric on the shearing mechanism has been attributed to two types of anisotropy i.e., inherent anisotropy and induced anisotropy. These two types of anisotropy first were known by Casagerande & Carillo [5]. The inherent anisotropy was established through the sedimentation of non-spherical particles and were measured based on the apparent long axes. Induced anisotropy is a result of applied shear loads and formation of a new structure in the contact normals to resist against these loads. To quantify the induced anisotropy, many attempts have been done (e.g., [2,6,7-9]). Using an assembly of irregular discs Biarez & Wiendieck [6] performed a biaxial compression test. They have found that the contact normals tend to concentrate parallel to the direction of the maximum compression. Oda [1] also, observed a similar behavior for natural sands in triaxial

Q. Yang et al. (Eds.): Constitutive Modeling of Geomaterials, SSGG, pp. 469–475.
springerlink.com

compression test. Biarez & Wiendieck [6] approximated the distribution of the contact normals by an ellipse where the principal axes of ellipse agree well with principal stress axes. Matsuoka & Geka [3] used a triangle as an approximation for the distribution of the contact normals. Using distinct element method (DEM) Rothenburg & Bathurst [7] showed that this distribution of the contact normals can be represented by a peanut-shaped function. Arthur et al. [10] and Wan & Guo [9] used the ellipse that was prepared by Biarez & Wiendieck [6] to calculate the fabric tensor and its evolution. However, in this study we used the peanut-shaped function that has already been proposed by Rothenburg & Bathurst [7], but we developed it to direct the calculation of the fabric.

2 Quantifying Fabric Anisotropy in the Hardening Process

Hardening in the granular materials is attributed to the changes of contact normals or induced fabric anisotropy ([8,11]). The Creation of new column-like rows in the granular mass is a result of unevenly transmission of the axial load in the vertical direction. To quantify the changes of the contact normals (or column-like rows) Kanatani [12] proposed the following equation:

$$F_{ij} = \int_0^{2\pi} n_i n_j E(\theta) d\theta \tag{1}$$

where n_i and n_j are the directions of the contact normals with respect to the Cartesian components X and Y respectively; $E(\theta)$ implies the contact normals distribution. The equation proposed by Rothenburg & Bathurst [7] to show the contact normals distribution is as follows:

$$E(\theta) = (1/2\pi)(1 + \alpha \cos 2(\theta - \theta_f)) \tag{2}$$

where α is the degree of anisotropy and θ_f is the major principal direction of the fabric tensor. The ratio between the major principal value F_1 and the minor principal value, F_3 of the fabric tensor can be presented as follows:

$$\left(\frac{F_1}{F_3}\right)_{ind} = \frac{1 + (1/2)\alpha \cos 2(\theta_\sigma - \theta_f)}{1 - (1/2)\alpha \cos 2(\theta_\sigma - \theta_f)} \tag{3}$$

where θ_σ is the major principal direction of the compressive stress. The parameters α and θ_f were obtained from the equations proposed by Taha & Shaverdi [13]. These equations are not presented here due to the limitation of the space and presented elsewhere. The magnitude of anisotropy α obtained is based on the micro-level analysis, and to calculate this parameter, all the main factors such as the ratio of shear to normal stress, the interparticle mobilized friction angle and the non-coaxiality between the stress and the fabric were taken into account.

Oda [8] also, presented a general function to calculate fabric anisotropy but he did not explicitly proposed an applicable equation in which the relations between the main factors are known.

3 Inherent Anisotropy

A numerous experimental data show that the shear strength in the granular materials depends on the inherent anisotropy (e.g., [1,2,4,11,14,15]). This is due to the fact that non-spherical particles are sedimented nearly parallel to the horizontal surface under the gravitational force. Inherent anisotropy remains near to unchanged during plastic shear deformation up to failure ([8]). Although Roscoe & Schofield [16] and Oda [17] observed that non-spherical particles tend to be limited rotation perpendiculars to the direction of a maximum principal stress (compression). To quantify the inherent anisotropy by the particle orientation a tensor $(F_{ij})_{inh}$ is introduced as follows:

$$(F_{ij})_{inh} = \int_{\Omega} m_i m_j E(m) d\Omega \qquad (4)$$

where m_i and m_j are the inclinations of the apparent long axes of particle m with respect to the Cartesian components X and Y respectively; $E(m)$ is the distribution function of particles, Ω is 4π for three dimensions (3D) and 2π for 2D problems.

4 Shearing in the Presence of Inherent Anisotropy (Combination of Inherent and Induced Anisotropy)

When a sample has a non-coaxiality between the stress and the particle deposition (inherent anisotropy) undergoes shearing, the contact normals rotate to concentrate in the maximum compression direction, hence we have both inherent and induced anisotropy. In this case, the ratio of F_1 / F_3 is obtained from the following equation:

$$(F_1 / F_3) = (F_1 / F_3)_{inh} . (F_1 / F_3)_{ind} \qquad (5)$$

The above ratio (F_1 / F_3) must be used in the constitutive modeling. The parameter $(F_1 / F_3)_{ind}$ changes with the shearing process because α and θ_f change with the external shear load. The above equation shows the evolution of the fabric in the shearing process in the granular mass. Verification with the numerical simulation and the experimental test show the validity of the above equation.

4.1 Verification with Numerical Simulation

Using numerical simulation Guo [18] shows the evolution of principal fabric ratio F_1 / F_3 and the rotation of principal fabric direction of Ottawa sand with $e_\circ = 0.65$ and $(F_1 / F_3)_{inh} = 1.33$, for two bedding angles, $\beta = 30^\circ$ and 60° at the same confining stress of $\sigma_3 = 200 kg / cm^2$ in triaxial compression tests. In Fig.1 and Fig.2 these simulations are shown. By applying equation (5), we can predict and simulate this fabric evolution.

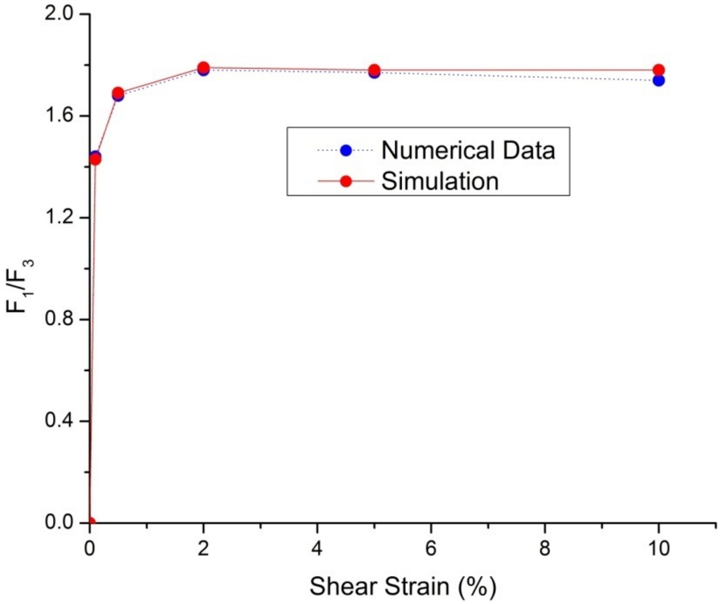

Fig. 1. Compares numerical simulation and the proposed equation for β =30^0, (Data from Guo [18])

4.2 Verification with Experimental Test

Oda [17] conducted some experimental tests to study the mechanism of fabric changes in sands by triaxial compression tests. He used uniform sand which was composed of quartz and feldspar grains with rounded to sub-rounded shapes. The size of these grains varies from 0.84mm to 1.19mm. He considered the ratio S_z / S_x as a fabric characteristic of anisotropic granular sand. This ratio is the same as the ratio F_1 / F_3 that was used in this study. The comparison between the magnitudes obtained from the experimental test and the calculation by using equation (5) reveals the validity of these formulations. The comparison between simulation and experimental tests are shown in Fig. 3 and Fig. 4.

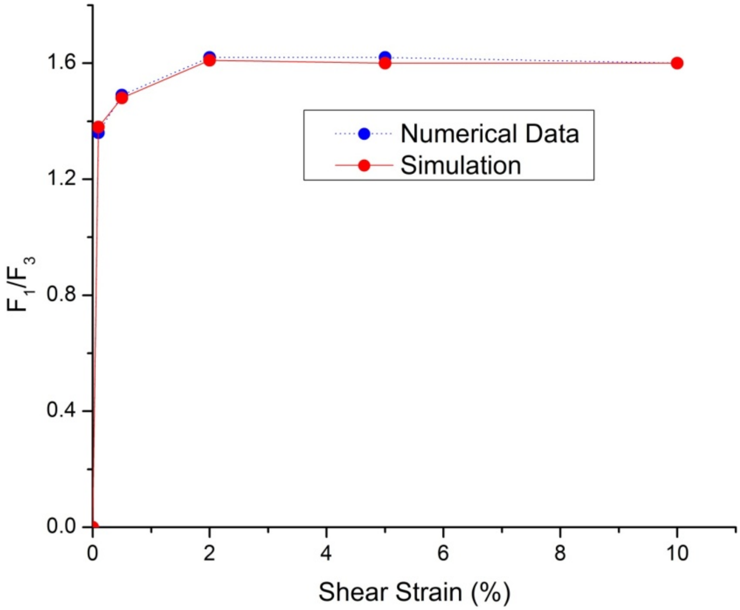

Fig. 2. Compares numerical simulation and the proposed equation for $\beta=60^0$, (Data from Guo [18])

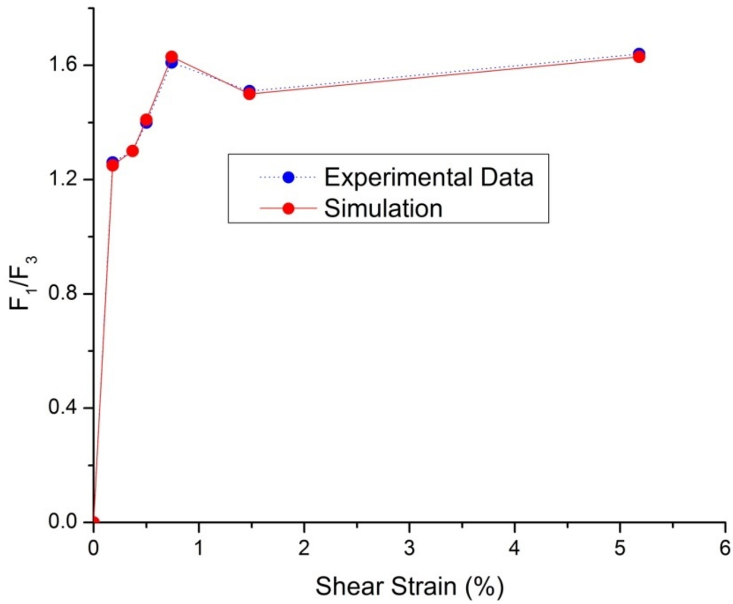

Fig. 3. Compares experimental test and the proposed equation for tapping method, (Data from Oda (1972a))

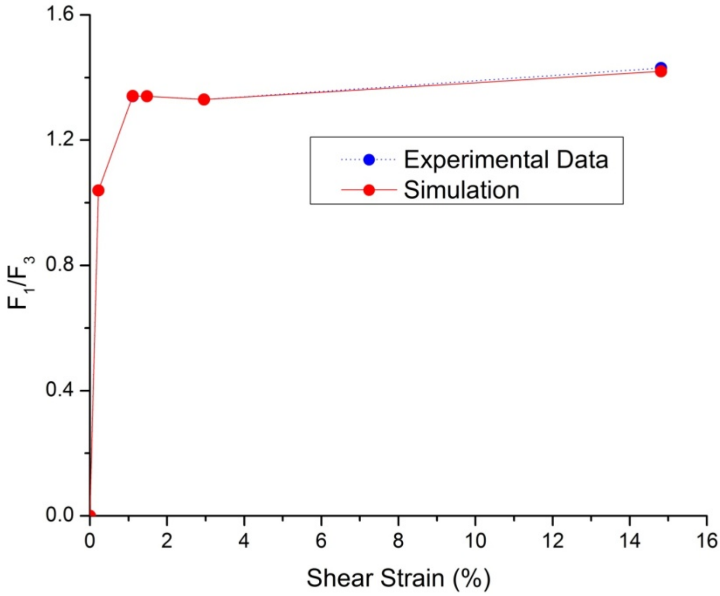

Fig. 4. Compares experimental test and the proposed equation for plunging method, (Data from Oda (1972a))

5 Conclusion

The equation presented can predict the evolution of the contact nromals during shear deformation in the granular mass. The mobilized stress ratio τ / σ on the spatial mobilized plane (SMP), the internal friction angle $\phi_{\mu mob}$, and the non-coaxiality between stress and fabric are the main factors that affect the evolution of fabric ([8]). These parameters were included in the equation to calculate the evolution of fabric. The effect of inherent anisotropy also, was included to account this element on the evolution of the contact normals. This equation was compared with numerical simulations and experimental tests to show its validity.

References

[1] Oda, M.: Initial fabrics and their relations to mechanical properties of granular materials. Soils and Foundations 12(1), 17–36 (1972a)
[2] Matsuoka, H.: A microscopic study on shear mechanism of granular materials. Soils and Foundations 14(1), 29–43 (1974)
[3] Matsuoka, H., Geka, H.: A stress-strain model for granular materials considering mechanism of fabric change. Soils and Foundations 23(2), 83–97 (1983)

[4] Yoshimine, M., Ishihara, K., Vargas, W.: Effects of principal stress direction and intermediate principal stress on undrained shear behavior of sand. Soils and Foundations 38(3), 179–188 (1998)
[5] Casagrande, A., Carillo, N.: Shear failure of anisotropic materials, J. Boston Soc. Cir. Engrs 31, 122–135 (1944)
[6] Biarez, J., Wiendieck, K.: La comparaison qualitative entre l'anisotropic mécanique et l'anisotropie de structure milieux pulverulents. C. R. Acad. Sci. 256, 1217–1220 (1963)
[7] Rothenburg, L., Bathurst, R.: Analytical study of induced anisotropy in idealized granular Materials. Geotechnique 39(4), 601–614 (1989)
[8] Oda, M.: Inherent and induced anisotropy in plasticity theory of granular soils. Mechanics of Materials 16(1-2), 35–45 (1993)
[9] Wan, R., Guo, P.: Effect of microstructure on undrained behaviour of sands. Canadian Geotechnical Journal 38(1), 16–28 (2001)
[10] Arthur, J.R.F., Koenders, M., Wong, R.K.S.: Anisotropy in particle contacts associated with shearing in granular media. Acta Mechanica 64(1), 19–29 (1986)
[11] Oda, M., Nemat-Nasser, S., Konishi, J.: Stress-induced anisotropy in granular mass. Soils and Foundations 25(3), 13 (1985)
[12] Kanatani, K.I.: Distribution of directional data and fabric tensors. International Journal of Engineering Science 22(2), 149–164 (1984)
[13] Taha, M.R., Shaverdi, H.: The evolution of fabric in the presence of the rotation of principal stress in the simple shear tests (submitted to published)
[14] Arthur, J.R.F., Menzies, B.K.: Inherent anisotropy in sands. Geotchnique 22(1), 115–128 (1972)
[15] Oda, M., Koishikawa, I., Higuchi, T.: Experimental study of anisotropic shear strength of sand by plane strain test. Soils and Foundations 18(1), 25–38 (1978)
[16] Roscoe, K.H., Schofield, A.N.: In stress-strain behavior of soils, Roscoe symposium memorial. Geotechnique 14(2), 143–167 (1964)
[17] Oda, M.: The mechanism of fabric changes during compressional deformation of sand. Soils and Foundations 12(1), 1–19 (1972b)
[18] Guo, P.: Modelling granular materials with respect to stress-dilatancy and fabric: A fundamental approach, civil engineering department. Alberta, University of Calgary. Phd. Thesis (2000)