Chapter 38

Post-liquefaction Cyclic Shear Strain: Phenomenon and Mechanism

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Abstract Under undrained cyclic loading, sand experiences decrease in effective stress, which can result in liquefaction. Test results show that large cyclic shear strain is generated at zero effective stress during undrained cyclic loading. This post-liquefaction shear strain has been observed to progressively increase in amplitude with increasing number of loading cycles until it eventually stabilizes at a bounded value. However, there has been no clear explanation on why and how this cyclic shear strain is generated. The fabric mechanism behind this post-liquefaction shear strain phenomenon is briefly discussed in this study.

38.1 The Basic Phenomenon

Under undrained cyclic loading, a sand sample experiences decrease in effective stress p , which can be large enough so that p approaches zero where the phenomenon of liquefaction takes place. The undrained stress path follows what is commonly known as the butterfly path shown in Fig. 38.1. Along with the reduction of p , some test results show that large cyclic shear strain is generated at a low but nontrivial shear stress values (Fig. 38.1a), but more recent evidence suggests that it is in fact generated at low enough shear stress values to be seen as zero (Fig. 38.1b, c). Zhang

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Fig. 38.1 Typical results from undrained cyclic laboratory and numerical tests on sand: (a) simple shear test on Nevada sand (Arulmoli et al. 1992); (b) cyclic torsional test on Toyoura sand (Chiaro et al. 2013); (c) 2D DEM biaxial test on circular particles (Wang et al. 2016)

and Wang (2012) referred to this shear strain as post-liquefaction shear strain γ_0 , considered to be generated at zero effective stress (i.e., liquefaction) state and has been observed to progressively increase in amplitude with increasing number of loading cycles until it eventually stabilizes at a bounded value. However, there has been no clear explanation on why, when and how this cyclic shear strain is generated. Without a clear understanding of this phenomenon, constitutive modelling would inevitably deviate from the actual behavior of the material, impeding the progress of validation of constitutive models by analyzing relevant BVP related to liquefaction as in the LEAP project.

38.2 Fabric Mechanism

Using DEM simulation, we were able to connect post-liquefaction shear deformation development to a new, theoretically measurable intrinsic fabric metric with a clear physical interpretation (Wang et al. 2016). This new fabric measurement, “Mean Neighboring Particle Distance” (*MNPD*), is the mean value over all particles of the “Neighboring Particle Distance” (*NPD*) as depicted in Fig. 38.2a, which is the mean surface-to-surface distance between a particle and its n closest neighbor particles,

Fig. 38.2 The concept of MNPd (Mean Neighboring Particle Distance) and its correlation with post-liquefaction shear strain: (a) illustration of the surface-to-surface distance between a particle and its three closest neighboring particles; (b) development of γ_0 and $MNPd_{max}$ in a typical DEM test; (c) correlation between γ_0 and $MNPd_{max}$ in each half loading cycle after initial liquefaction in 17 tests

with n being the number of contacts needed to support a stable load-bearing structure ($n = 3$ in 2D and 4 in 3D). $MNPd$ is formulated to capture a microstructural feature of granular materials that is closely related to deformation behavior in the post-liquefaction state by actually being a measure of “distance to establishing load-bearing contact” as opposed to a conventional measure of contact intensity, the coordination number. $MNPd$ ’s strong, unique correlation with γ_0 is evident from Fig. 38.2b, c. It has also been shown to influence the liquefaction resistance of sand (Wang et al. 2019). Therefore, it is expected that consideration of $MNPd$ can provide a promising path to incorporating the mechanism of the post-liquefaction cyclic shear strain phenomenon into a continuum constitutive framework for practical purposes.

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