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Influence of destructuration on elasto-plastic properties of dense gravel during cyclic shearing

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Introduction: In recent past, the deformation characteristics of dense gravels which fall in the category of hard soil is greatly considered by engineers, because of it's suitability for various important soil structures where a limited amount of displacement is allowed. The deformation characteristics of such geomaterials at small and intermediate strain levels, expressed in terms of elastic/elasto-plastic deformation stiffness are important parameters to evaluate structure movement and soil-structure interaction under working load conditions. This paper describes the results from drained cyclic triaxial tests on moderately to heavily compacted specimens of crushed calcareous stone denoted as Chiba gravel, and discuss the influences of destructuration on their elasto-plastic properties during cyclic shearing.

Test Procedure: Large rectangular prismatic specimens with dimensions of about 57 cm x 23 cm x 23 cm, prepared by manual compaction to a dry density range of 2.02 ~ 2.24 g/cm^3, were subjected to cyclic isotropic consolidation followed by large amplitude load-unload cycles of vertical stress while keeping a constant cell pressure under drained conditions (Fig. 1). At various stress level, small vertical cyclic loading was applied to evaluate equivalent elastic Young's modulus, E_{eq}. Strains were measured locally. No noticeable particle crushing by heavy compaction was observed. Refer to Balakrishnaiyer and Koseki (1998) for particle size distribution of the tested material and typical results from cyclic isotropic consolidation. The definition of vertical equivalent elastic Young's modulus E_{eq} and tangential modulus E_{tan} are given in Fig. 2.

Test Results & Discussion: The calculated E_{eq} values were corrected for a threshold single amplitude strain of 0.001% by using an empirical formula given by Flora et al. (1994), Jiang et al. (1997), which will be denoted as E_{eqc}. The deviation of E_{eqc} values evaluated during shearing from those estimated for the same vertical stress state during isotropic stress condition, which could be assumed to be values undamaged by shearing, may be a relevant index to represent the degree of damage to the soil structure (i.e., destructuration) by shearing. In relation to this, the E_{eqc} values were normalized by the corresponding values at the same stress level during isotropic consolidation (E^e) as assumed by;

$$E^e = E_O \cdot (\sigma_v / \sigma_O)^m \cdot f(e) \quad (1)$$

where σ_v is the current vertical stress and σ_O is a reference stress, set to 1.0 kPa in the present study. E_O and m are parameters evaluated based on results from isotropic consolidation and $f(e) = (2.17 - e)^2 / (1 + e)$, a function of void ratio (e), is an empirical formula (Hardin & Richard, 1963). Typical E_{eqc}/E^e and q/q_{max} relationships for moderately dense specimen and highly dense specimen during shearing with large amplitude unloading - reloading cycles are given in Figs. 3 and 4.

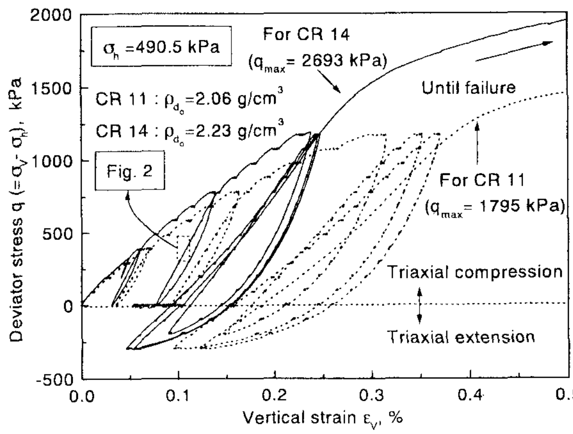

Fig. 1: Typical q and ε_V relationship during cyclic triaxial shearing for moderately and highly dense specimens.

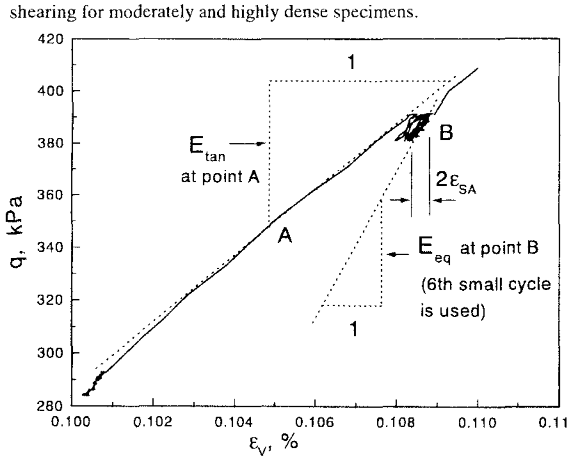

Fig. 2: Definitions for Young's moduli E_{eq} and E_{tan}.

Keywords: Gravel, Cyclic shearing, Destructuration, Triaxial test, Young's Modulus

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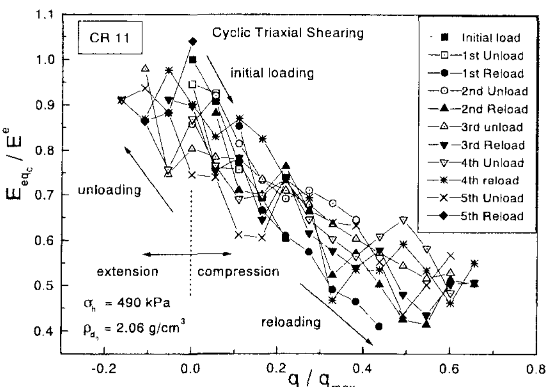

Fig. 3: Typical E_{eqc}/E^e and q/q_{max} relationship during cyclic shearing of moderately dense gravel.

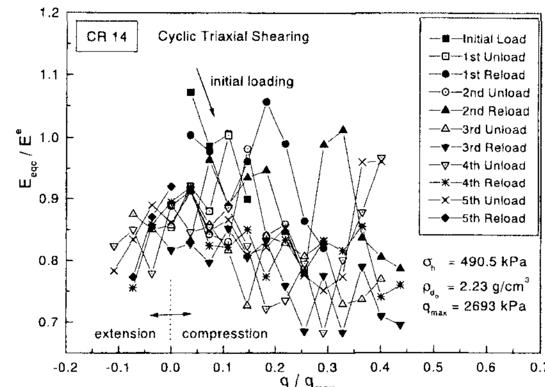

Fig. 4: Typical E_{eqc}/E^e and q/q_{max} relationship during cyclic shearing of highly dense gravel.

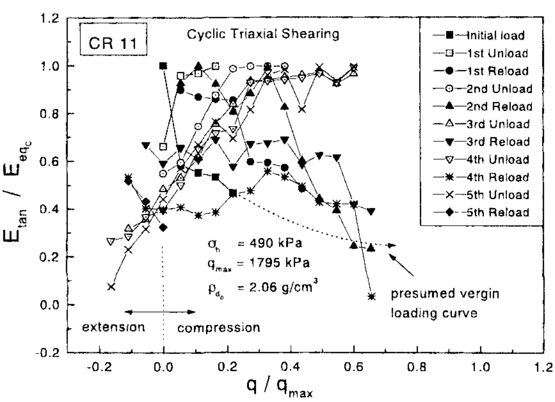

Fig. 5: Typical E_{tan}/E_{eqc} and q/q_{max} relationship during cyclic shearing of moderately dense gravel.

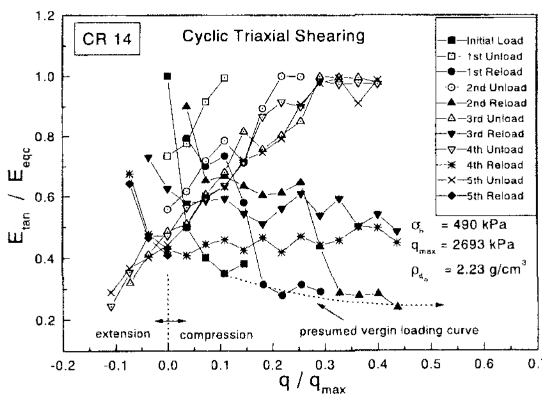

Fig. 6: Typical E_{tan}/E_{eqc} and q/q_{max} relationship during cyclic shearing of highly dense gravel.

During initial loading, the reduction in E_{eqc}/E^e was significant in both cases. The moderately dense one, however showed much larger damage than the highly dense one. During 1st unloading, the E_{eqc}/E^e values were increased with reducing q/q_{max} values in both cases, but they were not fully recovered to the values obtained during initial loading. Such cumulative reduction in the E_{eqc}/E^e values was observed during subsequent large unload-reload cycles. As an overall view, moderately dense specimens were observed with more damage ($E_{eqc}/E^e \sim 0.40$) compared to highly dense specimen ($E_{eqc}/E^e \sim 0.70$).

The ratio of E_{tan} to E_{eqc} shows the degree of plasticity, which may also be affected by destructuration by shearing. Typical E_{tan}/E_{eqc} and q/q_{max} relationship are given in Figs. 5 and 6. During loading or unloading a gradual reduction in E_{tan}/E_{eqc} was observed in both cases and a significant reduction was observed after the specimens were subjected to triaxial extension. As the q/q_{max} increases the E_{tan}/E_{eqc} values approaches to a value which could be the virgin loading curve as indicated by broken line in Figs. 5 and 6.

Conclusions: 1) The small strain elastic properties of dense gravel are significantly reduced during cyclic triaxial shearing possibly due to destructuration. The degree of destructuration is high in moderately dense specimen compared to highly dense one. 2) Triaxial extension history caused more reduction in E_{tan}/E_{eqc} values in both moderately and highly dense gravel.

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