Panel discussion: Effects of interparticle bonding on stiffness of geomaterials

Débat de spécialistes: Influence des liaisons entre particules sur la raideur des géomatériaux

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In many geotechnical engineering design works, it is very important to understand properly the stiffness change of the cited geomaterial against magnitude of the current shear strain or stress. The range of strain dealt with is wide as small as 0.0001% to the value at failure. Fig.1 shows stress-strain response in general in laboratory compression test. The E_{max} value refers to the elastic Young's modulus seen at very small strains in a plot of deviator stress, q, and axial strain, ε_a. The stress-strain relationship is linear up to the elastic-threshold strain, $(\varepsilon_a)_{EL}$ beyond which the stiffness varies with strain in a continuous manner up to the peak. In an attempt to characterize the stress-strain non-linearity, it is convenient for us to introduce reference strain, $(\varepsilon_a)_r$, which is the ratio of strength, Δq, to the initial stiffness, E_{max}. It should be mentioned that the $(\varepsilon_a)_r$ value does not show any significant variation for different geomaterials (Tatsuoka and Shibuya, 1992). When the stress-strain response is examined in terms of the normalized stress, $Y(=\Delta q/\Delta q_{max})$, and the normalized strain, $X(=\varepsilon_a/(\varepsilon_a)_r)$ the material showing perfectly linear stress-strain response fails at X=1. When comparing stiffness change of different geomaterials, it may be understood that the degree of stress-strain non-linearity becomes more significant as the tangent stiffness exhibits smaller value at any given stress of Y.

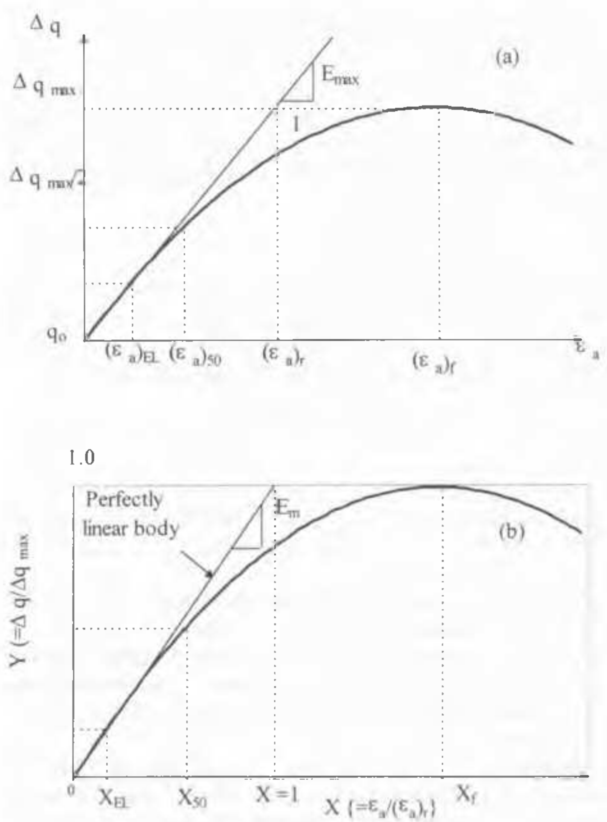
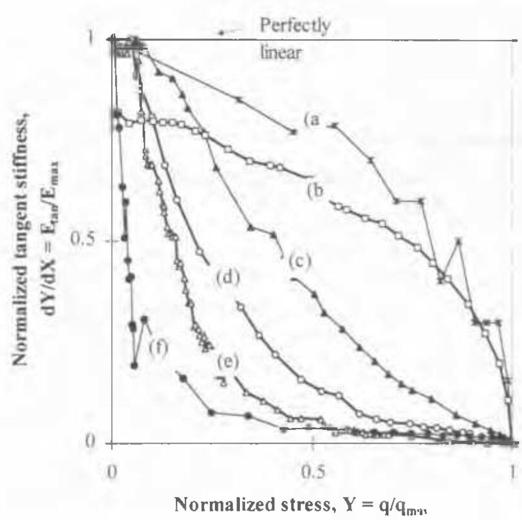


Fig.1 Representation of (a) actual stress-strain relationship and (b) normalized stress-strain relation

The variation of tangent Young's modulus, $E_{tan}(=dq/d\varepsilon_a)$, with stress for different geomaterials as subjected to monotonic shear in compression is shown in Fig.2. In common with the stress-strain relationship of all these materials, the dY/dX value is unity at the beginning of shear with Y=0, and the geomaterials fail at Y=1 by showing the dY/dX value of zero. It is also true that the dY/dX value remains at unity throughout shearing for an idealized material showing linear stress-strain relationship. It should be pointed out that the stress-strain non-linearity is more significant in the order of uncemented soils, sand and clay, cement-treated-sandy soils with cement content of 6% and 10%, natural sedimentary soft rock, and hard rock. These results may be understood such that the stress-strain relationship becomes more linear as the cementation or interparticle bonding of the geomaterial is more dominant. This is the very important aspect in this discusson.

Fig. 3 shows the results of a series of compression test performed on cement-treated sandy soil. The tests were performed in a triaxial apparatus recently developed at Hokkaido University (Shibuya et al., 1996). In this apparatus, a digital servo



(a) Oya tuff (Noma and Ishii, 1986); **(b)** Sagamihara mudstone (Ozawa et al.,1996); **(c)** Cement-treated sandy soil (cement content 10 % by weight); (Shibuya and Ozawa, 1996); **(d)** Cement-treated sandy soil (cement content 6 % by weight) (Shibuya and Ozawa, 1996); **(e)** Reconstituted clay (Shibuya et al., 1996); **(f)** Toyoura sand (e0=0.83) (Shibuya et al., 1991)

Fig. 2 Variation of tangent stiffness with stress for diferent geomaterials

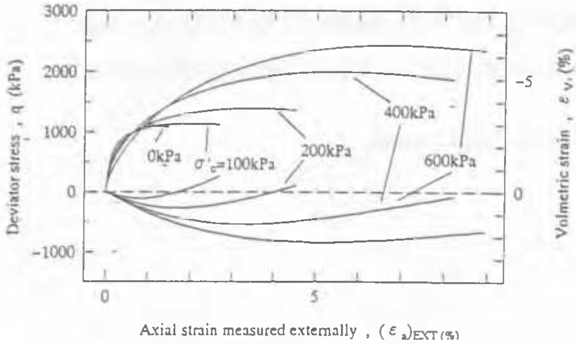


Fig.3 Stress-strain relationship of cemet-treated sandy soil in triaxial compression

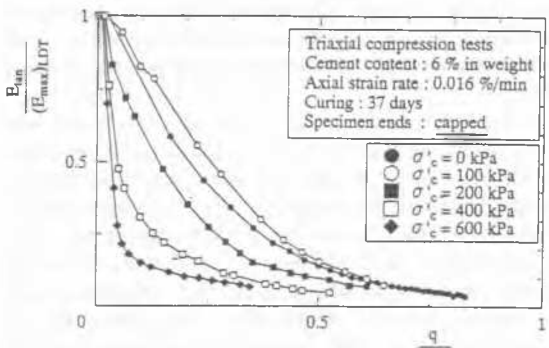
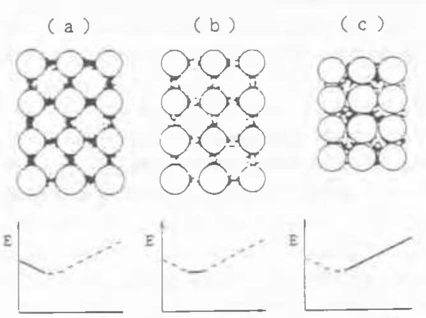


Fig.4 Effects of confining pressure on the relationship between E_{tan}/E_{max} and q/q_{max}



○ sand grain

■ cement suspention

Fig.5 Conceptual picture showing effect of confining pressure on E_{max} during consolidation

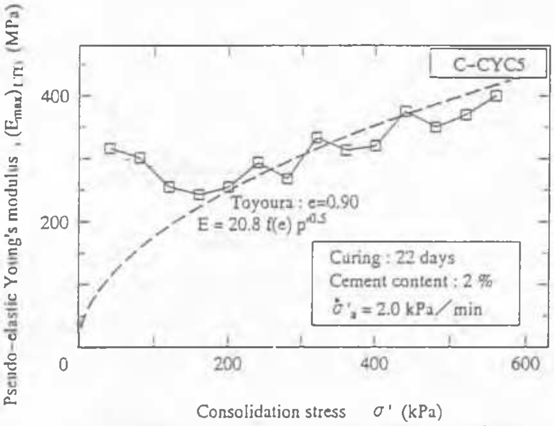


Fig. 6 Variation of E_{max} with confining pressure during consolidation

motor is employed in order to drive the loading piston. The axial deformation of the specimen was measured locally over the central portion. In so doing, bedding error at the specimen ends was successfully avoided in the measurement of axial deformation. The specimen ends are capped using gypsum. This technique has been proved effective in providing better uniformity of stress and strain in the relatively stiff sample. Identical specimens having the cement content of 6% were initially subjected to isotropic consolidation to different confining pressures, then sheared at a constant rate of axial straining (Shibuya and Ozawa, 1996). It can be seen that the overall stress-strain relationship was softer involved with more contractive response as the confining pressure increased.

Fig.4 shows the variation of the tangent stiffness normalized by the initial stiffness with Y. It is now clear that the stress-strain non-linearity became more significant as the confining pressure increased. It is reminded that this pattern of change in the tangent-stiffness and stress relationship resembles the pattern we have already seen for different geomaterials (see Fig.2). The relationship varies from the type of cemented geomaterials such as soft rock to the type of uncemented soils like clean sand and soft clay.

Fig.5 shows the variation of elastic Young's modulus of a specimen having weak cementation at the time of preparation when subjected to gradual increase in isotropic effective confining pressure. It is interesting to see that the variation of E_{max} with effective confining pressure may be described at three phases, E_{max} decreased in a gradual manner up to a certain level of confining pressure, then stayed more or less constant, and finally rejoined the similar relationship of uncementerd sand having the similar granular void ratio.

We interpret this characteristic behavior of the tangent stiffness-stress relationship that may be attributed to the continuos damage of interpartical bonding during consolidation, and also possibility during the subsequent shearing (Fig.6). In the first phase, the E_{max} stays constant against increase in the confining pressure, for which the damage of cementation occurs in an involving fashion. In this phase, the stiffness at very small strains may be governed predominantly by the cement suspension pad existing in between the soil particles. When the cementation breaks up, the relationship shows the pattern similar to that of uncemented sand, for which E_{max} increases exponentially with the increase in confining pressure.

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