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Modelling of Cyclic Stress-Strain Relationships of a Densely Compacted Gravel

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Introduction: The use of hyperbolic equation is very popular in modelling of a given highly non-linear stress-strain relation of soil or rock. Several attempts have been made in recent past by using different stress & strain parameters. Out of several proposals made so far, Tatsuoka & Shibuya (1991) have suggested a general hyperbolic equation (GHE), which can simulate a given stress-strain relation very well in a wide range of strain under working load conditions. From the above, the modelling of the monotonic loading curve, (i.e., the basic back borne curve) can be made. However, the modelling of the cyclic loading curve under unloading-reloading conditions is still in discussion among researchers. The well known Masing's 2^{nd} rule is found not always appropriate, and a modified method named as proportional rule has been proposed by Tatsuoka et al. (1997) and applied by Masuda (1998) for Toyora sand subjected to cyclic loading under plane strain condition. In this paper results of modelling of the densely compacted sandy gravel subjected to large vertical cyclic triaxial loading are presented.

Test Procedure: Two rectangular prismatic specimens of Chiba gravel with D_{max} of 40mm were prepared by manual compaction to high density (initial dry density ρ_{dO}=2.07 and 2.14 g/cm^3, initial water content ω_O=5.5%) and subjected initially to isotropic consolidation up to 883 kPa and then sheared under triaxial compression (i.e., $\sigma_V>\sigma_h$ denoted as TC) as well as triaxial extension ($\sigma_V<\sigma_h$, TE), while keeping horizontal stress (σ_h) constant at 883 kPa (Figs. 1 and 2). In test GT2, the initial loading started from TC to evaluate the back borne curve under TC, while in test GT3, it started from TE to evaluate the curve under TE. Several small vertical cyclic loading were applied at various stress levels to evaluate the equivalent elastic Young's modulus. An automated large scale triaxial apparatus was used, and the strains were measured locally by local deformation transducers (LDTs).

Test results & discussions: It is obvious from Fig.1 that the conventional q~ε_V relationship is not appropriate to find a mathematical modelling of unload-reload cycles based on the back borne curve because of the non-symmetry and also the change in the shape of the reloading parts. The relationship between $\sin(\phi)_{mob}$ [$=(\sigma_V-\sigma_h)/(\sigma_V+\sigma_h)$] and γ [$=\varepsilon_V-\varepsilon_h$] as shown in Fig.2 is better in terms of symmetry with TE and TC. In this study the $Y=\sin(\phi)_{mob}$ and $X=\gamma^P$ (irreversible shear strain obtained by subtracting elastic strain from total strain) relationship is considered for modelling the unloading-reloading portions. The back borne curve was fitted using the general hyperbolic equation [$Y=X/(1/C_1(X)+X/C_2(X))$] as suggested by Tatsuoka & Shibuya (1991). The cyclic loading portions were modelled in two ways; case-A) assuming symmetry of the back borne curves Y=f(X) under TC and TE for each test; and case-B) considering non-symmetry using the back borne curve of the other test to model the unloading portions.

Case-A) Assuming symmetry: Fig.2 shows the comparison of the experimental and modelled results for the unloading portions of test GT2. According to the proportional rule, the

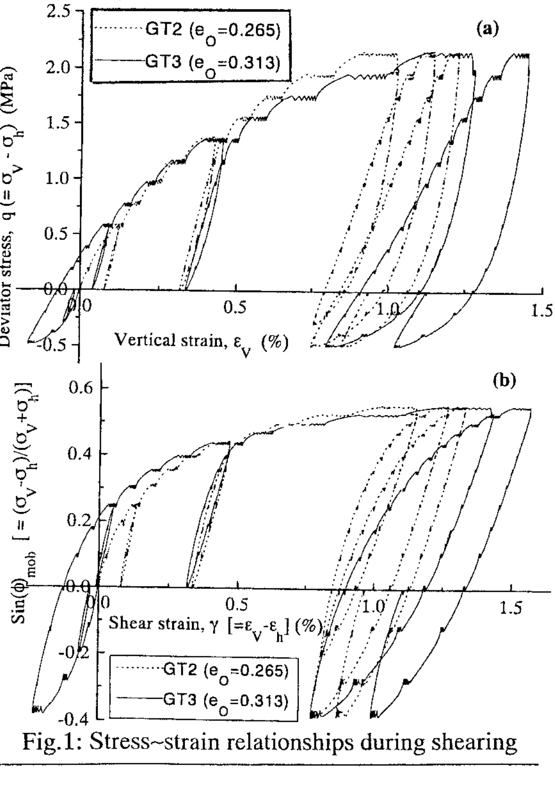

Fig.1: Stress~strain relationships during shearing

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n value assuming symmetry is always 2, so that the unloading curve starting from point A in the figure will merge the back borne curve at point B that is located on a straight line connecting point A and the origin. Refer to equations shown in Fig.2 for the definitions of n and the unloading curve Y=g(X). Under this assumption the proportional rule is equivalent to the Masing's 2nd rule. The results showed deviation from experimental data when moving from the starting point of unloading. Similar deviation was observed in Fig.3 for the results of test GT3.

Case-B) Considering non-symmetry: In Figs. 2 and 3 the modelled results considering non-symmetry are also compared with experimental results. The n values were evaluated so that the unloading curve will merge the back borne curve of the other specimen at point B', and they are generally not equal to 2. In the case of modelling GT2 the results seem to be better than those in case A, but it is not the case with GT3. Note that there was slight difference in the initial densities of two specimens, which was not considered in the modelling. In Fig. 4, the reloading portions are compared, and it could be seen that the reloading fittings by the proportional rule are better than those for unloading. The results of case-B shows better fitting than those of case-A.

Conclusions: The proportional rule assuming non-symmetry gave better results than assuming symmetry when modelling test GT2. However it was not the case in test GT3. It seems that the stress strain parameters need further modification in order to model the cyclic loading behavior properly.

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2) Tatsuoka et al (1997), "Characterizing the Pre-Failure Deformation Properties of Geomaterials", Theme lecture for the plenary session No.1, XIV IC on SMFE, Humburg, Sept. 1997, Balkema 2. 3) Masuda, T.(1998), "Study on the effects of pre-load on the deformation of excavated ground", Doctoral thesis, Univ. of Tokyo.

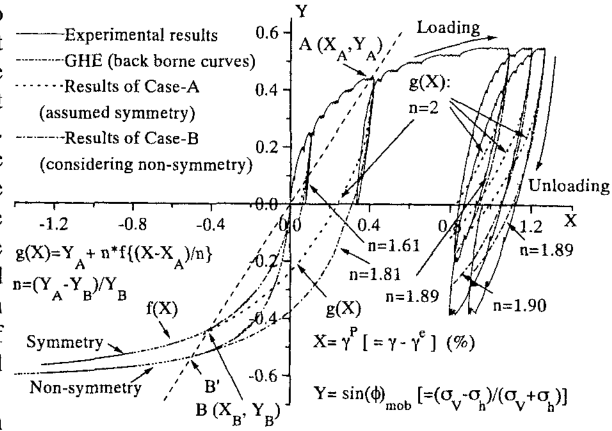

Fig.2: Comparison of the experimental and model results in the case of unloading of test GT2.

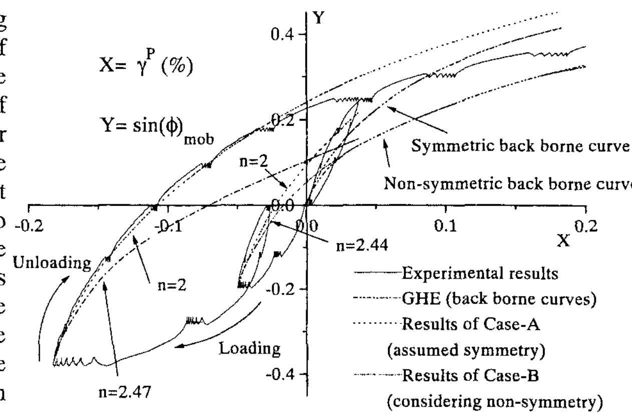

Fig.3: Comparison of the experimental and model results in the case of unloading of test GT3.

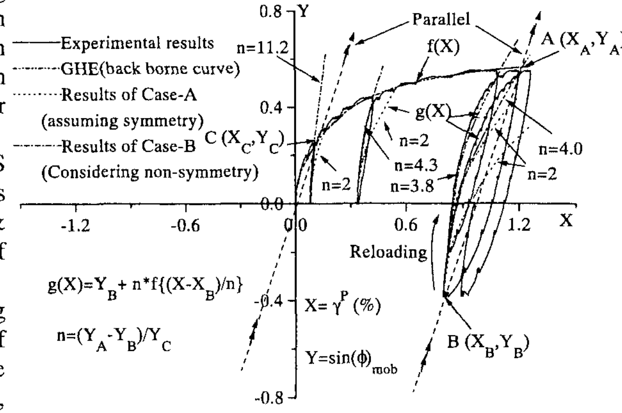

Fig.4: Comparison of the experimental and model results in the case of reloading of test GT2.