**Ⅲ－B 395** **Anisotropy in elastic deformation property of a dense gravel.**

*LeQuangAnhDan* University of Tokyo ; *Modoni,G* Univ. of Napoli
*Tatsuoka,F* University of Tokyo ; *Koseki,J* IIS, University of Tokyo

**Introduction**: The cross-anisotropic elasticity model could be relevant for vertically compacted granular materials as has been reported by many researchers. However, possible variations of horizontal elastic Young's modulus $E_h$ during triaxial compression and extension tests at constant horizontal stress $\sigma_h$ have not been examined yet. This point was carefully examined in this study to validate the cross-anisotropic elasticity model.

**Experimental program**: Large triaxial square-prismatic specimens of 58cm (height) *23cm (length)*23cm(width) (Fig.1) were prepared by compacting Chiba gravel ( 80% gravel and 20% sand : see Balakrishnaiyer et al 1998 for grading curve) in fourteen layers by manual compaction to reach high dry density ($\rho_d$ =2.23 g/cm$^3$). Local axial and horizontal strains, which were free from any bedding errors as well as membrane penetration, were measured by using in total 10 local deformation transducers (LDTs) (Goto et al 1991). Specimens were subjected to cyclic isotropic consolidation for a stress range from 49kPa to 490kPa, followed by large cycles of shearing at constant confining pressure ($\sigma_h$=490kPa). The two horizontal stresses were always equal to each other. Small cycles of either horizontal or vertical stress were applied at various stress levels during isotropic consolidation as well as cyclic shearing.

**Results and Discussions**: A typical stress-strain curve during small horizontal and vertical cyclic shearing are shown in Fig. 2 and Fig. 3. The single amplitude of vertical strain $(\varepsilon_v)_{SA}$ was less than 0.001% in most of the cases, while horizontal strain $(\varepsilon_h)_{SA}$ sometimes exceeded the above value. The measured stiffness values were corrected to those at $\varepsilon_{SA}$=0.001% by following the method suggested by Flora et al (1994) and Jiang et al (1997). From vertical small unload-reload cycles, we could directly obtain the vertical Young's modulus $E_v = \Delta\sigma_v / \Delta\varepsilon_v$ and the Poisson's ratio $\nu_{vh} = -\Delta\varepsilon_h / \Delta\varepsilon_v$ . On the other hand, the horizontal Young's modulus $E_h =(1- \nu_{hh}) \Delta\sigma_h / \Delta\varepsilon_h$ could be evaluated from horizontal small unload-reload cycles only by assuming a proper value for Poisson's ratio $\nu_{hh}$. In this paper, it was assumed that $\nu_{hh} = \nu_{vh}$ at isotropic stress state. Then the Young's moduli $E_v$ and $E_h$ were normalized by using the empirical equation $f(e)=(2.17-e)^2/(1+e)$ (Hardin and Richart,1963) to exclude the influence of the variations in the void ratio $e$ at current stress state.

The degree of inherent anisotropy can be seen from data at isotropic stress state (Fig. 5); $E_v$ is always larger than $E_h$, which is likely to result from heavy compaction in the vertical direction. As the full-

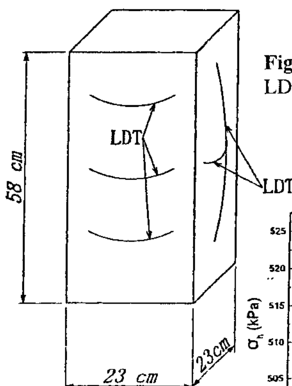


**Fig.1** A specimen and LDTs are setting (not in scale)

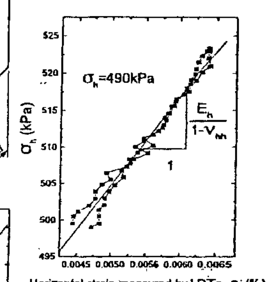


**Fig.2** Typical horizontal small unload-reload cycle

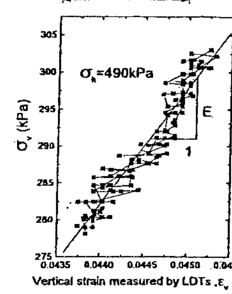


**Fig.3** Typical vertical small unload-reload cycle

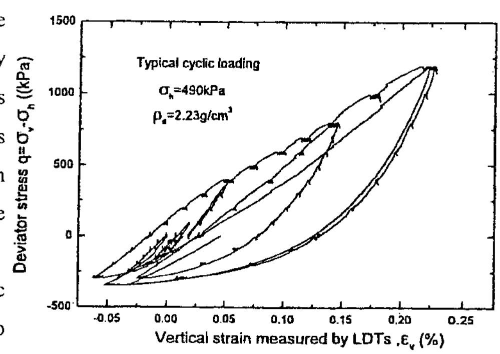


**Fig. 4** Stress-strain curve during cyclic loading

Key word: cross-anisotropic elasticity model ; inherent anisotropy ; heavy compaction .

Address: 7-22-1, Roppongi, Minato-ku, Tokyo 106, JAPAN ; Tel: 81/03-3402 -6321 ext 2571; Fax: 81/03-3479-0261

logarithmic plot of $E_v$ and $E_h$ versus $\sigma_m$ ($=\sigma_h=\sigma_v$ during isotropic consolidation) are essentially linear, they are fitted by $E_v/f(e)= E_{v0} *(\sigma_v/\sigma_0)^{m_v}$ and $E_h/f(e)= E_{h0} *(\sigma_h/\sigma_0)^{m_h}$, where $\sigma_0$ is a reference stress, set to 1.0 kPa for the present study. $E_{v0}$ , $E_{h0}$ , $m_v$ , $m_h$ are the parameters. In Fig. 5, the slope of the $E_h$ line is steeper than the slope of the $E_v$ line (i.e., $m_h>m_v$), which means that this inherent anisotropy decreased as stress level increased. This phenomenon was observed in most of the experiments.

Fig. 4 shows the typical overall stress-strain relationship during triaxial shearing, and Fig. 6 shows the value of $E_v$ and $E_h$ evaluated during this test. It may be seen from Fig. 6 that the measured value of $E_v$ follows basically the relationship $E_v/f(e)= E_{v0}*(\sigma_v/\sigma_0)^{m_v}$ established for isotropic stress states as many researchers suggested (Tatsuoka and Kohata,1995), while the slope $m_v$ between triaxial extension and compression is slightly different. A similar data from another test is shown in Fig. 7. The slopes m in triaxial compression and extension are slightly smaller and larger than that of the isotropic stress state, as the stress ratio $\sigma_1/\sigma_3$ increases in triaxial compression and extension. $E_v$ value decreases relatively to the respective value at the same $\sigma_v$ at the isotropic stress state, perhaps due to damage at high $\sigma_1/\sigma_3$ value. On the other hand, during shearing at constant confining pressure, $E_h$ is nearly constant (Fig. 6), whereas at high or low stress levels, effects of damage can also be seen.

**Conclusions** : *1)*The inherent anisotropy, perhaps due to heavy compaction, was observed at isotropic states and it decreased with the increase in the stress level. *2)* The horizontal Young's modulus $E_h$ kept nearly constant during triaxial shearing at constant confining pressure. 3)The test results confirmed the unique dependency of $E_v$ and $E_h$ on, respectively, $\sigma_v$ and $\sigma_h$ , implying a stress-induced anisotropy of the highly compacted gravel. 4)The decrease in both $E_v$ and $E_h$ at high stress ratio $\sigma_1/\sigma_3$ was observed in triaxial compression and extension.

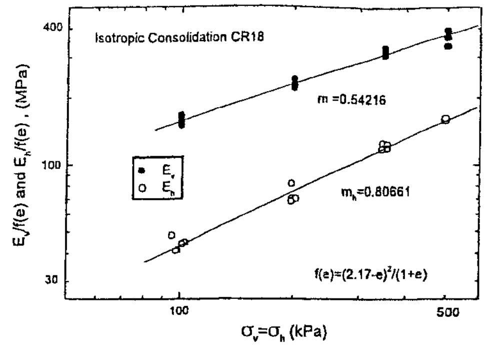


**Fig. 5** Horizontal and vertical elastic Young's moduli at isotropic stress state

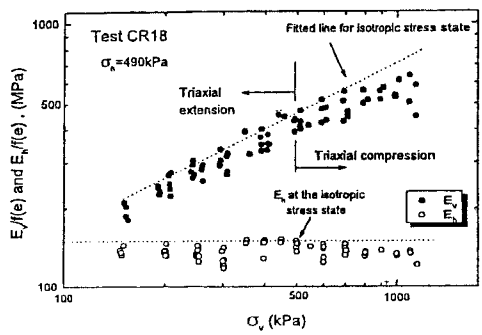


**Fig.6** Horizontal and vertical elastic Young's moduli during cyclic shearing at constant confining pressure

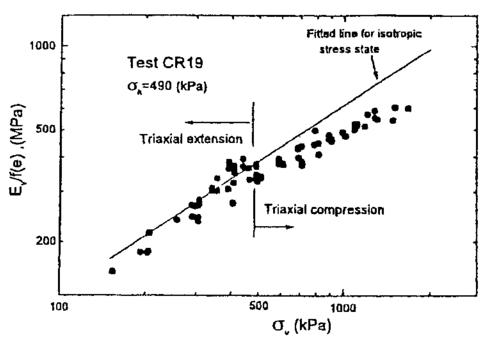


**Fig.7** Vertical elastic Young's moduli during cyclic shearing at constant confining pressure

**References**: *Flora et al(1994) :*Small strain behavior of gravel along some triaxial stress path ,IS-Hokaido 94, Vol.1. *Goto,S et al (1991)*:A simple gauge for local small strain measurements in laboratory. Soils and Foundations, Vol. 31, No.1, pp69-180. *Balakrishnaiyer, K et al (1998)*: Deformation characteristics of moderately to highly dense gravel at small strain levels, JGS. *Hardin,B.O and Richart ,F.E 1963* : Elastic wave velocities in granular soils . J.Soil Mech. Found. Div., ASCE, Vol. 89,No SM1, pp33-65. *Jiang et al,(1997)* :Inherent and stress system induced anisotropy in small strain stiffness of sandy gravel. Geotechnique Vol. 47. No.3. *Tatsuoka,F and Kohata,Y (1995)*:Stiffness of hard soils and soft rocks in engineering applications. Pre-failure Deformation of geomaterials, Vol. 2 , pp947-1067.