Effects of large cyclic and creep loading on peak strength of compacted gravel in triaxial compression tests

Effets de chargements cycliques de grande amplitude et de phases de fluage sur la résistance de pic de graviers compactés lors de tests triaxiaux en compression

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ABSTRACT

Effects of large cyclic and creep loading on peak strength of compacted gravel was investigated by performing a series of four triaxial compression tests using large scale apparatus in Koseki Laboratory, The University of Tokyo. The specimens were rectangular prismatic with dimensions of 50 cm high and 23.5 cm times 23.5 cm in cross-section. To measure the major principle stress σ_1, a load cell is located just above the top cap inside the triaxial cell in order to eliminate the effects of piston friction. The major principle strain ε_1 was measured not only externally but also locally with three pairs of vertical local deformation transducers (LDTs). Minor principle strain, ε_3 was measured by three pairs of horizontal local deformation transducers (H-LDTs). Chiba gravel (D_{max} = 38 mm, D_{50} = 6 mm and U_c = 33) was used as the test material. The specimens were prepared by employing automatic dynamic compaction and keeping dry densities within the range of 1.91-1.98 g/cm^3. During monotonic shearing stage after large cyclic as well as creep loading stages, sudden increase in the shear stress level without any considerable increase in axial strain was observed. From this study, it is concluded that if the gravel is compacted to a certain degree, there will be no significant effect of large cyclic or creep loading history on its peak strength.

RESUME

Les effets de chargements cycliques de grande amplitude et de phases de fluage sur la résistance de pic sur des graviers compactés ont été étudiés en réalisant une série de quatre essais triaxiaux en compression et en utilisant un matériel à grand échelle dans le laboratoire Koseki de l'Université de Tokyo. Les échantillons étaient de forme rectangulaire, de hauteur 50cm et de section 23.5cm x 23,5cm. Pour mesurer la contrainte principale σ_1, une cellule de pression a été installée juste au dessus du capuchon dans la cellule triaxiale dans le but d'éviter les effets du frottement avec le piston. La déformation principale ε_1 a été mesurée non seulement de façon externe mais aussi au niveau local avec l'aide de trois paires de transducteurs de déformation verticale locale (vertical local deformation transducers : LDTs). La déformation principale mineure, ε_3 a été mesurée avec trois paires de transducteurs de déformation horizontale locale (horizontal local deformation transducers : H-LDTs). Les graviers de Chiba (D_{max} = 38 mm, D_{50} = 6 mm and U_c = 33) ont été utilisés en tant que matériau de test. Les échantillons ont été préparés en utilisant une méthode automatique de compaction dynamique en conservant des densités sèches dans une plage de valeurs allant de 1.91 à 1.98 g/cm^3. Lors de la phase de cisaillement monotone après des chargements cycliques de grande amplitude et des phases de fluage, il a été observé une augmentation brutale du niveau de la contrainte de cisaillement, sans augmentation significative de la déformation axiale. De cette étude, il est conclu que si les graviers sont compactés jusqu'à un certain stade, des cycles de large amplitude ou des phases de fluage n'auront pas d'effet significatif sur la résistance de pic.

Keywords: compaction, triaxial, peak strength, gravel

1 INTRODUCTION

Compacted gravel has been used in the construction of huge embankments for dams, roads, railway tracks and airports. It is important to compare its strength and deformation properties under large cyclic and creep loading with that under monotonic loading for the rational designs. Large cyclic loading can be generated by seismic actions, water reservoir fluctuations, traffic loading, wind actions and dynamic compaction. Creep loading can be correlated with loading of the embankment before and during service. The performance of the structures depends significantly on the mechanical response of the constituent material to the action of monotonic, large cyclic or creep loading. For this purpose, in this paper strength properties under the above mentioned three kinds of loadings have been studied by conducting four triaxial compression tests. During monotonic shearing stage after large cyclic as well as creep loading stages, sudden increase in the shear stress level without any considerable increase in axial strain was observed. Similar behavior has been also observed in plane strain compression tests by Maqbool et al. 2005.

2 EQUIPMENT, MATERIAL AND TEST PROCEDURES

In this study large scale true triaxial apparatus (AnhDan et al. 2006) was employed to determine strength properties. In this apparatus all three-principle stresses (σ_1, σ_2, σ_3) can be controlled independently though in this study it was used just as a triaxial apparatus ($\sigma_2 = \sigma_3$) without confining plates. As shown in Fig.1, the specimen was rectangular prismatic with dimensions of 50 cm high and 23.5 cm times 23.5 cm in cross-section for all four tests. To measure the vertical stress σ_1, load cell is located just above the top cap inside the triaxial cell.

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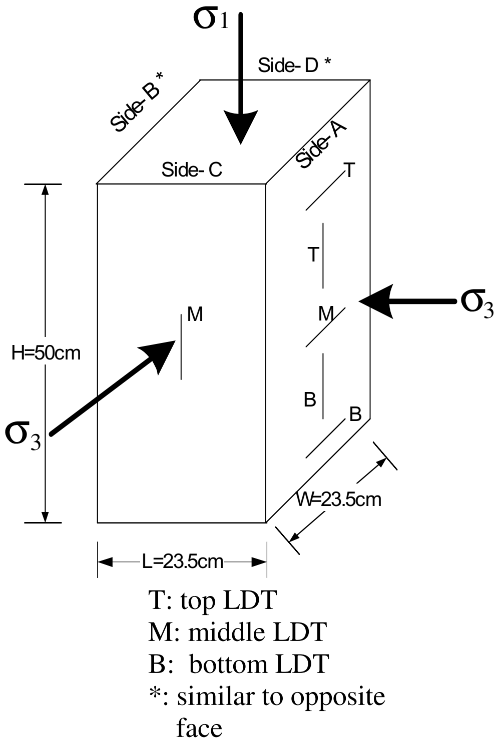

Figure 1. Positioning of LDTs on the specimen.

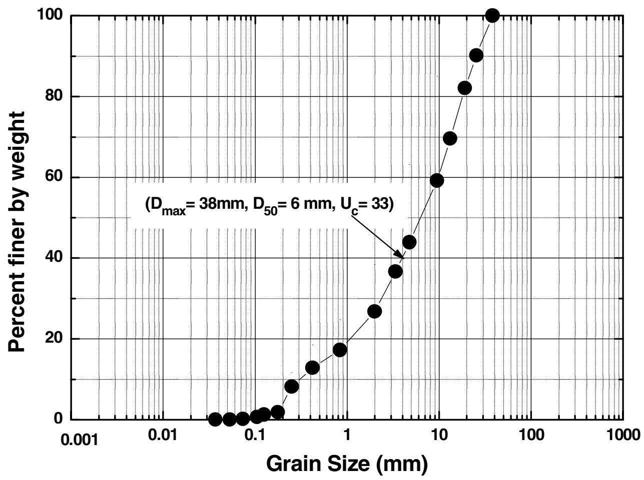

Figure 2. Grain size distribution of Chiba gravel.

The vertical strain ε_1 was measured not only with external transducers but also with three pairs of vertical local deformation transducers (LDTs; Goto et al. 1991), located at the top and bottom on sides-A & B while at the middle on sides-C & D of the specimen. The confining stress σ_3 was applied through the cell pressure, which was measured with a high capacity differential pressure transducer (HCDPT). The corresponding horizontal strain ε_3 was measured with three pairs of horizontal LDTs, located at top, middle and bottom on sides-A & B of the specimen.

Chiba gravel (D_{max} = 38 mm, D_{50} = 6 mm and U_c = 33) was used as the test material (Fig. 2). The specimens were prepared by employing manual or automatic dynamic compaction and keeping dry densities within the range of 1.91-1.98 g/cm^3. The stress path followed during these tests is given in Table-1.

Test Code	Stress path
TC-1	I.C*. = 50 - 100 - 50 - 100 (kPa)
	T.C. at σ_3 = 100 kPa
TC-12	I.C. = 50 - 100 - 50 - 100 (kPa)
	T.C. with σ_1 =100 - 550 - 150 - 350 (kPa), at σ_3 =100kPa
	T.C. with 100 L.C.** with amplitude of 400 kPa, N.A.*** at σ_1 = 350 kPa, frequency = 0.00104Hz and σ_3 =100 kPa
	T.C. at σ_3 =100 kPa
TC-13	I.C. = 50 - 100 - 50 - 100 (kPa)
	T.C. with σ_1 =100 - 450 - 150 - 450 - 300 (kPa) at σ_3 =100 kPa
	T.C. with 100 L.C. with amplitude of 300 kPa, N.A. at σ_1 = 300 kPa, frequency = 0.00139Hz and σ_3 =100 kPa
	T.C. with σ_1 =300 – 150 – 450 - 150 (kPa) at σ_3 =100 kPa
TC-14	I.C. = 50 - 100 - 50 - 100 (kPa)
	T.C. with σ_1 =100 - 550 (kPa), σ_3 =100 kPa
	Creep loading at σ_1 = 550 kPa for 14 hours
	T.C. with σ_1 =550 - 450 (kPa) at σ_3 =100 kPa
	T.C. with 50 L.C. having amplitude of 200 kPa, N.A. at σ_1 = 450 kPa, frequency = 0.00104Hz and σ_3 =100 kPa
	T.C. at σ_3 =100 kPa

Table 1. Stress path followed during triaxial compression tests. (Maqbool, 2005)
* Isotropic consolidation
** large cyclic loading; ***Neutral axis

3 TEST RESULTS AND DISCUSSIONS

Four specimens named as TC-1, TC-12, TC13 and TC-14 were subjected to different loading histories. Axial strain rate during monotonic loading stage in all four tests was kept equal to 0.08%/min. In the first test (TC-1) subjected to monotonic loading only, a strain softening behavior was not clearly observed as shown in Fig.3.

In the second test (TC-12), at a deviator stress q_1 of about 250 kPa, 100 cycles of loading/unloading with double amplitude of 400 kPa and a frequency of 0.00104 Hz were applied. As shown in Fig.4, during monotonic load stage after the large cyclic loading, sudden increase in q_1 without any considerable increase in axial strain was observed. In this test, the peak stress state was obtained immediately after the large cyclic loading.

In the third test (TC-13), at a deviator stress q_1 of about 200 kPa, 100 cycles of loading/unloading with double amplitude of 300 kPa and a frequency of 0.00139 Hz were applied. As shown in Fig.5, during monotonic load stage after the large cyclic loading, sudden increase in q_1 without any considerable increase in axial strain was observed but peak strength was not obtained immediately after cyclic loading. Therefore, the stress strain relationship observed in this test was different from that observed in TC-12. In spite of difference in the stress-strain curves, the magnitude of peak strength was same.

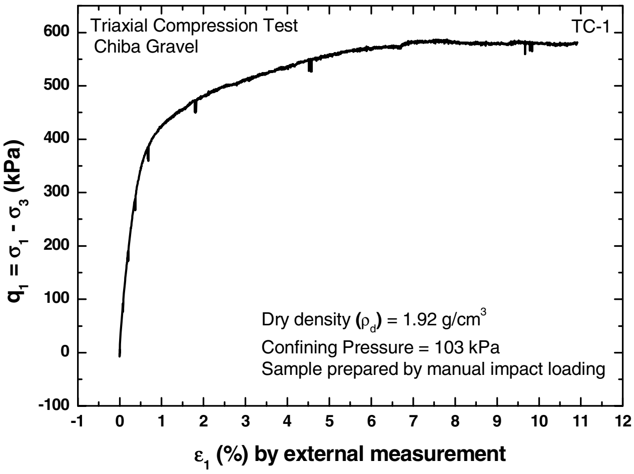

Figure 3. Stress-strain relationships for TC-1.

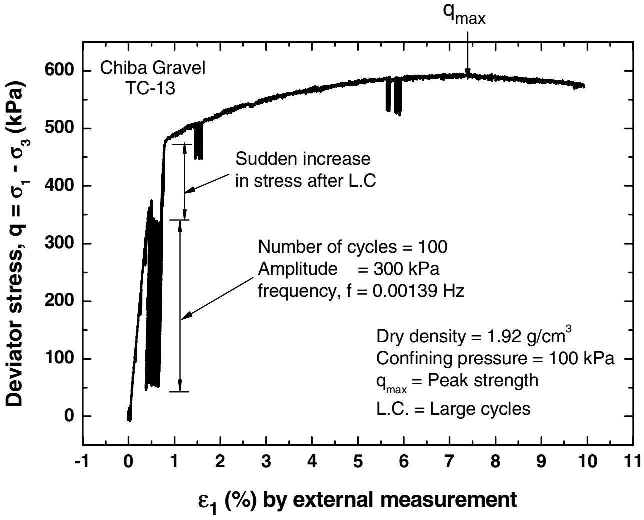

Figure 5. Stress-strain relationships for TC-13.

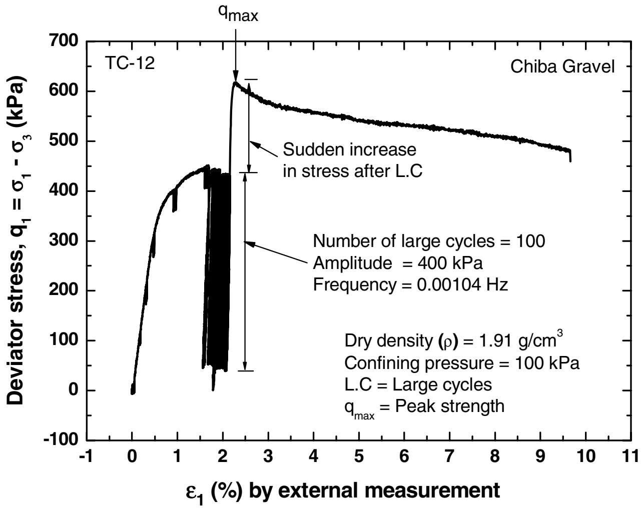

Figure 4. Stress-strain relationships for TC-12.

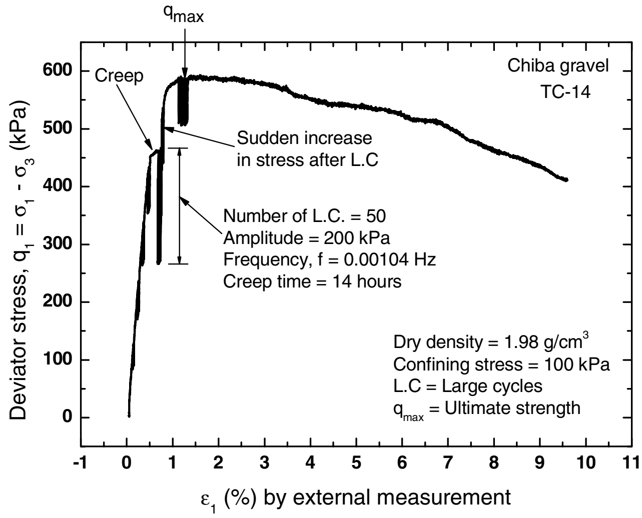

Figure 6. Stress-strain relationships for TC-14.

In the last test (TC-14), creep loading was applied just before large cyclic loading at a deviator stress q_1 of about 450 kPa for about 14 hours. As shown in Fig.5, sudden increase in q_1 without any considerable increase in the axial strain was observed after combination of creep and large cyclic loading.

In an overall comparison of stress-strain curves, as shown in Fig.7, the peak strength (q_{max}) was found similar with a maximum difference of 5% in all four tests irrespective of the difference in the loading histories, while the level of axial strain ε_1 corresponding to the peak stress state was significantly small in TC-14 as compared to that in other three tests. This deviation may be linked with the application of combination of large cyclic and creep loading in TC-14. Moreover, as shown in the same figure, during monotonic shearing stage after large cyclic loading, sudden increase in the shear stress level without any considerable increase in axial strain was observed in all three tests, TC-12, TC-13 and TC-14. The effects of number of cycles, amplitude, deviator stress corresponding to neutral axis and frequency of cyclic loading on peak strength of compacted gravel still needs to be investigated. In addition to that, the duration and the stress level corresponding to the application of creep loading should also be checked by conducting several tests under similar testing conditions on compacted gravel.

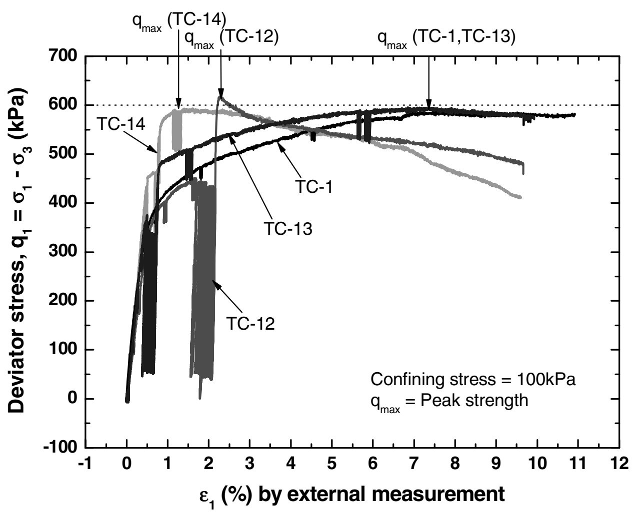

Figure 7. Stress-strain relationships for all four tests.

4 CONCLUSIONS

1- The peak strength (q_{max}) was found similar with a maximum difference of 5% in all four tests irrespective of the difference in the loading histories, while the level of axial strains ε_1 corresponding to the peak stress state was different among the four tests.

2- During monotonic loading stage after large cyclic as well as creep loading stages, sudden increase in the shear stress level without any considerable increase in axial strain was observed.

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