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SYNOPSIS: A series of static and cyclic triaxial tests was carried out on compacted greywacke sandstone containing small amount of fines. Permanent strain of saturated or air-dried sample induced by cyclic loading was measured for different cyclic loading sequences, initial shear stress, and fine content. The shear deformation and strength of those samples were also investigated by monotonic loading on virgin and post-cyclic loading samples.

INTRODUCTION

Granular materials are widely used for filling and ballast. Ballast and subgrade play a major part in the maintenance life of track structures, because they are the source of permanent deformation associated with the deterioration of the surface and the line. Ballast is also one of the principal means of repairing this deterioration caused by traffic, earthquakes, and other environmental factors (Selig & Sluz, 1978).

Deformation and strength characteristics of clean sand and gravel have been extensively investigated. However, they are not always clean in the field. Detrimental fines (materials passing the 0.074 mm sieve) are produced during crushing, stockpiling, transportation of aggregate to a jobsite, and compaction during construction (Pintner et al., 1987). Mud pumping could be the cause of detrimental fines in ballast. This paper reports the results of the tests carried out to investigate the effects of variations in degree of saturation, initial shear stress, applied loading pattern, and fine content in the coarse materials on the deformation and strength characteristics.

LABORATORY TEST

A series of static and cyclic triaxial tests was carried out on compacted samples of greywacke sandstone which were taken from the quarry site of Chiew Larn Dam in Thailand. The material was sieved to obtain a grain size distribution shown in Figure 1. Fine particles were made by grinding of gravel and then mixed thoroughly with coarse materials as much as 0 %, 1 % and 5 % of dry weight. Then, the mixture was compacted in the mold. The dry unit weight of the sample was about 15.0 to 15.9 kN/m^3. The initial void ratio of these samples was about 0.73 to 0.82. Some of the samples were saturated before consolidation.

Compacted samples were consolidated under the same confining stress, σ'_{rc} = 19.6 kPa, with three different axial stresses, σ'_{ac} = 19.6, 39.2 and 78.4 kPa. Then, cyclic stress was applied to the sample in drained condition. Though

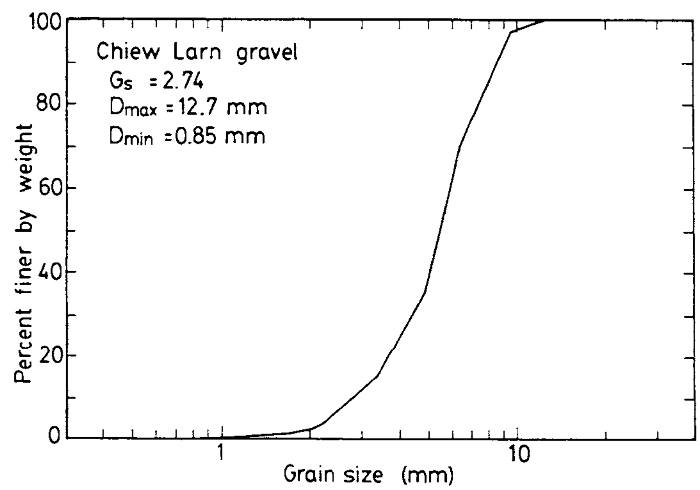

Fig.1 Grain Size Distribution of Coarse Material

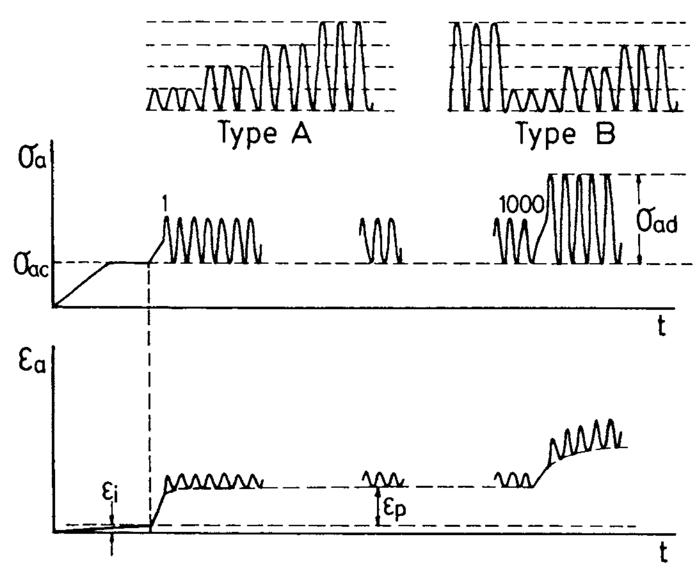

Fig.2 Schematic Illustration of Cyclic Loading

the dynamic stress in the ground induced by traffic is complicated (Ishihara, 1983), the stress condition was simulated by load cycles only on the compression side. Axial load application and resultant strain are schematically illustrated in Figure 2. For each of the initial stress conditions, four levels of cyclic axial stress, σ_{ad}, were applied in sequence, and each cyclic loading was repeated for 1000 times. Two types of load sequence were used in the tests, i.e. Type A and Type B. Stress amplitude was increased stepwise in Type A, as $\sigma_{ad} / \sigma_{rc}$ = 1.0, 2.0, 3.0, 4.0, whereas in Type B the maximum amplitude of cyclic stress was applied prior to the smaller amplitudes, i.e. $\sigma_{ad} / \sigma_{rc}$ = 4.0, 1.0, 2.0, 3.0. Static triaxial compression tests were also performed on both virgin and post-cyclic loading samples.

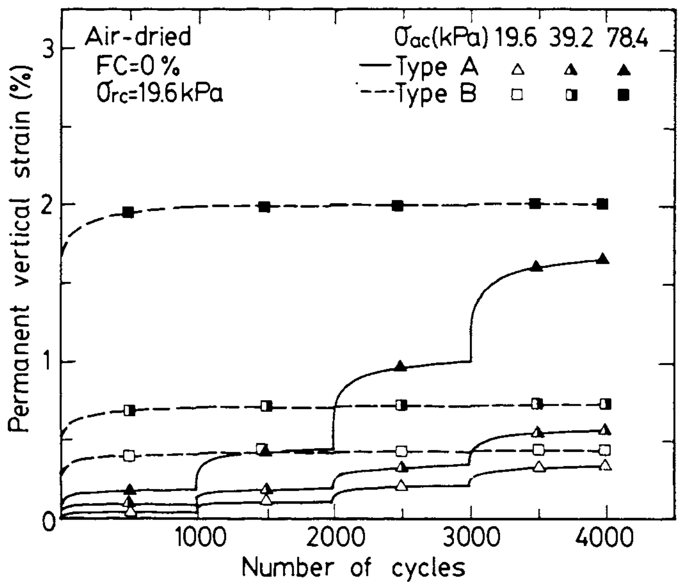

Fig.3 Permanent Vertical Strains versus Number of Cycles of Air-Dried Samples (FC = 0 %)

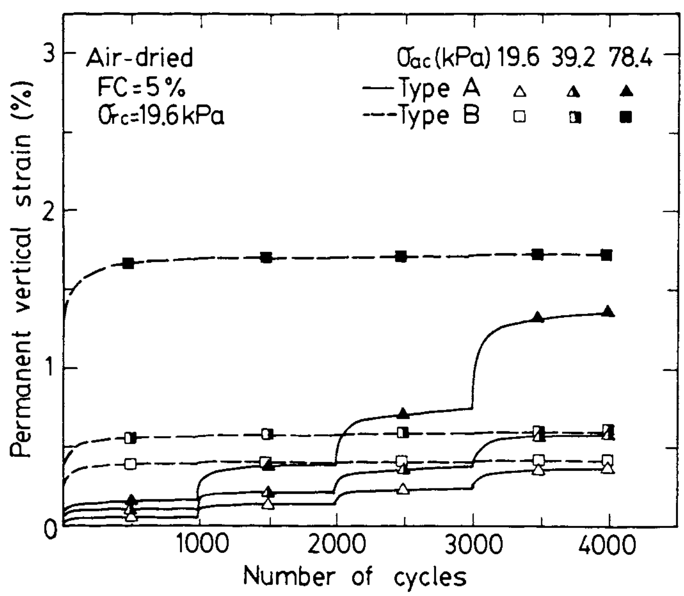

Fig.4 Permanent Vertical Strains versus Number of Cycles of Air-Dried Samples (FC = 5 %)

CYCLIC LOADING TEST RESULTS

Permanent vertical strains were plotted against number of cycles in Type A and Type B tests under different initial shear stress states as shown in Figures 3 and 4 for the air-dried samples with fine content of 0 % and 5 %, respectively. As seen in these figures, the residual strain accumulated with the application of cyclic stress. In Type A test, some initial cycles of loading in each stage produced very large permanent strain followed by a period where the permanent strain was proportional to the logarithm of the number of load cycles, thus the rate of increase in permanent strain reduced rapidly with the number of cycles. When the amplitude of cyclic load was increased, the permanent strain started to increase again. On the other hand in Type B test where the maximum cyclic load was apllied first followed by smaller magnitudes, large permanent strain was induced only in the first stage, while the subsequent low level cyclic loadings did not make a significant contribution to the permanent strain. It was also found in the figures that the permanent strain was more in the sample with higher initial shear stress. For given fine content and initial shear stress, it was noticeable that, after all four stages, the residual strain in Type B test was more than that in Type A test. The sequence of applied stress affected the final value of permanent strain (Brown & Hyde, 1975; Stewart, 1986).

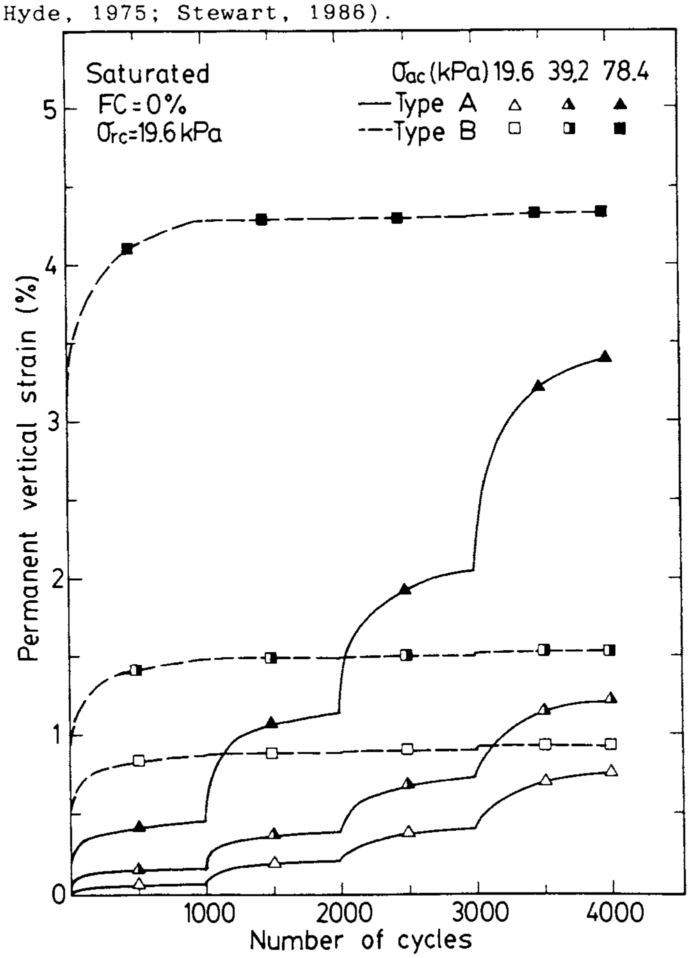

Fig.5 Permanent Vertical Strains versus Number of Cycles of Saturated Samples (FC = 0 %)

Shown in Figures 5 and 6 are permanent vertical strain versus number of cycles in Type A and Type B tests for saturated samples containing 0 % and 5 % of fines respectively. Almost the same characteristics were observed as the results on air-dried samples. However, the residual strain of saturated sample continued to accumulate even after 1000 cycles of loading in each stage.

To summarize the cyclic load test results, the permanent strains at the end of respective type of cyclic loading test (after 4000 cycles) are plotted against the fine content for each initial shear stress and degree of saturation as shown in Figure 7. It is seen in this figure that the residual strain of saturated sample was higher than that of air-dried sample and it was more pronounced in the sample with higher initial shear stress. The effect of fine content did not affect obviously the amount of residual strain induced by cyclic loadings, when fines were mixed with coarse particles up to 5 %, though the residual strain decreased with the fine content to some extent in the tests on saturated samples with very high initial shear stress.

TRIAXIAL COMPRESSION TEST RESULTS

Static triaxial compression tests were performed on virgin and post-cyclic loading samples. The static stress-strain curves are shown in Figure 8 for the saturated virgin samples containing 5 % fine as an example. The curve had a gentle slope and the shear resistance was higher for higher initial shear stress. Air-dried virgin samples showed characteristics similar to saturated virgin samples. On the other hand, the initial slope of the stress-strain curve of the post-cyclic loading sample was very steep as shown in Figure 9. The shape of the curve was like those of elastic-perfectly plastic materials.

The shear strengths obtained in the static tests are summarized in Figure 10. The deviator stresses at failure of saturated and air-dried samples under the confining stress of σ_{rc} = 19.6 kPa are plotted against fine contents for the virgin samples and post-cyclic loading samples after two different types of load sequence. As can be seen in the figure, the shear strength of the virgin sample was considerably lower than those of the post-cyclic loading samples in fully saturated condition. It was also lower than the shear strength of the air-dried virgin sample. On the contrary, the shear strength of air-dried virgin sample was almost the same as those of air-dried post-cyclic loading samples.

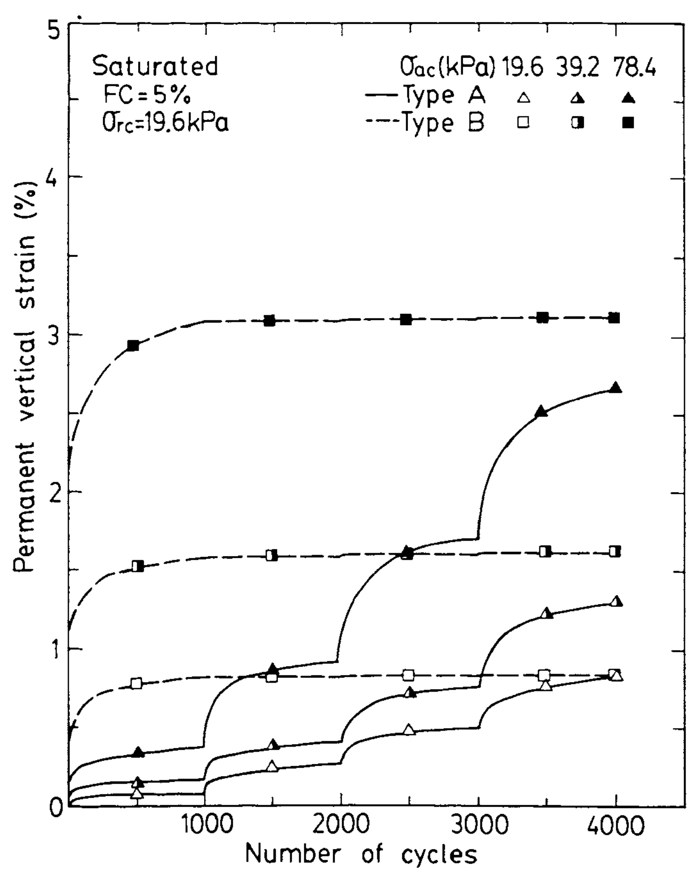

Fig.6 Permanent Vertical Strains versus Number of Cycles of Saturated Samples (FC = 5 %)

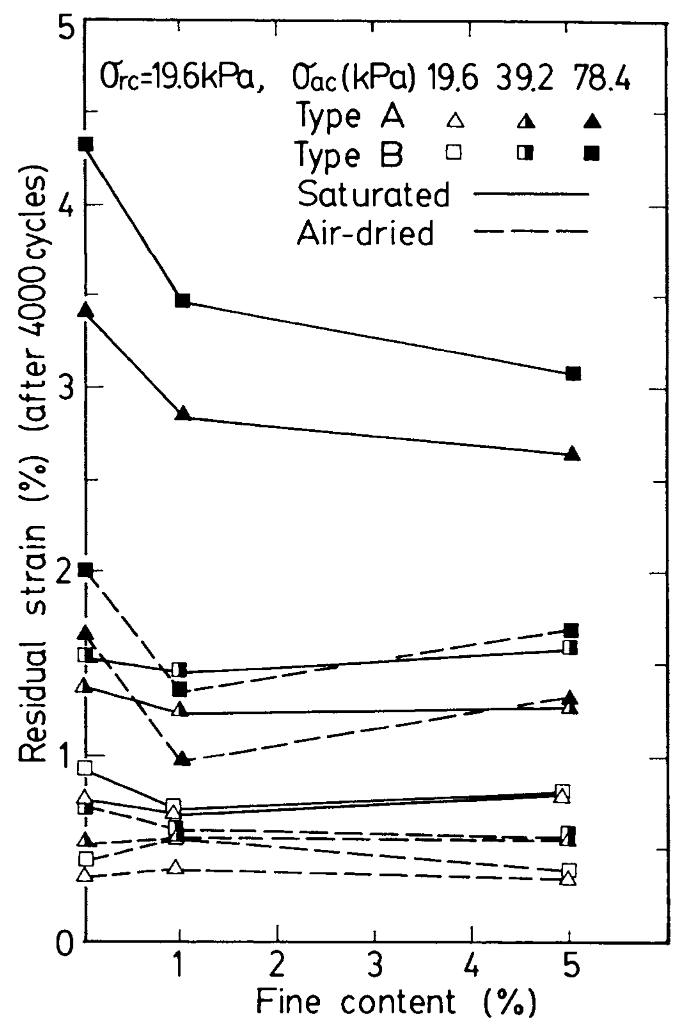

Fig.7 Residual Strain after 4000 Cycles versus Fine Content

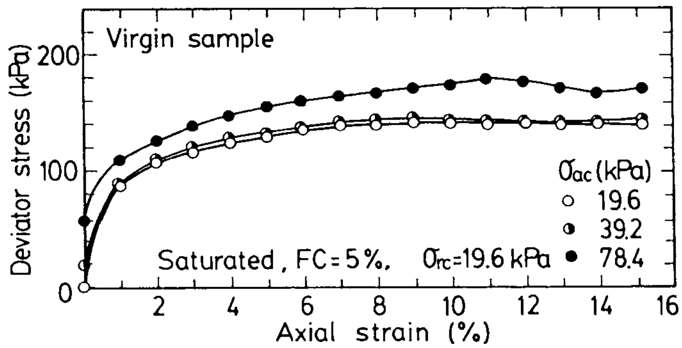

Fig.8 Stress-Strain Curves of Saturated Virgin Samples (FC = 5 %)

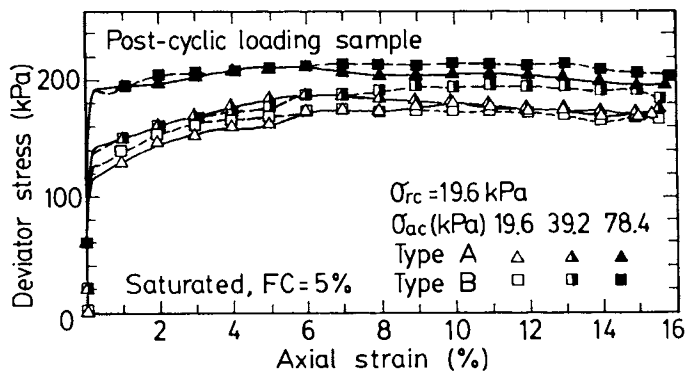

Fig.9 Stress-Strain Curves of Saturated Post-Cyclic Loading Samples (FC = 5 %)

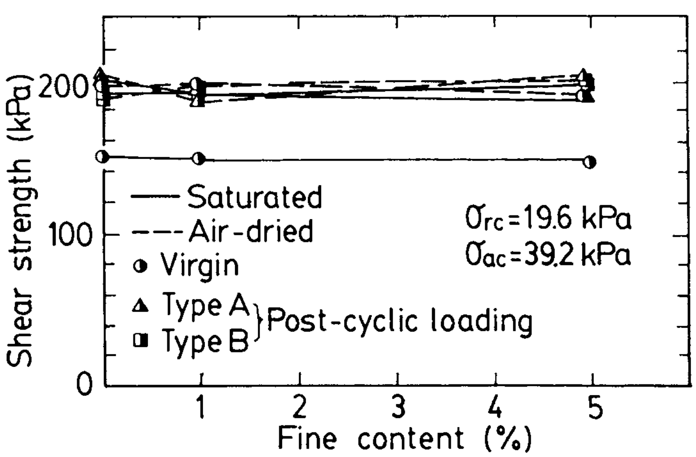

Fig.10 Shear Strength versus Fine Content

Difference in the shear strength, in addition, was relatively small among the post-cyclic loading samples irrespective of the loading sequence or the degree of saturation. Whether the sample was saturated or air-dried and whether the cyclic stress was applied to it or not, the shear strength was not much affected by the amount of fine content up to 5 %.

CONCLUSIONS

A series of static and cyclic triaxial tests was carried out on compacted greywacke sandstone containing small amount of fines to study the permanent strain due to the cyclic load application. From the test results of this study, following conclusions were obtained.

1. Under the same initial stress and fine content conditions, the residual strain induced by cyclic loading was more in Type B test than in Type A test irrespective of the sample saturation.

2. The residual strain of the air-dried sample after cyclic loading was lower than that of the saturated sample.

3. The residual strain after cyclic loading did not have a clear relationship with the fine content up to 5 %.

4. The initial slope of the stress-strain relationship of the post-cyclic loading sample was very steep. The shape of the curve was like those of elastic-perfectly plastic materials.

5. The shear strength of a virgin sample was considerably lower than that of a post-cyclic loading sample in fully saturated condition. It was also lower than that of an air-dried virgin sample.

6. The shear strength of an air-dried sample did not change much with cyclic load application.

7. Difference in the shear strength was relatively small among the post-cyclic loading samples irrespective of the loading sequence or the degree of saturation.

8. The shear strength was not much affected by the amount of fine content up to 5 %.

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