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Static tests of concrete block on gravel deposits

Kiyonari Mori, Norimasa Hayashi & Tatsuya Kishimoto
Kumagai-Gumi, Tokyo, Japan

Yoshiharu Kiyota
Kajima Corporation, Tokyo, Japan

Shuichi Nakayama
Nuclear Power Engineering Center, Tokyo, Japan

Akira Enami
Nihon University, Tokyo, Japan

ABSTRACT: The object of this study is to investigate the cyclic deformation characteristics of the in-situ gravel layer by statically applying cyclic loads to Quaternary deposits under the condition of the earth contact pressure of approximately 470kPa which is similar to actual reactor buildings, and to establish the methodology for the seismic design of nuclear power plants built on Quaternary deposits. The loading was applied on concrete blocks constructed on the in-situ gravel layer. From the test results, the non-linearity of the gravel layer was investigated to large shear strain range exceeding 10^{-3}. And the non-linearity was simulated by 2-dimensional FEM analyses using the soil properties estimated by in-situ and laboratory tests. As a result of this study, it is confirmed that the deformation characteristics of Quaternary deposits can be evaluated reasonably by these analyses. The soil properties used in the analyses can be appropriately determined by various tests.

1 INTRODUCTION

The basic policy in Japan requires nuclear reactor buildings to be built on rock site. However, in order to increase available locations for nuclear power plants in future, the investigation of siting technology on Quaternary deposits has been carried out as a project of the Nuclear Power Engineering Center (NUPEC). In this study, the cyclic deformation characteristics of gravel deposits subjected to shear strains over wide strain range were investigated to establish the methodology for the seismic design of nuclear power plants built on Quaternary deposits. This static loading tests were performed by giving statical cyclic loads to concrete blocks (30MN, 50MN) constructed on the in-situ gravel layer, and the obvious features of this test compared with previous studies and experiments for gravel deposits are summarized as follows:

1) Large scale field tests for the 8m × 8m area of gravel deposits under the condition of the earth contact pressure of 470kPa which is similar to actual reactor buildings.

2) Statical cyclic loading tests.

3) Shear strain level of the soil exceeds 10^{-3} and the non-linearity of the deformation is remarkable.

Other aspects of this project are described in the companion papers submitted to this Conference. The outline of the project and preliminary test results are described in the paper by Watabe et al (1991).

2 STATIC LOADING TESTS

2.1 Selected site

The test site was selected in the field of Tadotsu Engineering Laboratory of NUPEC, in Kagawa Prefecture, Japan. For the test deposit, a diluvial gravel layer was chosen which has high possibility of becoming the bearing soil when building a nuclear power plant on the Quaternary deposits. Since there was an about 10m thick reclamation layer of dredged material overlying the selected test gravel layer, the surface soil was excavated to the distance of 11m below the ground surface to expose the diluvial gravel layer for construction of concrete blocks. The ground water level was lowered by using wells and controlled to hold at the distance of -1.5m from the excavated ground surface.

2.2 Loading method

The concrete blocks used for this tests are test block and reaction block, as shown in Fig.1. The test block is designed to have the dimensions in plan 8m× 8m at the lower part and 12m× 12m at the upper part and 10m height so that the earth contact pressure of approximately 470kPa could be attained. Statical cyclic loading was applied by a pair of hydraulic jacks (maximum loading limit is 6MN/jack) at the center of the gravity of the test block in both push and pull directions.

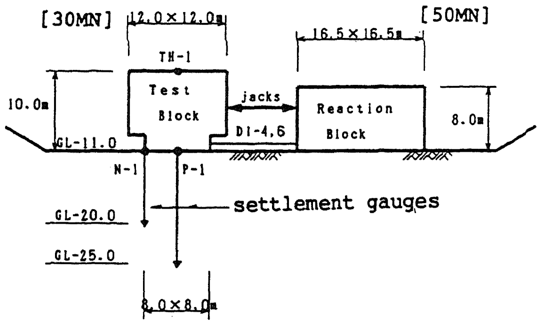

Fig.1 Layout of the static loading tests

2.3 Loading pattern

For the static loading tests, the target shear strain level of the soil was 10^{-3}. While maintaining the stability of the test block the loads were increased so that the necessary strain level could be obtained. The loads were applied in both push and pull directions at the speed of 1.18MN/min, and the loading level was increased in 10 steps of 980kN increment up to the maximum 9.8MN. At each loading step the cyclic loading was repeated 5 times, as shown in Fig.2.

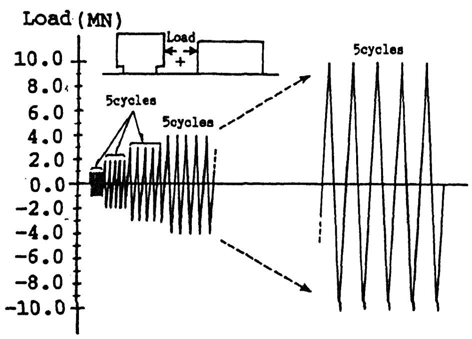

Fig.2 Loading pattern

2.4 Measurement items

The items measured and the measuring instruments are as follows:

1) Vertical displacement of the soil by settlement gauges

2) Tilt of the test block by tilt gauges

3) Lateral relative displacement between the test block and the reaction block by lateral displacement gauges

2.5 Results of static loading tests

Hysteresis loops of vertical displacement of the soil, tilt of the test block, and lateral displacement between the test block and the reaction block are shown in Fig.3 - Fig.6. Where in order to simplify the figures, the each loop represents 980kN to 9.8MN at the fifth cycle of the each loading step, so each loop does not continue. Some remarks obtained from the test results are as follows:

1) Regarding the vertical displacement of the soil, when the load exceeded 4.9MN, then the residual settlement after unloading became noticeable (the maximum is 37mm at 9 8MN loading), and the amount of settlement showed a tendency to increase as the load increased (the maximum is 40mm at 9.8MN loading).

2) Regarding the tilt of the test block, when the load increased in excess of 4.9MN then the increase of the amplitude became noticeable and the non-linear effect was observed to be remarkable. Moreover, a residual tilt occurred in the direction of pull load.

3) In the same manner of the tilt, regarding the lateral displacement between the test block and the reaction block, the amplitude increased with increasing load, and residual lateral displacement occurred in the direction of pull load.

4) The shear strain level of the soil exceeded 10^{-2} at near the corner of the test block, and exceeded 10^{-3} at wide area below the test block when the loading cycle was 9.8MN, as shown in Fig.7.

5) The deformation characteristics of the gravel deposits have strong non-linearity in a large shear strain range, and residual deformation increased as the load increased.

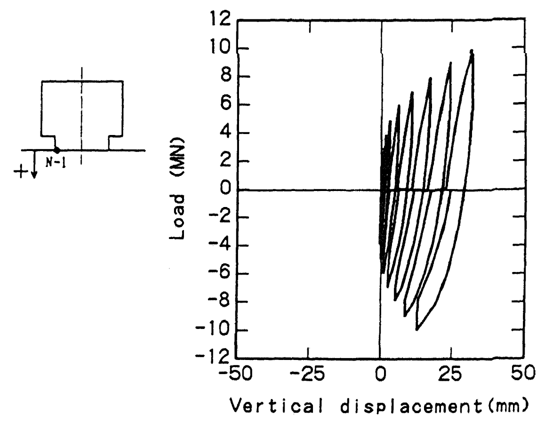

Fig.3 Vertical displacement (N-1)

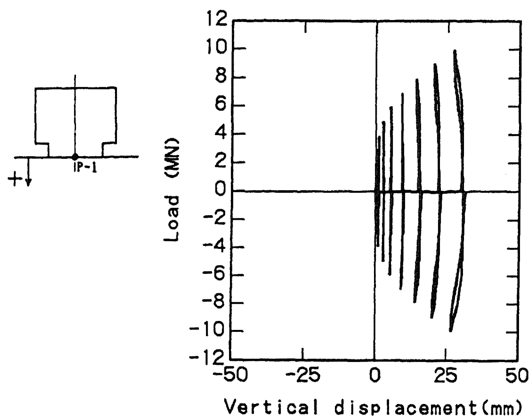

Fig.4 Vertical displacement (P-1)

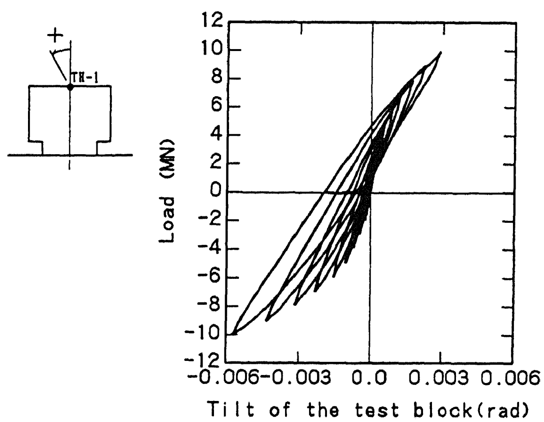

Fig.5 Tilt of the test block (TH-1)

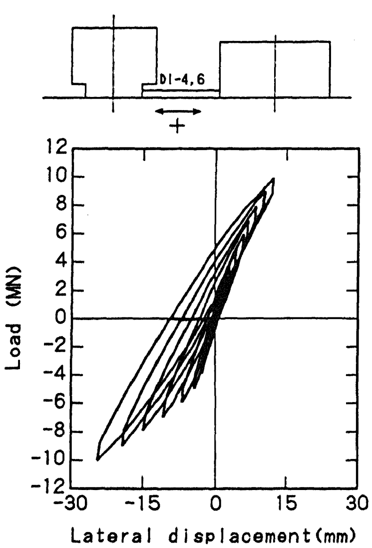

Fig.6 Lateral displacement between the test block and the reaction block (DI-4,6)

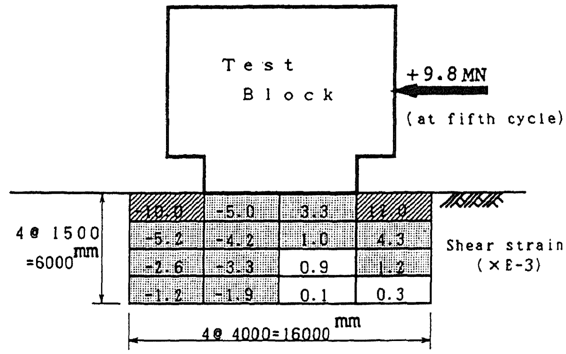

Fig.7 Shear strain of the soil

3 SIMULATION ANALYSES

3.1 Analytical method

Simulation analyses were worked out using Hara-Kiyota Model (Kiyota et al, 1988), and Nishi Model (Nishi et al, 1990). In this paper, Analysis 1 means the analysis by Hara-Kiyota Model and Analysis 2 means by Nishi Model. Analysis 1 is a non-linear method based on experimental equations which explain well the initial shear modulus obtained from laboratory tests, decline of the soil stiffness, and growing of the damping coefficient, but it can not explain dilatancy characteristics. So this method evaluates the amount of settlement independently using the shear strain loop of each soil element after FEM analysis completed. Analysis 2 is a method based on elasto-plastic theory to evaluate dilatancy characteristics directly using the material properties of gravel determined by various tests.

3.2 Analytical procedure

Analytical procedure is as follows:

1) The soil stress condition before static loading tests is calculated by means of Duncan-Chang model which is used for analyses of influences of excavation of surface soil and construction of concrete blocks. The FEM model is shown in Fig.8. The bottom of the model has a fixed condition, and at both sides, horizontal displacement is restrained.

2) Simulation analyses with Analysis 1 and Analysis 2 are performed on the same loading pattern as the Static loading tests. Analytical soil properties were estimated by laboratory tests of undisturbed gravel samples (Suzuki et al 1992) and tortional tests on large in-situ soil columns (Tateishi et al 1992). For both analyses, the relation between the initial shear modulus and effective confining stress of the gravel layer is given from the results

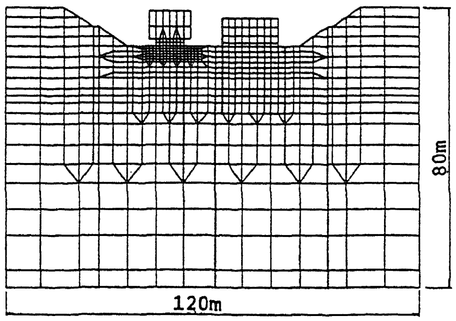

Fig.8 Analytical FEM model

of tortional tests on large in-situ soil columns as follows:

$G_0 = 3800 \times (\sigma_{m0}')^{0.8}$

G_0 :initial shear modulus(kPa)

σ_{m0}':effective confining stress(kPa)

The FEM model is shown in Fig.8. The bottom of the model has a fixed condition, and at both sides, vertical displacement is restrained. In Analysis 1, calculations were repeated until the stress-strain relation converges enough within each solution step. In Analysis 2, calculation was a load incremental method with a pitch of 19.6kN to ensure the accuracy of computation.

3.3 Results of simulation analyses

The items measured to compare with analytical value are the vertical displacement of the soil (N-1, P-1), the tilt of the test block (TH-1), and the lateral displacement between the test block and the reaction block (DI-4,6), as shown in Fig-1. Hysteresis loops at 9.8MN cycle by Analysis 1 and Analysis 2 are shown in Fig.9 -Fig.12 for each item measured. And relationships of load and deformation are shown in Fig.13-Fig.16. In these relationships, N-1 represents the settlement at fifth push loading, P-1 represents the settlement at fifth unloading, TH-1 and DI-4,6 represents the half of double amplitude at fifth cycle. Analysis 1 has a tendency of wider hysteresis loop than the measured value and Analysis 2 has a tendency of narrower loop. Relationships of load and deformation show that the amount of the vertical settlement of soil is almost the same between the analytical value and the measured one. Thus two methods of analysis simulates the measured values. And the tilt of the test block and the lateral displacement between the test block and the reaction block are almost the same until 6.86MN loading between Analysis 1 and Analysis 2, but when the loading exceeds 6.86MN, Analysis 2 produces lower values than Analysis 1. The ratio of Analysis 1 to the measured value is almost constant until 9.8MN.

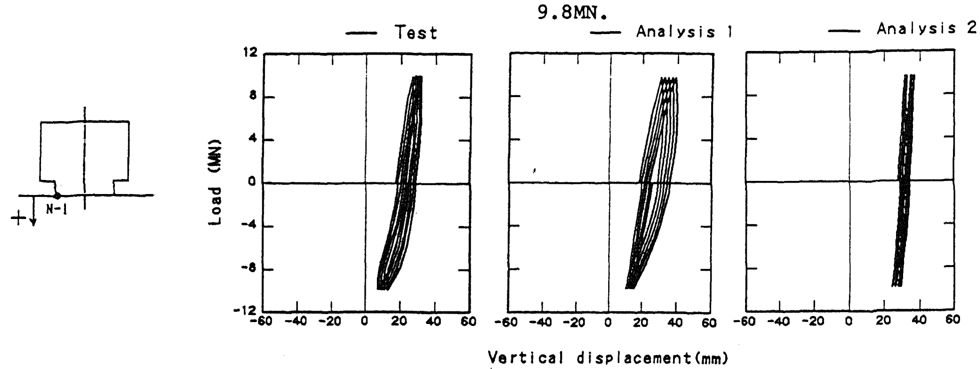

Fig.9 Hysteresis loop of the vertical displacement (N-1)

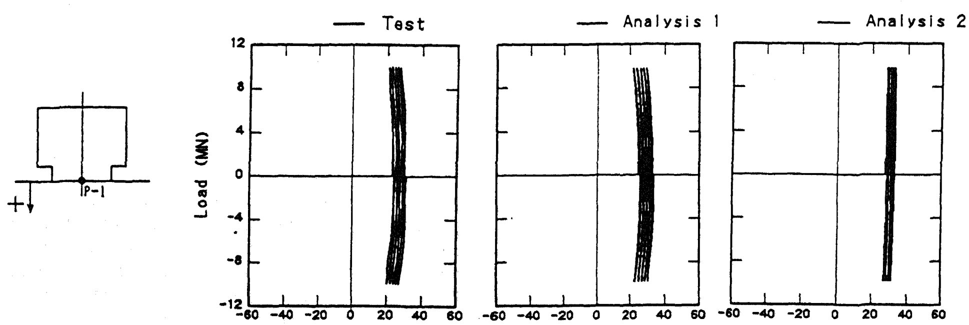

Fig.10 Hysteresis loop of the vertical displacement (P-1)

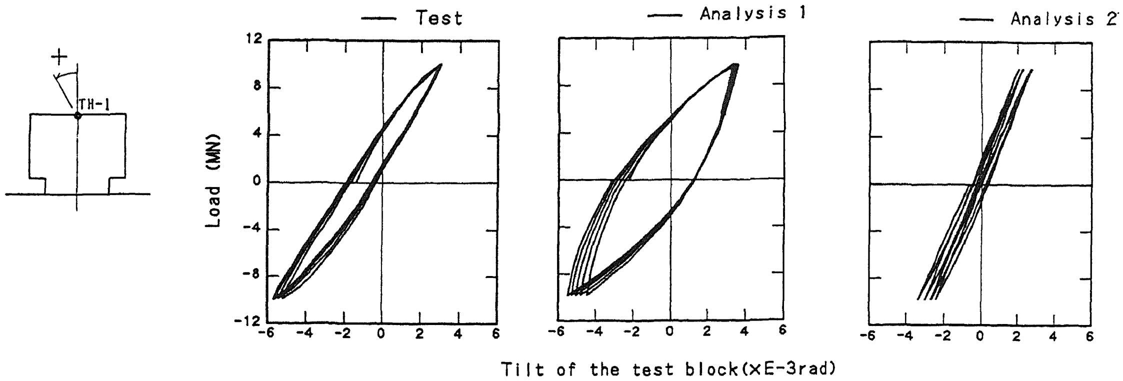

Fig.11 Hysteresis loop of the tilt of the test block (TH-1)

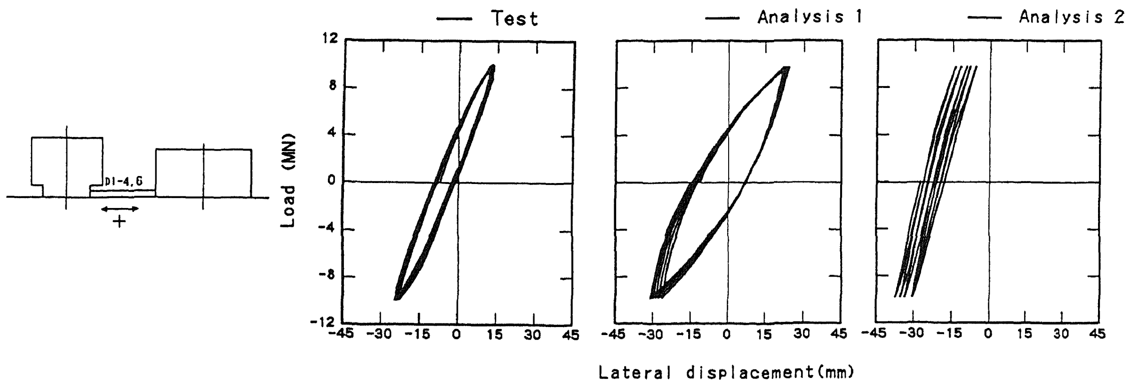

Fig.12 Hysteresis loop of the lateral displacement between the test block and the reaction block (DI-4,6)

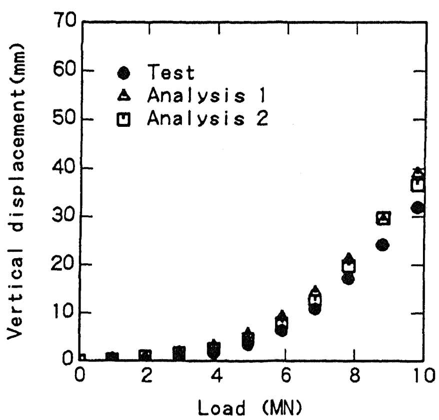

Fig.13 Relationship of load and the vertical displacement (N-1)

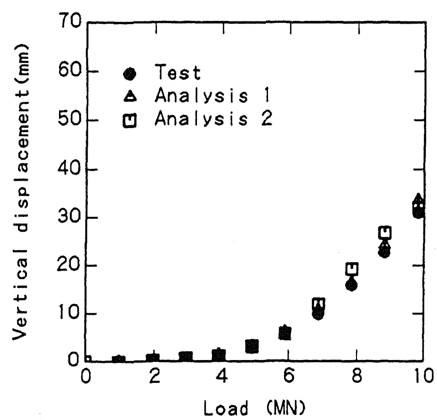

Fig.14 Relationship of load and the vertical displacement (P-1)

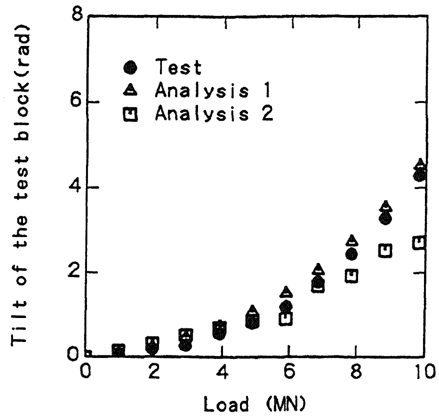

Fig.15 Relationship of load and the tilt of the test block (TH-1)

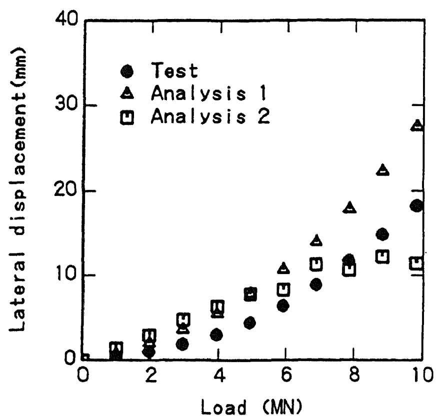

Fig.16 Relationship of load and the lateral displacement between the test block and the reaction block (DI-4,6)

4 CONCLUSIONS

As a result of this static loading tests on the actual diluvial gravel deposits, valuable data were collected regarding the cyclic deformation characteristics of Quaternary deposits under the condition of the earth contact pressure which is similar to actual reactor buildings. When the load exceeded 4.9MN, the amplitude of the tilt of the test block and the lateral displacement increased considerably, and the non-linear phenomenon of the soil was observed to be remarkable. Especially, the residual settlement after unloading became noticeable. At the final stage of the test, the shear strain level of the soil exceeded 10^{-3} below and around the test block.

After this static loading tests, two methods of FEM non-linear analyses were performed to simulate the field tests. The dilatancy characteristics can be estimated indirectly by Analysis 1, directly by Analysis2. Both analyses can simulate the non-linearity of the soil deformation. Evaluation of the cyclic deformation characteristics of Quaternary deposits was found out to be possible provided that soil properties from in-situ and laboratory tests are determined.

As a result of this study, a lot of excellent data were collected to verify the seismic siting technology for nuclear power plants built on Quaternary deposits. The actual reactor buildings in Japan are embedded, so the effect of embeddment will be a future subject.

5 ACKNOWLEDGEMENTS

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