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Cyclic deformation properties of gravel deposits

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ABSTRACT: There are many subjects to investigate on the way to establish the methodologies for seismic design of nuclear reactor buildings located on the Quaternary sand and gravel site in Japan. This paper presents important items, namely, evaluation of engineering characteristics of the soil, and analysis of soil dynamics and soil-structure interaction, for establishing the methodologies by means of investigation of large scale field tests on the Quaternary sand and gravel deposits.

1 INTRODUCTION

There is a basic policy in Japan that a nuclear reactor building must be constructed on a rock site. However, such sites are quite limited. In order to cope with the middle and long term siting problems, it has become necessary to develop new siting technology which may lead to increasing the available location for site selections and effective utilization of land. One of the solutions of this problem can be to locate a reactor building on the Quaternary deposits. The large scale field tests were carried out (as shown in Fig.1 and Fig.2)[1] on the Quaternary sand and gravel deposits (shear wave velocity is approximately 380m/sec) at the site of Tadotsu Engineering Laboratory of The Nuclear Power Engineering Center(NUPEC), in Kagawa Prefecture, Japan. Two objectives of those tests are: one is to obtain public acceptance by verifying the soil stability during large earthquakes by performing field tests using large scale models, that have the condition as close as possible to an actual nuclear reactor building, and the other is to confirm the adequacy of evaluation method for seismic design.

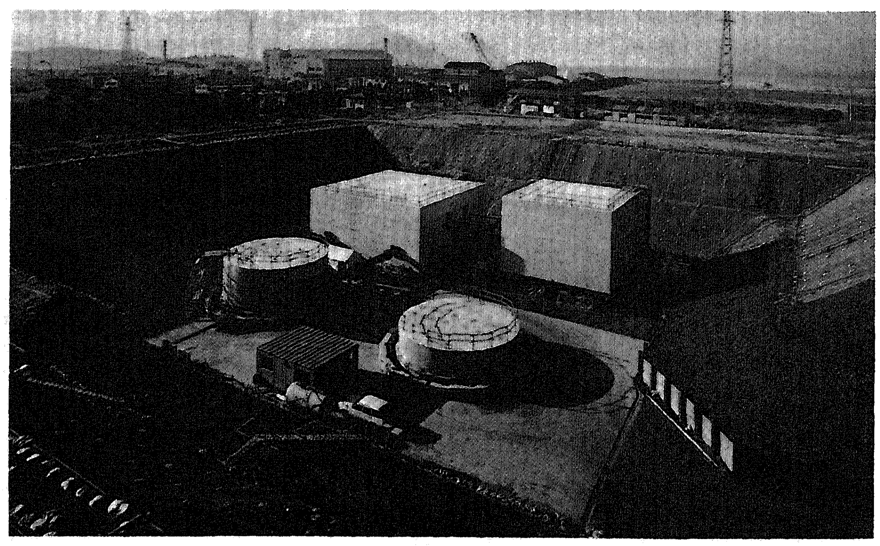


Fig.1 General view of the field test model

This paper describes an over-view on the results of large scale field tests on the Quaternary sand and gravel deposits comprehensively. It is considered great helpful to establish the methodology for seismic design of nuclear power plants located on the Quaternary sand and gravel site.

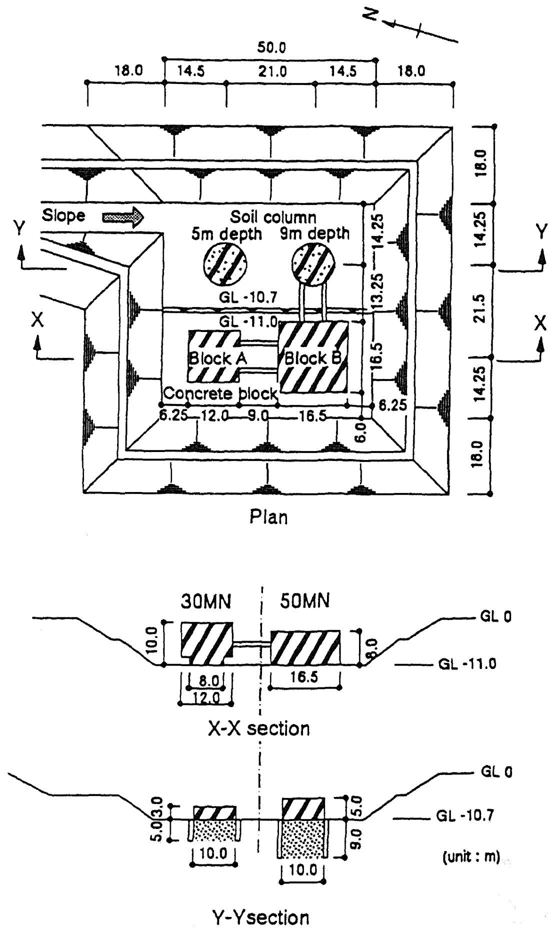


Fig.2 Layout of the field test model

2 METHODS

In order to establish the methodology for seismic design of nuclear reactor buildings constructed on the gravel deposits, the following three items are considered to be important.

1. Evaluation of engineering characteristics of the soil
2. Analysis of soil dynamics and soil-structure interaction
3. Establishment of input seismic motion

Hence, in this study, the following four subjects are referred to:

(1) Soil investigation
(2) Soil column test, and simulation analysis results
(3) Concrete block test, and simulation analysis results
(4) Shear-stack test, and simulation analysis results

Each test is expected to amass data related to the important items, shown in Table 1.

(1) In the soil investigation[2], laboratory tests were carried out, which use the high quality undisturbed frozen gravel samples to clarify the engineering characteristics of the gravel deposits and to incorporate them into the simulation analysis of the large field tests.

(2) In the soil column test[3], dynamic torsional loading test and static cyclic torsional loading test were carried out, in which two large cylindrical natural gravel specimens were utilized to investigate the dynamic properties and the cyclic deformation characteristics of gravel deposits subjected to a small shear strain level of 10^{-6} to a large shear strain level of 10^{-3}.

(3) In the concrete block test [4,5], dynamic loading test and static cyclic loading tests were carried out. Two huge concrete blocks on the gravel deposits, not embedded, were utilized to obtain many data of the dynamic soil-structure interaction at a state with about 470kPa contact pressure which is similar to the actual reactor building in Japan.

(4) In the shear-stack test[6], static cyclic loading test and shaking table test were carried out, where large shear-stack contained very dense sand on the shaking table was used to clarify nonlinear behavior on soil-structure interaction at large strain levels occurred by a strong shaking.

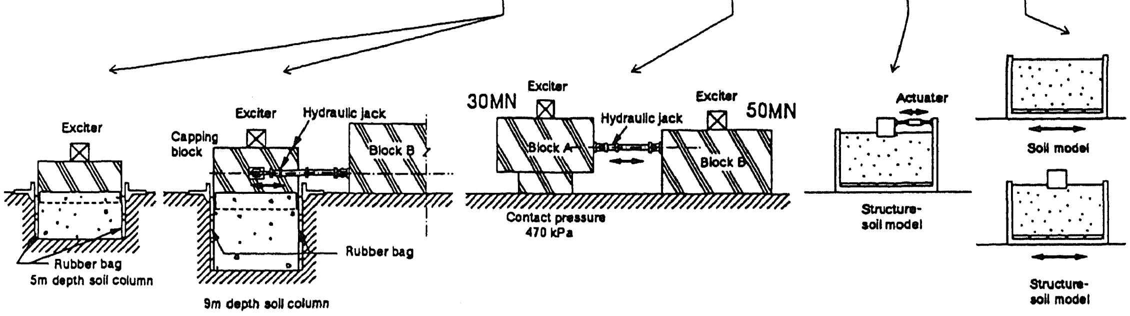
3 RESULTS

3.1 Evaluation of the engineering characteristics of soil

The relationship between initial shear modulus of gravel G_0 subjected to cyclic shear deformation and effective confining stress σ_m' in the soil investigation and soil column test are shown in Fig.3. It is clearly observed that G_0 increase in proportion to σ_m' in both tests. The relationship between shear modulus ratio G/G_0 and shear strain ratio $\gamma/\gamma_{0.5}$, and the relationship between dumping ratio h and $\gamma/\gamma_{0.5}$ in those tests are shown in Fig.4 and Fig.5. Where, shear modulus G is divided by G_0, and shear strain γ is divided by $\gamma_{0.5}$ that is shear strain level at $G/G_0 = 0.5$, in order to eliminate the effect of confining stress. The characteristics of dependence on shear

Table 1 Outline of tests

		Soil investigation	Soil column test: Static load	Soil column test: Dynamic load	Concrete block test: Static load	Concrete block test: Dynamic load	Shear-stack test: Static load	Shear-stack test: Shaking table
Investigation method of soil engineering property		○	○	○				
Soil engineering property	Cyclic shear deformation	○	○	○	○	○	○	○
	Initial strain				○			
Soil seismic stability	Nonlinearity of soil property	○	○	○	○	○	○	○
	Soil-structure interaction					○	○	○
	Effect of excess pore water pressure	○	○	○				○
	Amplification characteristic			○		○		○
Target level of maximum shear strain		—	5m depth: — 9m depth: 10^{-3}	5m depth: 10^{-4} 9m depth: 10^{-5}	Block A: 10^{-3} Block B: —	Block A: 10^{-4} Block B: 10^{-5}	10^{-3}	10^{-3}
Test method		Tri axial test In-situ test						



strain are almost identical between the soil investigation and soil column test in which specimen is a huge undisturbed gravel sample. Hence, it is confirmed that the soil laboratory test using undisturbed frozen gravel sample can be one of the available methods in order to evaluate the characteristics of gravel deposits.

3.2 Analysis of soil dynamics and soil-structure interaction

In the simulation analyses of the three tests, namely, dynamic loading test of soil column, dynamic loading test of concrete block, and shear-stack test using shaking table, the soil properties under shear deformation were assumed as shown in Fig.6. Some examples of the test results of resonance characteristics and their simulation analysis results for the medium shear strain level of 10^{-4} are shown in

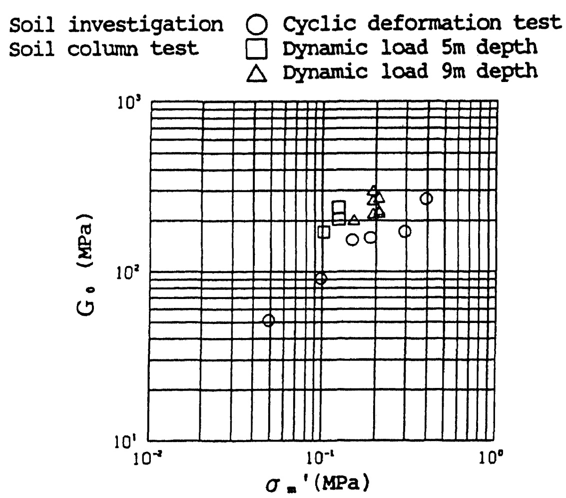


Fig.3 Relationship between initial shear modulus and effective confining stress

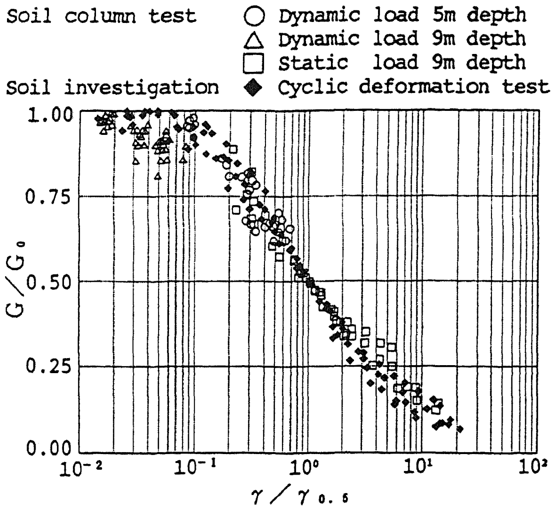


Fig.4 Relationship between shear modulus ratio and shear strain ratio

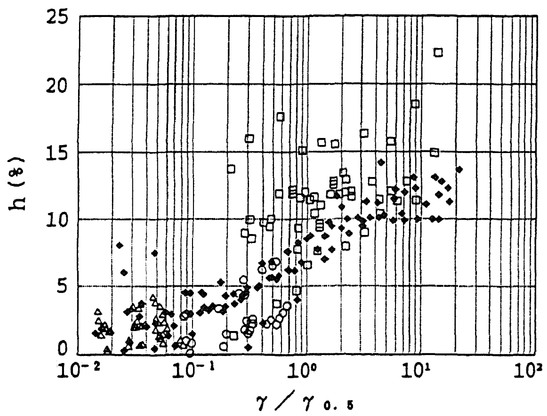


Fig.5 Relationship between dumping ratio and shear strain ratio

Fig.7, and an example of relationship between load and shear strain is shown in Fig.8. The analysis method of simulation for concrete block test is axi-symmetric finite element method, that for soil column test is axi-symmetric grid model, and that for shear-stack test is one dimensional multi-reflection theory. In either case, equivalent linear method using Hardin-Drnevich model or modified Hardin-Drnevich model was adopted.

As shown in Figs.7 and 8, it was verified that the results of large field tests can be simulated by the equivalent linear methods on condition that the cyclic characteristics of shear deformation is adequately determined. However, it was assumed that initial shear modulus are related to initial strain and confining stress of soil, hence it is necessary to assess these effects. Accordingly it is acknowledged that if only initial shear modulus and cyclic characteristics are adequately determined, it is possible to predict the behavior of gravel deposits, which are subjected to medium shear strain level of 10^{-4} occurred by an earthquake, using equivalent linear method that are generally applied to seismic design in Japan.

Time histories of load term, axial strain, and excess pore water pressure of the soil investigation and soil column test in the large strain level of 10^{-3} are shown in Fig.10. Those indicate clearly that the accumulation of residual settlement and the reduction of excess pore water pressure caused by dilatancy appear. In the static cyclic loading test of the concrete block, nonlinearity of soil appeared intensely at 5MN loading, where the shear strain of soil exceeds 1×10^{-3}, especially, residual

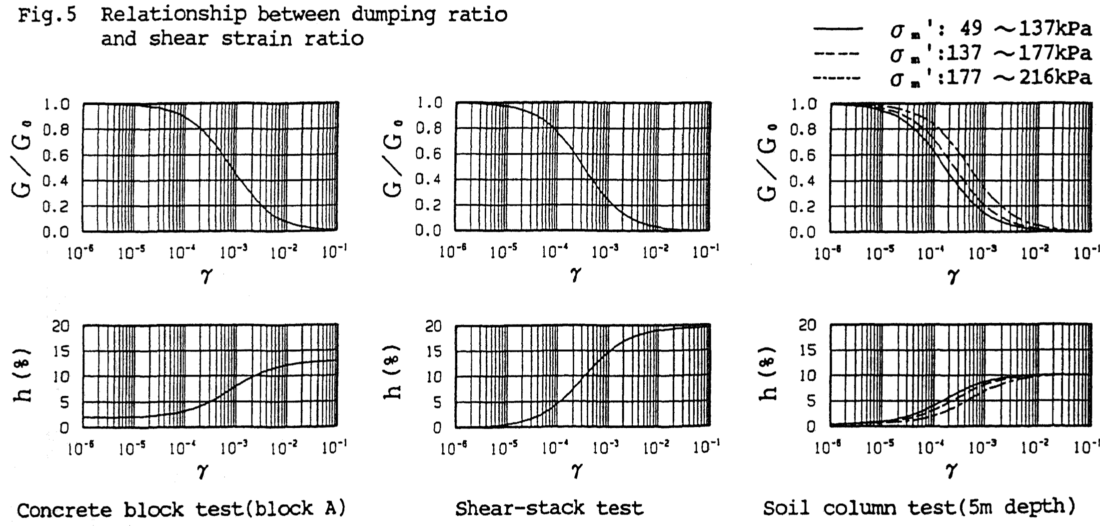
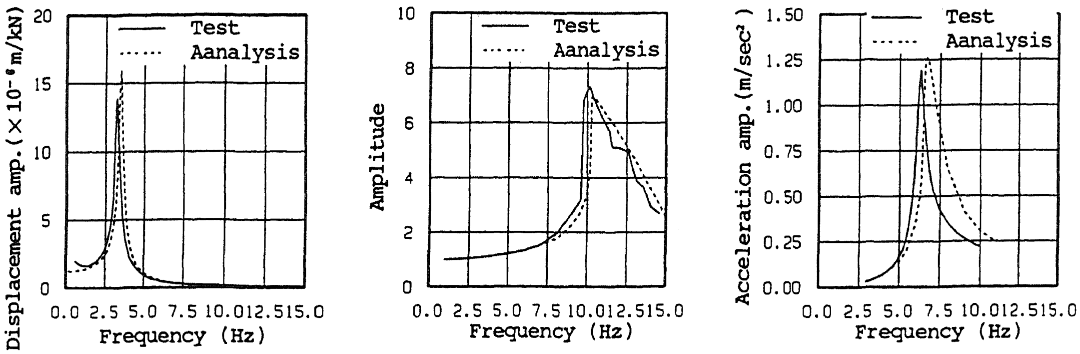


Fig.6 Soil properties used in simulation analyses



Concrete block test(block A) Shear-stack test Soil column test(5m depth)

Fig.7 Amplification characteristics of soil in the shear strain level of 10^{-4}

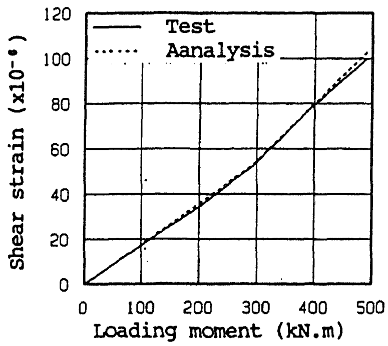


Fig.8 Relationship between loading moment and shear strain (soil column test: 5m depth)

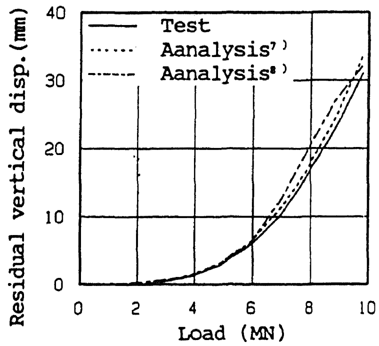
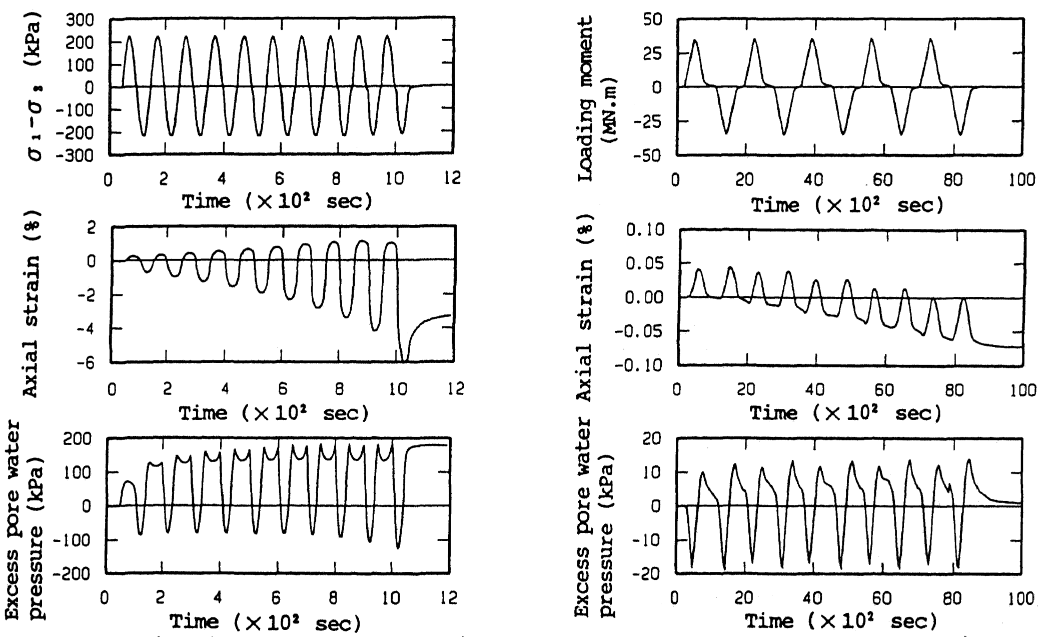


Fig.9 Settlement at center point (concrete block test: block A)



Soil investigation (Cyclic strength test) Soil column test(9m depth)

Fig.10 Time history of load, axial strain and excess pore water pressure settlement occurred remarkably (as shown in Fig.9). This phenomena was firstly observed at nature gravel deposits. Results of simulation analyses using Hara-Kiyota model [7] and Nishi model[8] , those are nonlinear analysis method considering dilatancy, are good coincident with the result of concrete block test. Hence, it is acknowledged that the excess pore water pressure and dilatancy are necessary to be taken into consideration in evaluating settlement of a structure constructed on the gravel deposits in the large strain level of 10^{-3}.

3.3 Amplification characteristics of soil

It is necessary to consider a nonlinearity of engineering characteristics of soil in order to evaluate the amplification characteristics of soil during earthquake. Based on the results of simulation analyses for the shear-stack test using shaking table and dynamic loading test of soil column (as shown in Fig.7), it can be said that the one dimensional multi-reflection theory and grid model, which applied equivalent linear method are an available method for estimating the amplification of horizontal motion of gravel deposits.

4 CONCLUSIONS

From the results of the over-view mentioned above, the following conclusions can be stated:

1. The soil laboratory test using undisturbed frozen sample is adequate to evaluate the characteristics of gravel deposits.
2. Evaluation of initial shear modulus, depending on confining stress and shear strain of soil, which subject to cyclic shear deformation, are essential to estimate the seismic stabilities of nuclear power plant constructed on the gravel deposits.
3. It is recognized that the behavior of gravel deposits in the medium strain level of 10^{-4} induced by an earthquake can be evaluated by means of equivalent linear method.
4. The excess pore water pressure and dilatancy are necessary to be taken into consideration in evaluating settlement of a structure supported on the gravel deposits in the large strain level of 10^{-3}.

5 ACKNOWLEDGEMENT

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