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SEISMIC VERIFICATION PROGRAM OF NUCLEAR POWER PLANTS QUATERNARY DEPOSIT IN JAPAN

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1. Background

Siting of N.P.P.s on Quaternary deposits is common in Europe and the U.S.A.. In Japan, however siting on rock has been required so far because of frequent occurrence of intense earthquakes.

The technology to build N.P.P.s on Quaternary deposits is hopeful to extend the siting option because rock sites are limited in Japan. So,Nuclear Power Engineering Corporation (NUPEC) has been operating an investigation program regarding the soil stability, R/B concept, safety of plant equipment etc. under the sponsorship of the Ministry of International Trade and Industry of Japan and the cooperation of scholars and industry from 1983 to 1998. The final goal of the program is to establish a draft of guidelines on seismic design for siting on Quaternary deposits. In this report, the outline of this project and present status are mentioned.

2. Outline of the project

This project consists of three sub-projects. The summary of each sub-project is described as follows with a flowchart showing the process of this project(see Figure 1).

2.1 Investigation of soil stability during large earthquakes

The large-scale field tests were carried out on Quaternary sand and gravel deposits, from 1983 to 1989 in order to verify the soil stability during large earthquakes. The tests are as follows: 1) Soil investigation, 2) Soil column test, 3) Concrete block test, 4) Shear-stack test. Total investigations were performed using those test results and their simulation analyses.

2.2 Investigation of the seismic capability of reactor building and equipment

To verify overall technology for the siting on Quaternary deposits,such items have been studied as reactor building (R/B) concept, stabilities of soil and R/B and safety of plant equipment.

2.3 Investigation of seismic evaluation method

Investigations to establish a draft of guidelines for the seismic design of N.P.P. built on Quaternary deposits and to determine the design basis

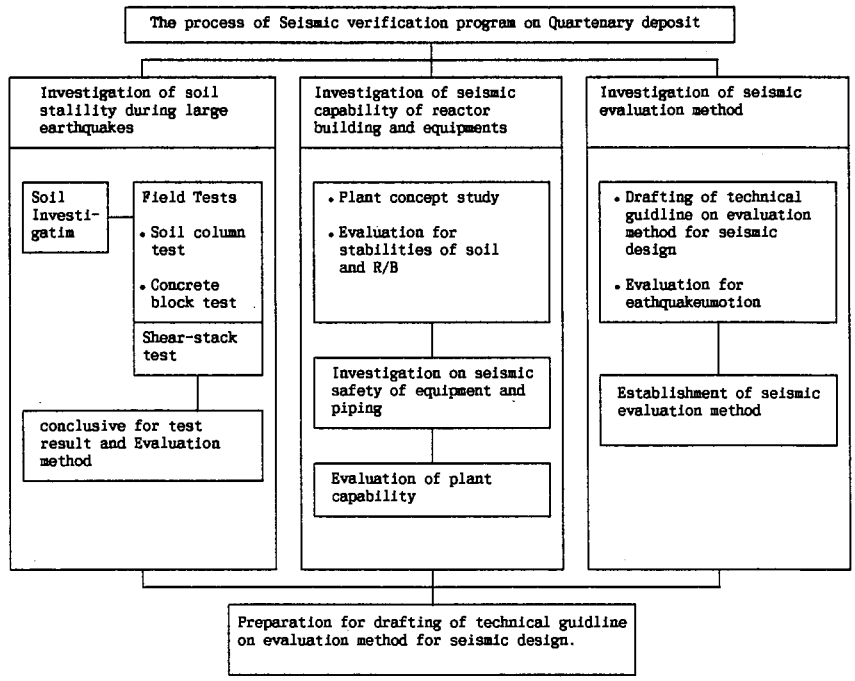


Fig.1 Process of the seismic verification program for Quaternary deposits

earthquake have been under way incorporating the results of sub-projects 2.1 and 2.2.

3. Present status of each investigation sub-program

The present status of three sub-projects are as follows:

3.1 Investigation of soil stability during large earthquakes

The large scale field tests were carried out (as shown in Figure 2) on Quaternary sand and gravel deposits (shear velocity is approximately 380m/sec) at the site of Tadotsu Engineering Laboratory of NUPEC, in Kagawa Prefecture, Japan. Two objectives of those tests are:one is to verify the soil stability during large earthquakes by performing field tests using large scale models, which have conditions as close as possible to an actual nuclear reactor building, and the other is to confirm the adequacy of evaluation method for the stability tests.

In this investigation, the following four subjects were performed:

a) Soil investigation [2]
b) Soil column test [3]
c) Concrete block test [4] [5]
d) Shear-stack test [6]

Each test was expected to gather data related to the important items, shown in Table 1.

As the conclusion of those tests, the followings could be stated: [7].

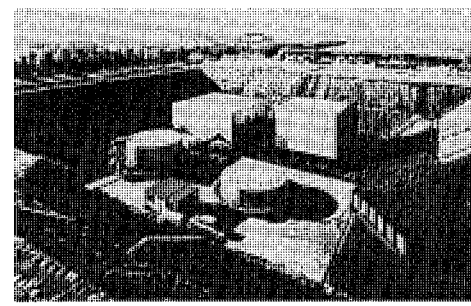


Fig.2 General view of the field test model

(1) The soil laboratory test using undisturbed frozen samples is adequate to evaluate the characteristics of a Quaternary sand and gravel deposits. The relationship between shear modulus ratio and shear strain ratio is shown in Figure 3, and relationship between dumping ratio and shear strain ratio is shown in Figure 4.

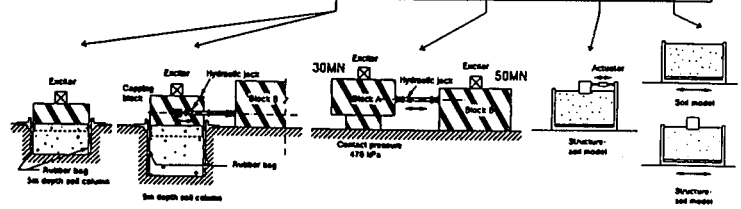
(2) Evaluation of initial shear modulus, depending on confining stress, which subject to cyclic shear deformation, is essential to estimate the seismic stabilities of reactor building constructed on a Quaternary sand and gravel deposit site. The relationship between initial shear modulus and effective confining stress is shown in Figure 5.

(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 eqivalent linear method. The amplification characteristics of soil in the shear strain level of 10^{-4} is shown in Figure 6.

(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}. The time histories of load, axial strain and excess pore water pressure are shown in Figure 7.

Table 1 Outline of tests

		Soil investigation	Soil column test		Concrete block test		Shear-stack test	
			Static load	Dynamic load	Static load	Dynamic load	Static load	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 —	5m depth 10^{-3}	5m depth 10^{-4}	5m depth 10^{-3}	Block A 10^{-3}	Block B —	Block A 10^{-4}	Block B 10^{-3}	10^{-3}	10^{-4}
Test method		Tri axial test In-situ test						



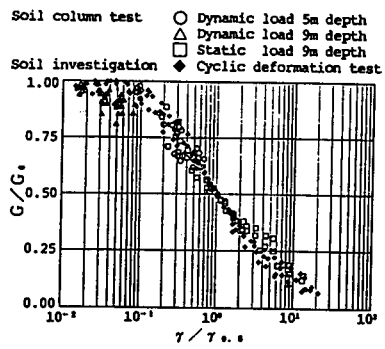


Fig.3 Relationship between shear modulus ratio and shear strain ratio

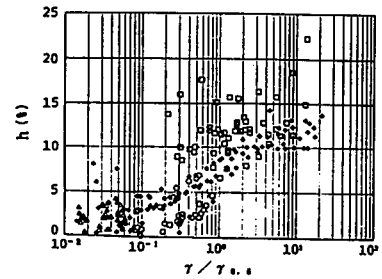


Fig. 4 Relationship between dumping ratio and shear strain ratio

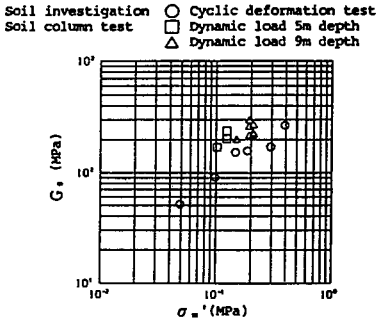


Fig.5 Relationship between initial shear modulus and effective confining stress

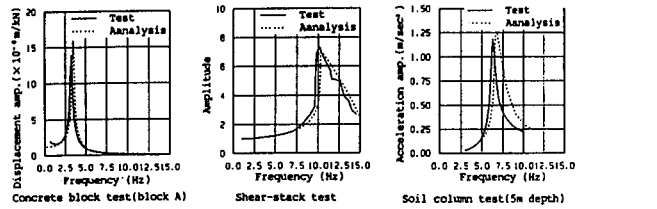


Fig.6 Amplification characteristics of soil in the shear strain level of 10^{-4}

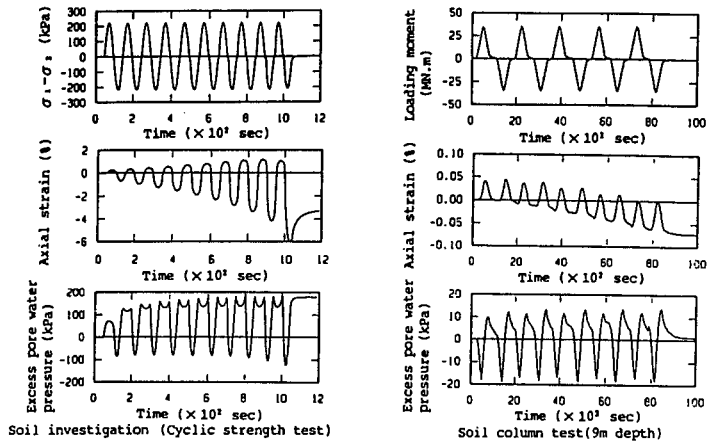


Fig.7 Time history of load, axial strain and excess pore water pressure

3.2 Investigation of the seismic capabilities of reactor building and equipment

a. Plant concept study

To extract technical issues for plant systems, first of all, thermal power stations and chemical plants on Quaternary deposits were investigated.

Based on the results of this investigation, the countermeasurers for R/B arrangement to mitigate the technical issues were studied as follows:

(1)Rearrangement of heavy equipment from upper floor to lower floor

(2)Reduction of primary containment vessel height

(3)Lightened upper structure and enlargement of R/B base-mat size

And the following several cases of plant concept for BWR and PWR were examined according to studying the effective R/B mat types for siting on Quaternary deposits. Each plant concept for BWR are shown in Figure 8.

(1)The current R/B concept which has been sited on rock so far in Japan is applied for siting on Quaternary deposits.

(2)A common mat building concept in which R/B and other buildings are arranged on a common mat to reduce bearing pressure.

(3)A enlarged and stepped mat building concept to keep the stability for sliding during earthquake.

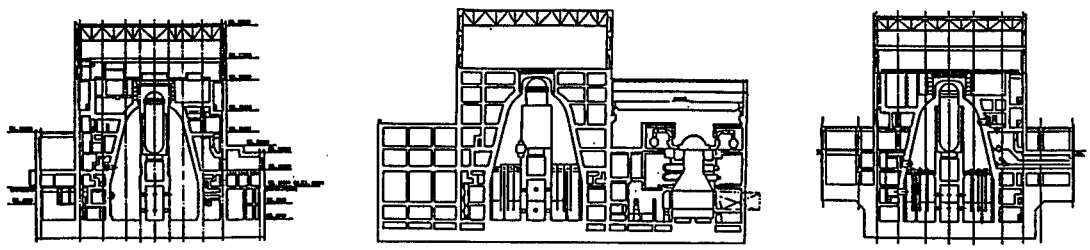


Fig.8 Plant concepts

b. Seismic stabilities of building and bearing soil and technical issues of plant equipment

Characteristics of Quaternary deposits are compared to rock, where soil strength and stiffness are smaller and ground motion in low-frequency range is larger.

A series of soil-structure interaction analysis by FEM was worked out on each plant concept shown in Figure 8 to clarify the technical issues concerning stabilities of building, and bearing soil and issues of plant equipment. The series of soil-structure interaction analysis by sway and rocking model incorporating embedment effect was worked out to study the effect of soil condition and embedment depth. Plant response characteristics on Quaternary deposits have been identified(see Figure 9). Evaluation on these issues will be continued and seismic safeties of building,bearing soil and plant equipment will be verified.

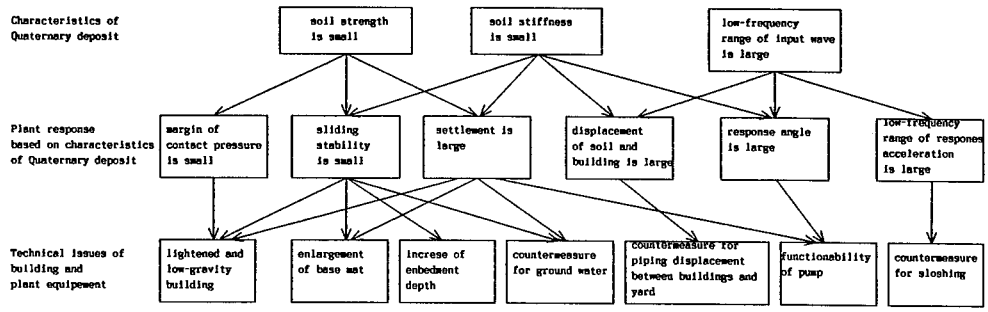


Fig.9 Technical issues of building and plant equipment

3.3 Investigation on seismic design evaluation method

a. Drafting of technical guidelines on evaluation method for seismic design

To establish the drafting of guidelines on the seismic design for siting of N.P.P. on Quaternary deposits, incorporating with the results of verification tests in this project and achieved research and development studies in the other projects, the following items have been studied.

a)Geological Survey
b)Soil Investigation
c)Seismic Ground Motion
d)Stability of Soil Foundation
e)Structural Analysis and Design
f)Seismic Safety of Equipment and Piping
g)Stability of Surrounding Slope
h)Seismic Safety of Outdoor Important Structure

b. Evaluation on seismic ground motion

In order to investigate seismic design of the structure constructed on Quaternary deposits which is softer compared with bed rock, it has become necessary to define properties of seismic ground motion propagating in Quaternary deposits and non-linearities caused by increase of soil strain occuring during large ground motion.

The following two methods will be considerd in evaluation on seismic ground motion as shown in Figure 10.

a)Amplification analysis based on design basis ground motion defined on outcrop

b)Evaluation on the spectrum of ground motion at the surface of Quaternary deposit referring to observed records

The following survey and investigations are continued in the light of the justification of the above mentioned two methods.

- Collection of ground motion records in Quaternary deposits
- Characteristics of peak amplitude
- Characteristics of response spectrum
- Analysis of duration time and envelope curve
- Non-linear characteristics of soil during intense ground motion
- Survey of vertical component of ground motion in Quaternary deposits

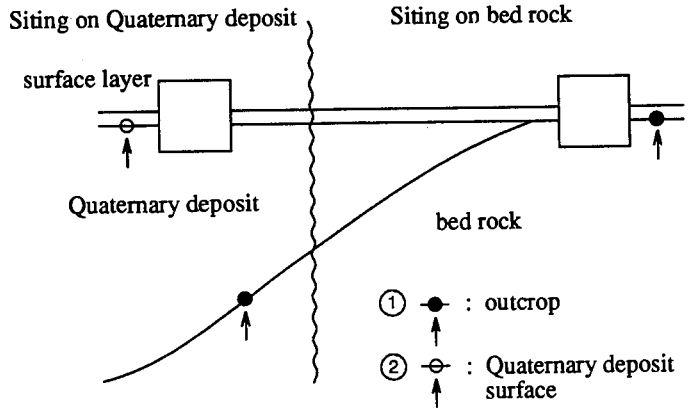


Fig.10 Evaluation on Seismic Ground Motion

4. Conclusion

The seismic verification program of N. P. P. s which will be built on Quaternary deposits in future in Japan has been investigated. The evaluation on the technical issues of building and plant equipment will be continued and seismic safety of building, bearing soil and plant equipment will be confirmed. The investigation on seismic safety of equipment and piping is scheduled from 1995 to confirm plant seismic safety.

5. Acknoledgement

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