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PRELIMINARY ASSESSMENT ON DYNAMIC INTERACTION OF DEEPLY BURIED NUCLEAR POWER BUILDINGS

K. TOGASHI[1], Y. KITAGAWA[1], H. KAWAMURA[2], and K. ANDO[2]

1) Civil Engineering and Architectural Department, The Japan Atomic Power Company, Ohtemachi Bldg., 1-6-1, Ohtemachi, Chiyoda-ku, Tokyo 100, Japan
2) Design Department No.2, Obayashi Corporation, 2-2-9, Hongo, Bunkyo-ku, Tokyo 113, Japan

ABSTRACT

This paper summarizes dynamic interaction of structures which have different shape, size, and foundation system through a feasibility study of a deeply buried Advanced Boiling Water Reactor (ABWR). This evaluation is performed by dynamic experiment and analysis. The scale of experiment is 1/100, and real sand is used to consider non-linear behavior of soil. Six cases are included soil model, single reactor building (R/B), turbine building (T/B) with pile foundation, T/B with slurry + pile foundation, and R/B-T/B (both foundation cases) coupled models. We confirm that dynamic behavior of R/B and T/B with non-linear behavior of soil. The applicability of two dimensional dynamic analysis is validated by comparing experiment result for behavior of structures. All structures followed by surrounding soil, and especially T/B with pile foundation is strongly influenced because of its foundation type.

KEYWORDS

Dynamic Experiments, Analysis, Soil-Structure Interaction, Deeply buried, Nuclear Facility, Reactor Building, Turbine Building, Pile Foundation

INTRODUCTION

Next generation, stable clean electricity supply is required. Safety and economical concerned, smaller-scale large-capacity reactors have been developed and planed at nuclear power plants. The expansion of site feasibility makes an Reactor Building(R/B) be buried about 40m for direct support on bed rock. For more deeply buried R/B, it will be required to evaluate the dynamic behaviors of buildings and interaction between soil and buildings during strong earthquake, which will give us an appropriate design frame work.

Soil-structure interaction and structure-structure interaction have been evaluated experimentally and analytically through the feasibility study of twin-type Advanced Boiling Water Reactor (ABWR) and a Turbine Building (T/B).

In the preliminary stage[1], a base case layout is set up as Fig. 1. The reactor building with 85m diameter is planned to directly supported by the bed rock located below 65m sediments. For construction of R/B, cylindrical slurry wall is planned for bearing the earth pressure and keeping water tightness. A turbine building (T/B) with 210m × 110m rectangular shape is supported by pile or pile + slurry wall foundation.

Geological condition of the expected site is consists of about 65m Quaternary sediments with 10m-soft sand, 15m-sandy gravel, and 40m-silt. The bed rock is located below the sediments and the water table is 4m below the ground surface.

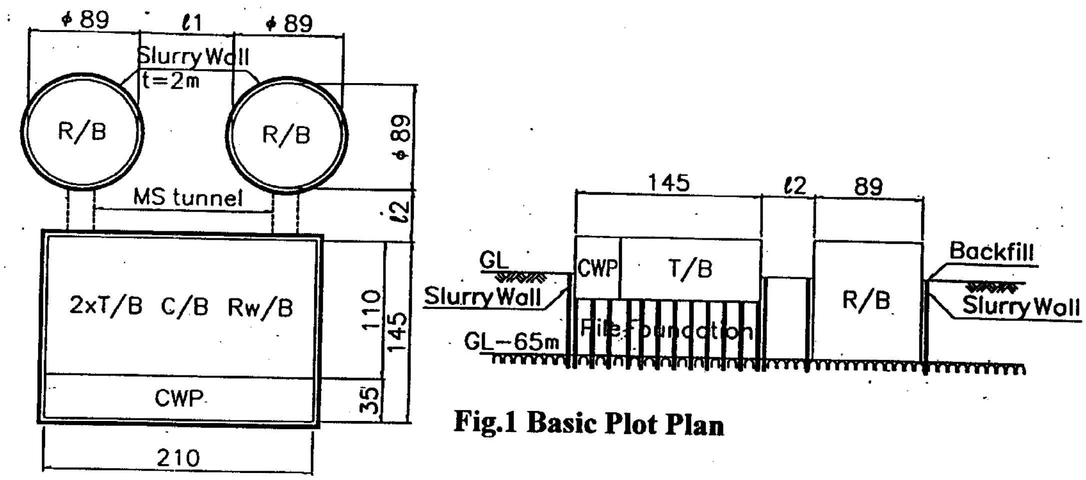

Fig.1 Basic Plot Plan

OBJECTIVES

One of the main objectives of this feasibility study is to assess the dynamic interaction of earthquake between a deeply buried cylindrical R/B directly based on bed rock and a rectangular T/B supported by pile foundation during strong earthquake as well as ordinary earth and groundwater pressure.

Another is to validate the numerical method for evaluation of interaction between R/B and T/B as well as soil-structure interaction.

As an additional object, the dynamic behavior of T/B with pile foundation and pile + slurry wall foundation are compared and evaluated.

Based on this preliminary assessment, we try to archive the design methods for supported structures such as T/B with considering interaction of R/B closely constructed to T/B because of high performance generating steam system.

EXPERIMENTAL CONDITION

As mentioned above, geological condition of expected site is complex and non-linearly behaved during earthquake. In the experiment, soil model is single sand layer, called Gifu-sand which is selected for experiment because it is widely used[2] and well known material, and easy evaluation of non-linear behavior, setting and remaking same condition. Before experiment, S-wave velocity and geological properties of sand layer including non-linearity is measured as shown in Table 1 and Fig. 2. To keep the soil condition, density is checked during experiment.

Similitude rule is introduced in Table 2. For example, structural scale of experiment is 1/100 of real structures . Acryl is used for material of structure model and structural properties are also shown in Table 3. R/B model is connected to shaking table as same condition as real R/B directly supported by host rock.

Harmonic wave and artificial design seismic waves (See Fig. 3), S1 (157 gal at the base of R/B) and S2 (291 gal at the base of R/B) are used as input motion for analysis and experiments.

Table 1 Soil Propertiies

Matrial	Gigu-sa (sand)
Dry density (kg/cm3)	1.58
S-wave Velocity (m/sec)	120
Initial Shear Modulas (t/m2)	2300

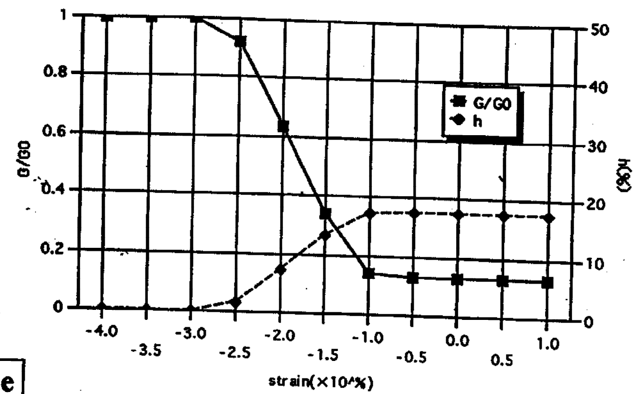

Fig. 2 Dynamic Property of Soil

Table 2 Similitude Rule

Item	Model	Real	Similitude
Geometric ratio (m)	1.0	100.0	$1/\lambda$
Density Ratio (t/m3)	1.6	1.6	$1/\eta$
S-wave Velocity (m)	120	384	$(\eta/\lambda)^{0.25}$
Elasticity Ratio (kg/cm^3)	3.0E4	3.0E5	$(\eta\lambda)^{-0.5}$
Acceleration Wave	S1, S2	S1, S2	1
Strain	1	10	$(\eta\lambda)^{-0.5}$
Characteristic Frequency (Hz)	29	0.9	$\eta^{0.25}\lambda^{0.75}$

Table 3 Structural Properties

Material	Acryl
Density (t/m3)	1.13
Young Modulus (kg/cm2)	3.0E5
Poason ratio	0.37

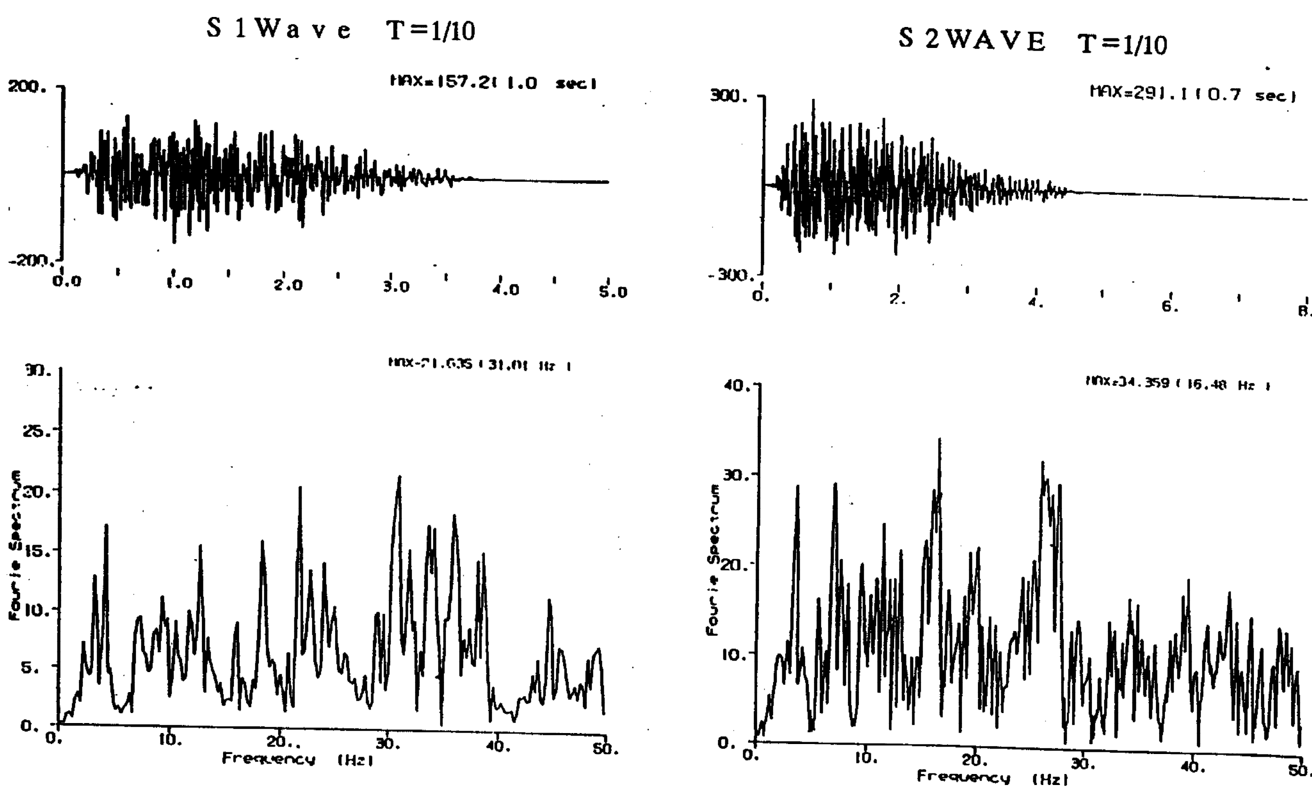

Fig. 3 Input Motion

MODELS AND METHODS

Cases of experiment and analysis are shown in Fig. 4. Case 1 is soil model for calibration between experiment and analysis. From case 2 to Case 4, single structure with soil model is evaluated. Case 5 and Case 6 are for interaction between R/B and T/B.

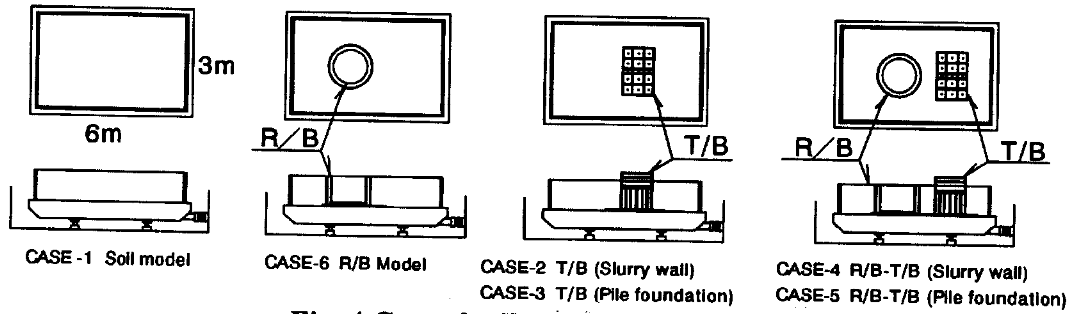

Fig. 4 Cases for Experiment and Analysis

1) Experiment

One of the largest shaking table[3] in Japan is used for dynamic experiment and size of model container is 6.5m length, 3.0m wide, and 0.65m depth filled with sand. 1/100 scale dynamic experiment is carried out, so 65m
sand layer is modeled. Steps of experiments are as follows;

i) Measure characteristic period of structures, sand layer, and container,
ii) Set the strain gages, acceleration gages, and earth pressure gages,
iii)Locate single building (R/B, T/B) inside container,
iv)Shake the model with harmonic wave (40gal, 60gal, 80gal) and artificial design waves (S1 and S2) until 50Hz, and
v) Evaluate the dynamic interaction of R/B-T/B.

2) Analysis

Case-1 to Case-6 are dynamically analyzed by two dimensional finite element method (code: FLUSH). Analysis models shaking table and sand container as shown in Fig. 5. Measured wave during experiment is used as input motion.

To model two dimensionally, share stiffness and bending stiffness are equivalently evaluated as experimental model. In cylindrical R/B, all cross sectional area is effective for bending stiffness, and half of cross sectional area is effective for share stiffness[4]. In case of rectangular T/B, web is for share, and flange is for bending stiffness.

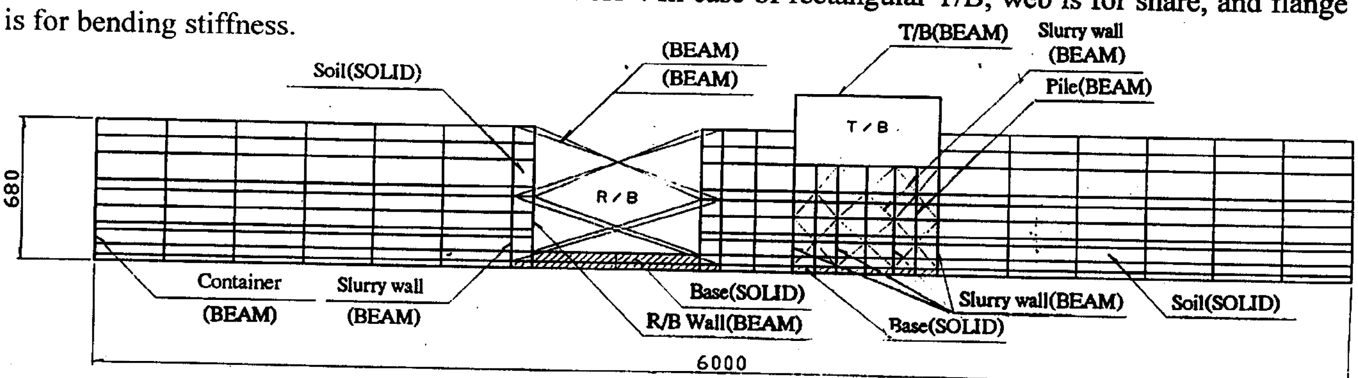

Fig. 5 Model of Analysis

RESULTS

Characteristic periods of each sand layer, R/B, T/B with pile foundation, and T/B with pile + slurry wall foundation are compared between experiment and analysis in Table 4. According to this comparison, analysis model is well represent the experiment.

Table 4 Characteristic Frequency (Hz)

Properties	Experiment	Analysis
Sand layer	26	26
R/B	73	65
T/B with pile foundation	10	10
T/B with pile + Slurry wall	97	80

1) Experiment

From the experiment, we confirm that behavior of soil around the structure is strongly influenced by the stiffness and/or shape of structures. Also structures are followed by the surrounding soil which behaves non-linearly during earthquake.

Experimental results of Case-1 to Case-6 are summarized as follows:

a) Dynamic behavior of R/B

According to the experimental result of R/B behavior shown in Fig. 6, R/B is followed by the surrounded ground which behaves non-linearly during the earthquake motion. But acceleration of R/B are relatively smaller than ones of ground. The influence of R/B on surrounding soil is negligible where the distance is more than one diameter from R/B. This trend is also found in the analysis.

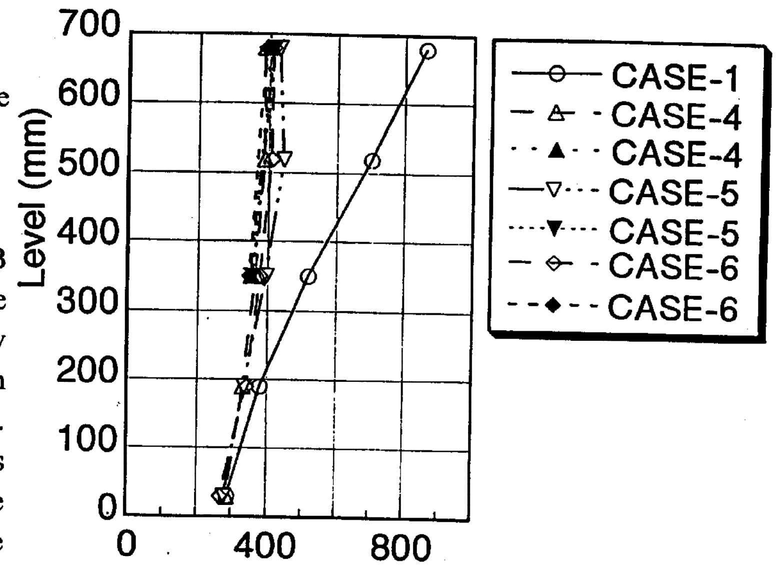

Fig. 6 Maximum Acceleration of R/B

b) Dynamic behavior of T/Bs

The experimental results of Case-2 (T/B with pile foundation) and Case-3 (T/B with pile+srully wall foundation) are shown in Fig. 7. It is confirmed that T/B with pile foundation is shake almost same level as ground motion during earthquake. T/B with pile foundation moved more than T/B with pile+srully wall foundation.

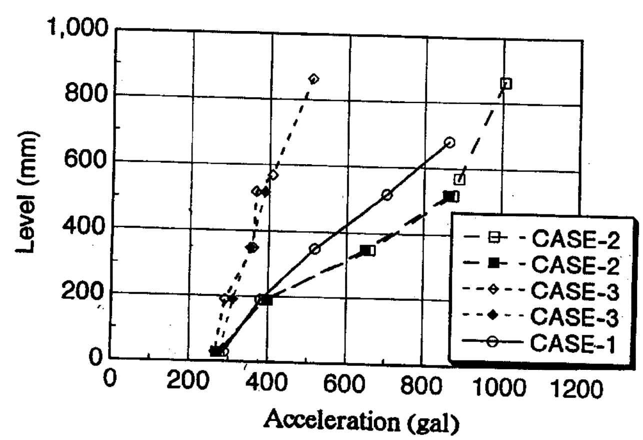

Fig. 7 Maximum Acceleration of T/B

c) Interaction between R/B and T/B

Case 4 (R/B-T/B with pile foundation) and Case 5 (R/B-T/B with pile + slurry wall foundation) shown in Fig. 8, are R/B-T/B interaction cases. The acceleration of T/B are decreased from ones of single model in

Case 4. According to the result of Case 5, T/B with pile + slurry wall foundation is not influnced by R/B strongly. The acceleration and displacement of soil between R/B and T/B (see Fig. 9) decreased from ones of single model. The relative displacement between R/B and T/B of Case 4 is approximately three times larger than one of Case 5 (see Fig. 10). These results are also simulated by the analysis of these models.

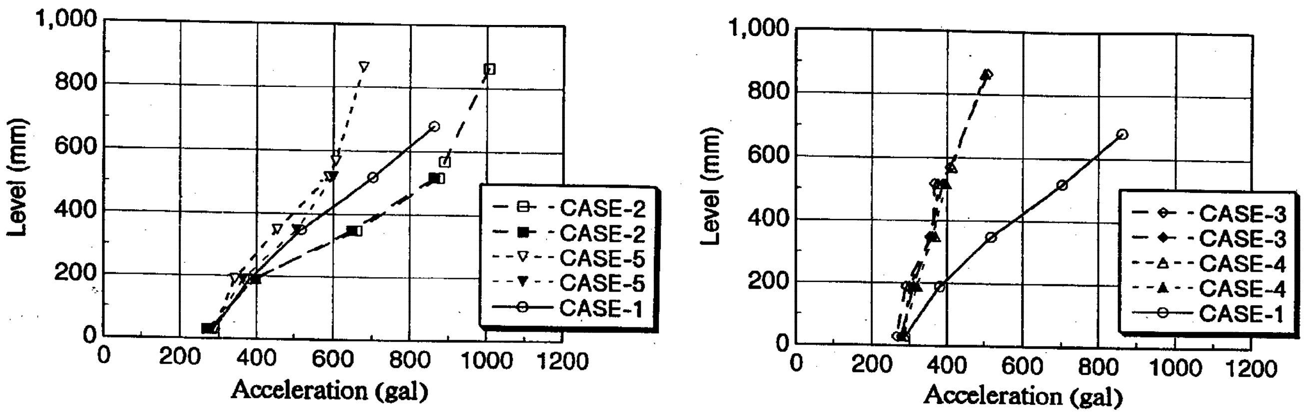

Fig. 8 T/B maximum accleration displacement with comparing single T/B and R/B-T/B

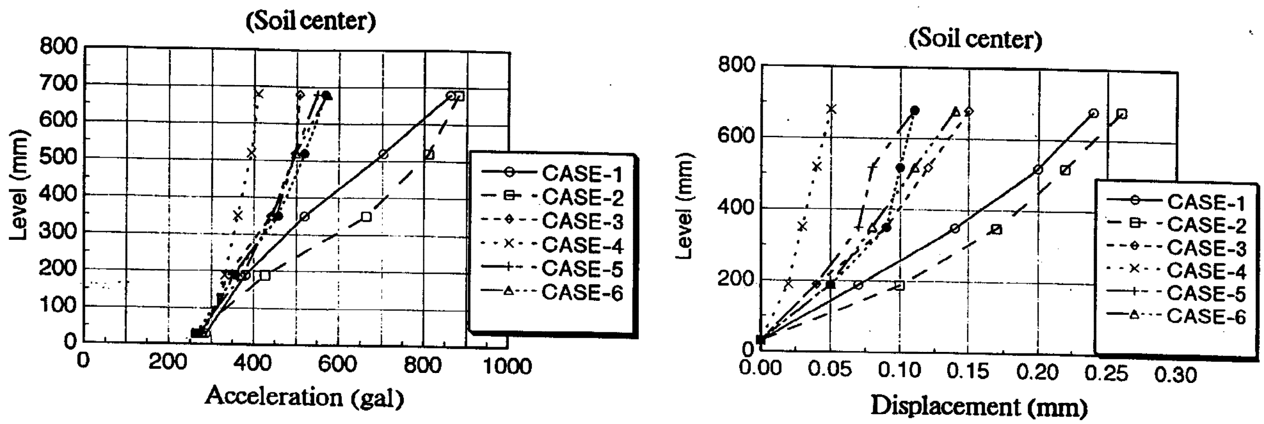

Fig. 9 Maximum Acceleration of Soil with all cases

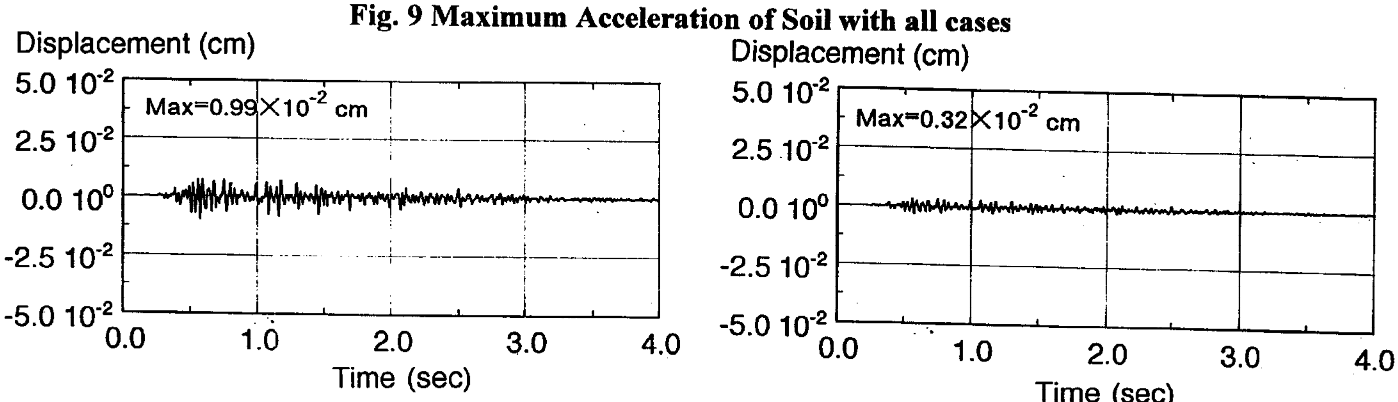

Fig. 10 Relative Displacement between R/B and T/B

2) Analysis

Soil model simplified from the geological condition is simulated the real soft soil with non-linear properties corresponding to the strain of soil. We confirm dynamic behavior of deeply buried coupled structures.

a) Dynamic behavior of R/B

According to the analytical result of Case 6 shown in Fig. 11, R/B is followed by the surrounded ground and acceleration and displacement of R/B are relatively smaller than ground, which are same trend as experiment.

The result of ground motion indicates that the difference of acceleration between R/B and soil in experiment is smaller than one of analysis, because the cylindrical R/B in the experiment creates stress-flow more smooth than two dimensional modeling.

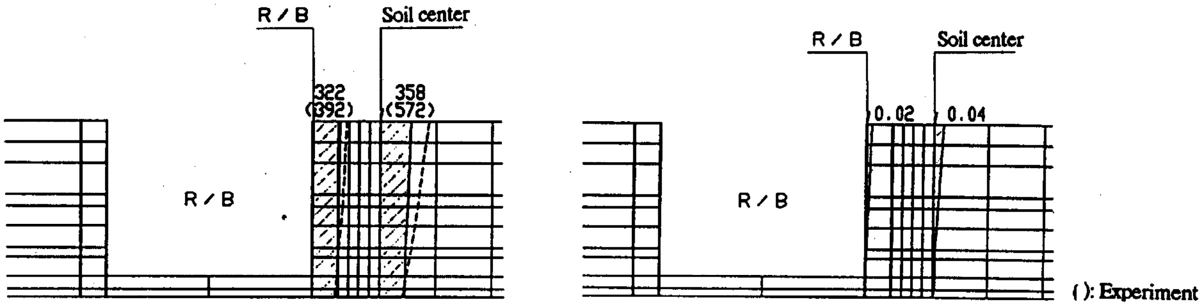

Fig. 11 Maximum Acceleration of R/B and Soil

b) Dynamic behavior of T/Bs

The analytical results of Case 2 (T/B with pile foundation) and Case 3 (T/B with pile+srully wall foundation) are shown in Fig. 12. In the figure, experiment and analysis are almost same. It is confirmed that acceleration and displacement of T/Bs are about same as ones of ground. T/B with pile foundation moved more than T/B with pile+srully wall foundation. These trends are also found in the experiment.

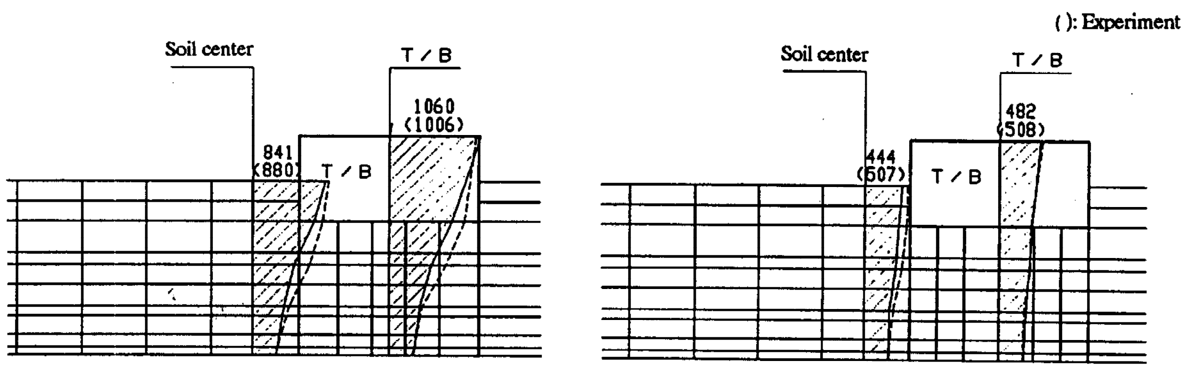

Fig. 12 Maximum Acceleration of T/B

c) Interaction between R/B and T/B

Analytical result of Case 4 (R/B-T/B with pile foundation) and Case 5 (R/B-T/B with slurry wall) are shown in Fig. 13. According to the result, the acceleration and displacement of soil between R/B and T/B are decreased from ones of single T/B model. This area of soil is restricted by both side structures. Soil between the structure is strictly bounded by both side structures in two dimensional analysis, when the experiment express the cylindrical shape exactly. The relative displacement between Case 4 is approximately five times larger than one of Case 5 (see Fig.14) as same as experiment result.

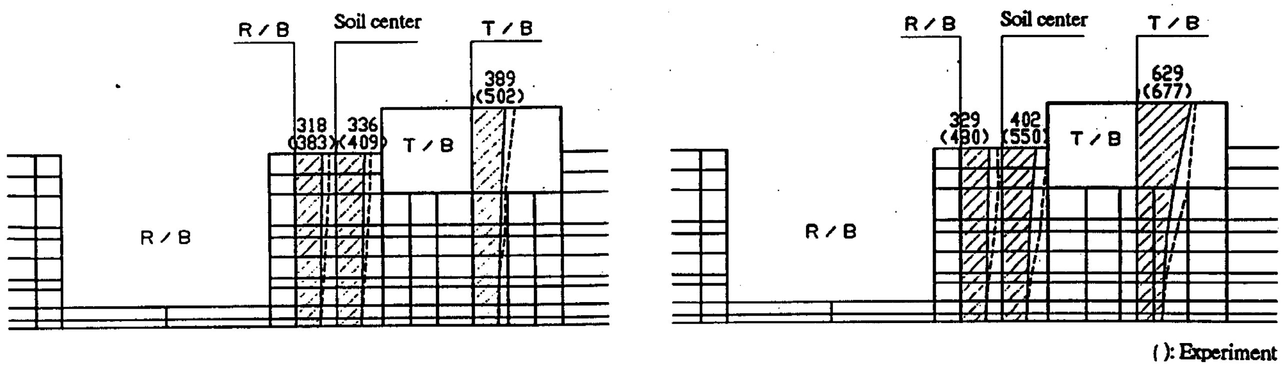

Fig. 13 Maximum Acceleration of R/B-T/B

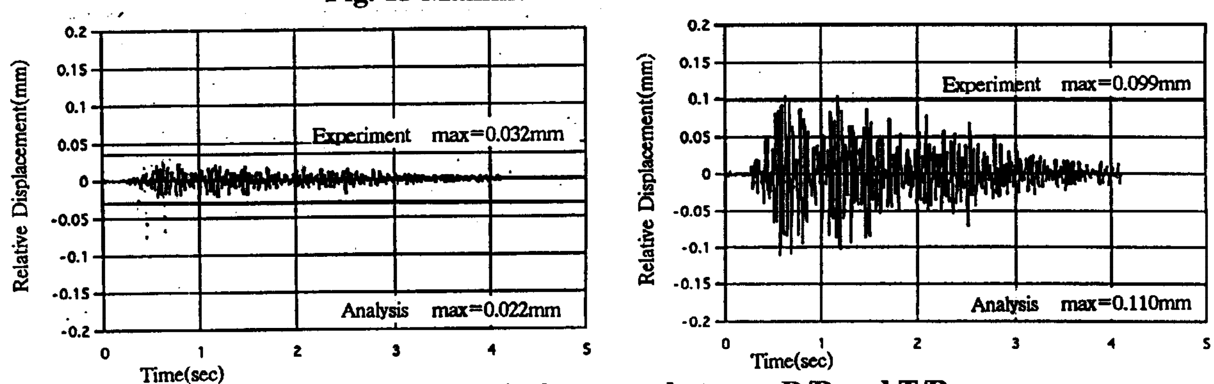

Fig. 14 Relative Displacement between R/B and T/B

CONCLUSION

At the design stage of deeply buried ABWR, we have to consider influence of adjacent structures. Especially, pile foundation structure has to be evaluated its behavior with surrounding soil as well as influence of R/B, because pile foundation is not so rigid.

The dynamic behaviors of buildings are well evaluated by two dimensional dynamic analysis through the analysis and experiment. Two dimensional dynamic analysis is applicable for the preliminary structural analysis. In the mean time, to evaluate soil stability more precisely during strong earthquake, three dimensional dynamic analysis which will be able to model the shape of structures and their foundation system exactly, is preferable.

Currently, we are carrying out the experiment of soil-R/B model under the condition of 50G using centrifuge at University of California at Davis for reasonable evaluation of earth pressure and groundwater pressure. At the next step, experiments of more precise model and development of analytical method are planned for establishment of design frame work.

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