



## Preliminary assessment on dynamic interaction between turbine building with pile foundation and deeply reactor building

Kawamura H.<sup>(1)</sup>, Ando K.<sup>(1)</sup>, Kitagawa Y.<sup>(2)</sup>, Togashi K.<sup>(2)</sup>

(1) *Obayashi Corporation, Japan*

(2) *The Japan Atomic Power Company, Japan*

### ABSTRACT

We have carried out the preliminary assessment on dynamic interaction of nuclear facilities that have different shape, size, and foundation by the strong earthquake with 1/100 scale dynamic experiment and analyses through a feasibility study of a deeply buried twin-type Advanced BWR. Large scale 3D static analysis is performed to evaluate the influence on direction of input motion which supplements a 2D dynamic analysis. All results are integrated to establish the design method of the system including the pile foundation Turbine Building.

### KEYWORDS

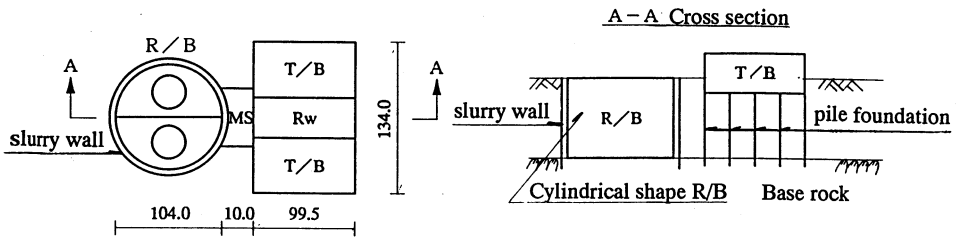
Dynamic interaction, Soil-Structure interaction, Deeply buried, Reactor Building, Turbine Building, Pile foundation, Large scale composite model.

### INTRODUCTION

We have assessed deeply buried twin-type Advanced Boiling Water Reactor (ABWR) with combination of Turbine Building (T/B) with pile foundation for last four years. The limitation of site feasibility makes an Reactor Building (R/B) be buried about 70m to directly supported by bed rock. It will be required to evaluate the dynamic behaviors of buildings and interaction between soil and structures during strong earthquake, that evaluation will give us an appropriate design frame work.

We have already done the basic study of soil-structure interaction and R/B - T/B interaction through analyses and prototype experiments for last three years based on plot plan set up as Fig. 1. The experiments were performed for evaluation of dynamic interaction between deeply buried R/B and T/B with pile foundation through the soil which behaves non-linearly during the earthquake. Two-dimensional dynamic analysis was also applied for comparing experiment results.

Based on the study, in this paper we have conducted the two-dimensional dynamic analysis with non-linear soil behavior and three-dimensional static analysis with equivalent seismic load.



**Fig. 1 Plot Plan**

## OBJECTIVES

One of the main objectives is to develop the design strategies of this new system through assessing the dynamic interaction between deeply buried cylindrical R/B directly based on bed rock and rectangular T/B supported by pile foundation during strong earthquake as well as ordinary earth and groundwater pressure.

We set the several steps to be a final goal.

- 1st step : 1/100 scale dynamic experiment to know the basic interaction between R/B and T/B
- 2nd step: Validation of two-dimensional analysis using 1/100 scale model with experiment.
- 3rd step: Two-dimensional analysis for prototype with assumed geological condition to assess the real scale interaction.
- 4th step: Three-dimensional analysis for evaluating how R/B and T/B are influenced by the different direction of input motion.
- 5th step: Integration of the feasibility study to archive an appropriate design framework.

## CONDITION

As mentioned in Fig.1, R/B with 104.0m diameter are 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 due to the excavation of inside soil. T/B with 134.0m×99.5m rectangular shape supported by pile is also planned. The distance between R/B and T/B is assumed to be 10m for consideration of cost performance.

Geological condition of the candidate site is assumed to consist of about 65m Quaternary sediments with 10m-soft sand, 15m-sandy gravel, and 40m-silt which are non-linearly behaved during the earthquake with dynamic strain. The bed rock is located below the

sediments and the water table is 4m below the ground surface.

Artificial design seismic wave, S2 (291 gal at the base of R/B) for ultimate stage, is used as input motion for dynamic analysis. Input force to the three-dimensional analysis is treated as a parameter. One input (Case-1) is that acceleration of simple soil model is converted to the force, and another (Case-2) is calculated by shear forces. One more input (Case-3) is converted from displacement as shown in Fig.2.

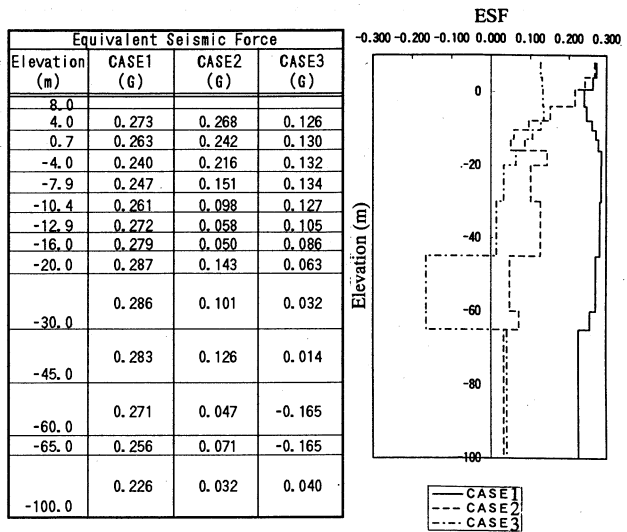


Fig. 2 Input force for static analysis

## SHORT SUMMARY OF PREVIOUS STUDY

The previous analysis and experiment are introduced for background information. One of the largest shaking table in Japan was used for 1/100 scale dynamic experiment and size of model container was 6.5m length, 3.0m wide, and 0.65m depth filled with sand, so 65m sand layer is modeled. The experiment was performed for evaluation of dynamic interaction between deeply buried Reactor Building (R/B) and Turbine Building (T/B) with pile foundation through the soil which behave non-linearly during the earthquake. The applicability of two-dimensional dynamic analysis was also validated by comparing experiment result for behavior of structures. From the experiment, we confirmed the following behaviors:

### a) Dynamic behavior of Soil

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.

### b) Dynamic behavior of R/B

Acceleration and displacement of R/B are relatively smaller than those 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.

### c) Dynamic behavior of T/B

It is confirmed that T/B shakes almost the same level as ground motion during earthquake. T/B with pile foundation moved more than T/B with pile + slurry wall foundation. The influence of T/B on surrounding soil is negligible for maximum acceleration and

displacement.

#### d) Interaction between R/B and T/B

The acceleration and displacement of T/B and soil between R/B and T/B are decreased from ones of single model. The displacement of T/B and soil between the structures are restricted by R/B. The acceleration of R/B is not so influenced by T/B, but the displacement is increased.

We confirm that two-dimensional dynamic analysis is applicable for the preliminary structural analysis. It means that the dynamic behaviors of buildings are partially evaluated by two-dimensional dynamic analysis with equivalent linear method which is approximation of non-linear property of soil. 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.

## **MODELS AND METHODS**

Based on the results of former study, we have conducted the following analyses:

- Two-dimensional finite element method for dynamic analysis with real size structures and assumed soil condition which behave non-linear with dynamic strain,
- Three-dimensional finite element method for static analysis using equivalent seismic load.

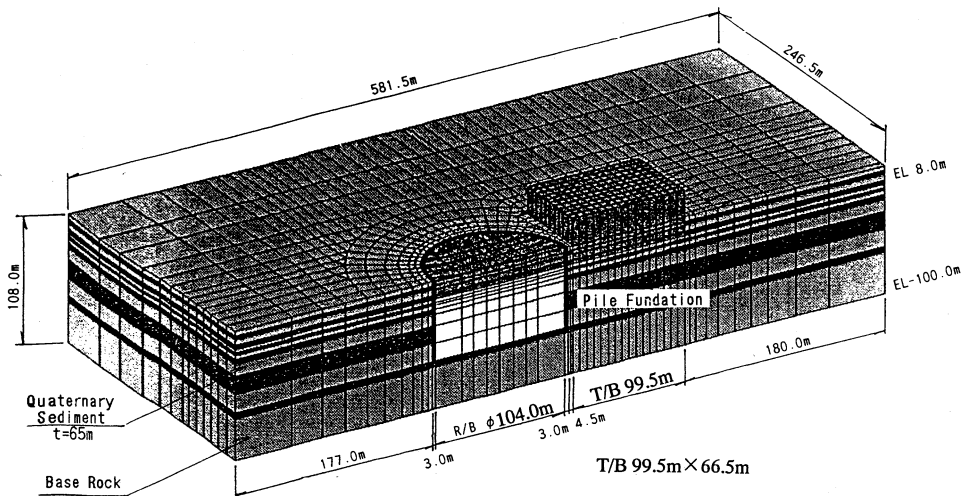
### **1) Three-dimensional static analysis**

Three-dimensional static analysis is adapted for evaluating which direction of horizontal input motion gives most interaction between R/B and T/B. Fig.3 shows three-dimensional model. Direction of horizontal input motion is set as a parameter for three dimensional analysis. Four directions are chosen to evaluate the three-dimensional effect as mentioned in Fig. 4. One direction is parallel to the R/B-T/B and another is perpendicular to R/B-T/B direction. Two more diagonal direction is chosen additionally for three-dimensional effect.

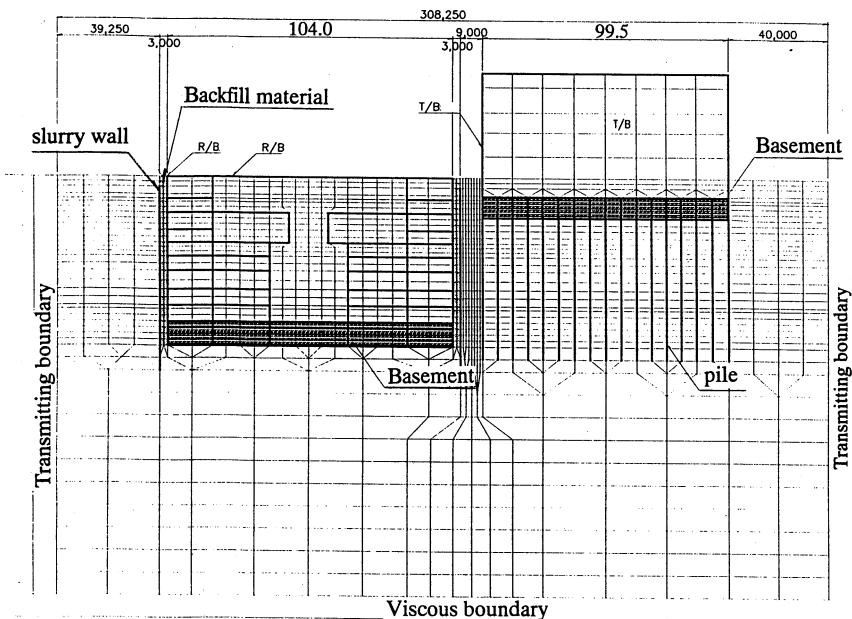
### **2) Two-dimensional dynamic analysis**

Two-dimensional dynamic analysis for R/B-T/B was performed with one effective direction to know how design force is difference between single structure like R/B (or T/B) and R/B-T/B. Analysis cases are following: single T/B, single R/B and R/B-T/B. R/B-T/B model is shown in Fig.4 for example. All cases are dynamically analyzed by two-dimensional finite element method (code name: FLUSH).

In order to make model two-dimensionally, share stiffness and bending stiffness are equivalently evaluated as prototype structure. In cylindrical R/B, all cross sectional area is effective for bending stiffness, and half of cross sectional area is effective for share stiffness. In case of rectangular T/B, the web is counted for share stiffness, and flange is evaluated as bending stiffness. This modeling method is proposed by JEA, and we validated with this R/B-T/B system by comparing the experiment and analysis, as mentioned above.



**Fig. 3 Three-dimensional model for static analysis**



**Fig. 4 Two-dimensional model for dynamic analysis**

## RESULTS

### 1) Three-dimensional analysis

The result of selected points with four directions are plotted in Fig.5. Displacements are somehow arbitrary. From distribution plot of moment and shear force, most critical point is center line which pile is the closest to the R/B, and also most important direction is parallel to R/B-T/B. For design the pile of T/B, closest pile line is strongly influenced by R/B.

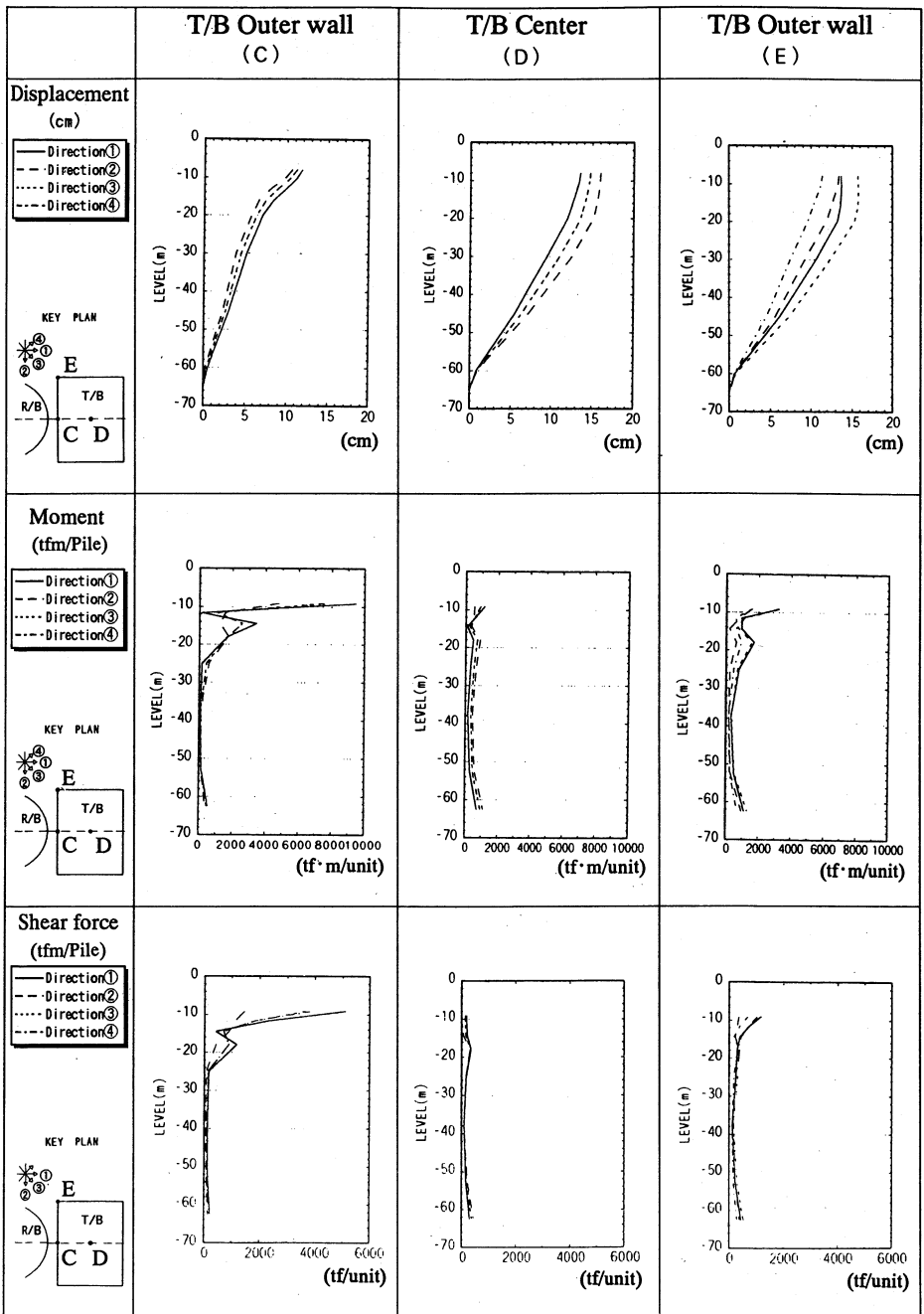


Fig. 5 Result of three-dimensional analysis

2) Two-dimensional analysis

Basic trends for all cases are same as 1/100 scale dynamic experiment using R/B-T/B composite model single layer soil<sup>[2]</sup>. To compare 2D and 3D analyses, the response of piles are very similar which depend on the distance from R/B. As mentioned above, three-dimensional effects are observed.

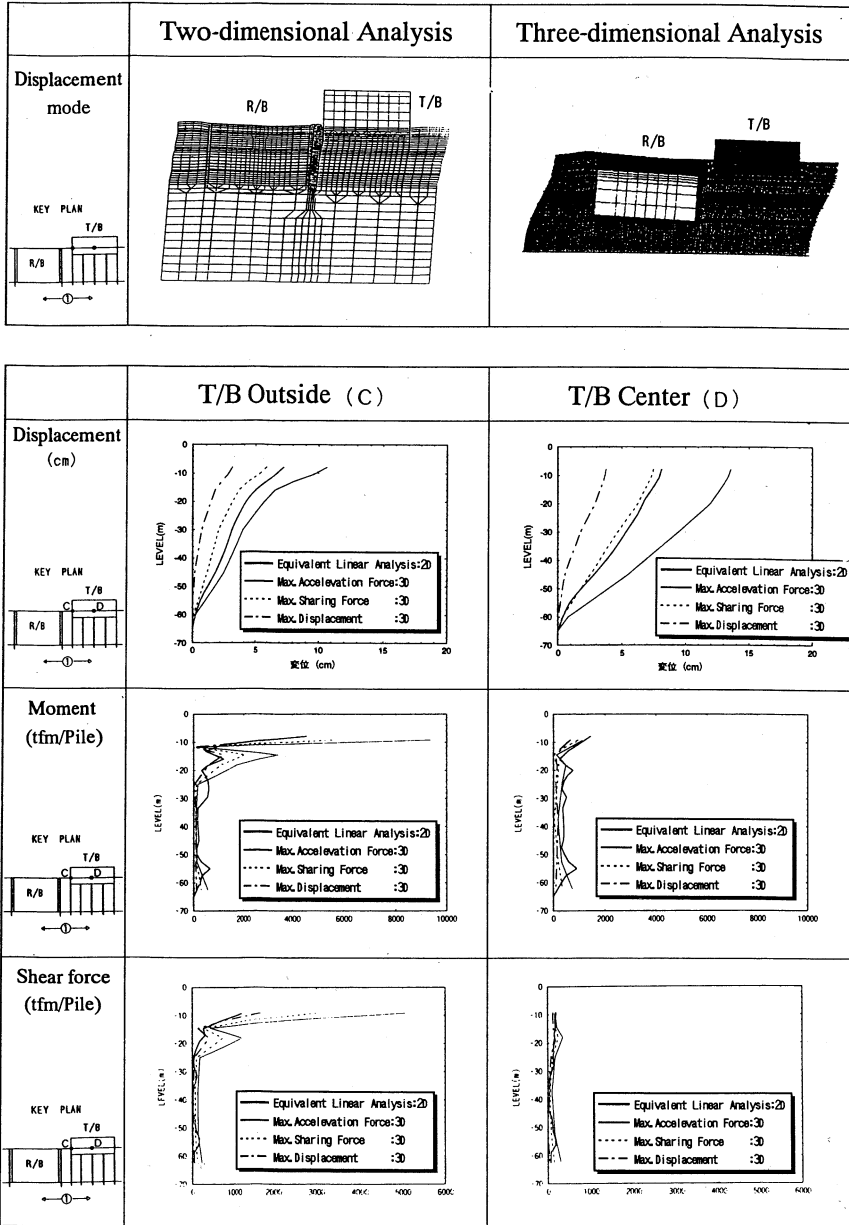


Fig. 6 Comparison between two and three dimensional analyses

## PROPOSED DESIGN AND ASSESSMENT PROCESS

Based on the experiments and analyses, we proposed the following items:

- 1) Dynamic behavior of R/B and T/B should be evaluated in order to assess the structural longevity against design earthquake.
- 2) As T/B with pile foundation would be affected by R/B because of its stiffness and constrained forces, dynamic analysis should be carried out to evaluate displacement mode and design force.
- 3) Due to analyze dynamic interaction between R/B and T/B, the relevant displacement is estimated. It will make a MS duct design more realistic.
- 4) In the design stage, R/B and T/B might be evaluated as a single structure, check and review stage should be on process before setting the specification of structures.

## CONCLUSION

Consequently, T/B with pile foundation will be strongly influenced by R/B which has a rigid and strong stiffness. 3D analysis introduces that T/B will behave in different modes with different directions of earthquake. We confirm how R/B and T/B are influenced by different directions of input motion. As far as the result obtained from three-dimensional analysis, earthquake parallel to the R/B -T/B direction creates the maximum moment, shear force and minimum axial force. In the meantime, torsion is observed, and details of stress distribution of piles really depend on the direction of earthquake. It suggests that the critical direction and torsion force should be considered at the design of pile foundation.

At the design stage of deeply buried ABWR, we have to consider the 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 flexible.

## REFERENCES

1. Togashi K., Y. Kitagawa, T. Morita, H. Kawamura and K. Ando: Preliminary Assessment on the influence of Distance between Nuclear Power Buildings, 13th International Conference on Structural Mechanics in Reactor Technology, 1995.
2. Togashi K., Y. Kitagawa, H. Kawamura and K. Ando: Preliminary Assessment on dynamic interaction of deeply buried power buildings, 11th World conference of earthquake engineering, 1996.