Transactions of the **14th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 14), Lyon, France, August 17-22, 1997 **K09/4**

System evaluation of slurry wall and backfill material surrounding buried reactor building during and after earthquake

Ando K.(1)**, Kawamura H.**(1)**, Kitagawa Y.**(2)**, Togashi K.**(2)
(1) Obayashi Corporation, Japan
(2) The Japan Atomic Power Company, Japan

ABSTRACT

Preliminary assessment on the role of slurry wall combined with different type of backfill materials around the reactor building is summarized through a feasibility study of a deeply buried Advanced Boiling Water Reactor. Dynamic analysis for earthquake and ground water flow analysis are performed. We evaluate the dynamic behavior of structures and the inflow rates into the slurry wall pit which is estimated from the damage zone by earthquake. A slurry wall will work as the water tightness structure as well as the earthquake energy buffer component.

KEYWORDS

Seismic analysis, Groundwater flow analysis, Composite system, Backfill, Slurry wall, Deeply buried structure, Nuclear facility, Reactor Building

INTRODUCTION

Nuclear energy is continuously used for the coming generation to supply stable and clean electricity. Safety and economical concerned, smaller-scaled large-capacity reactors have been researched and developed at nuclear power plants in Japan. The limitation of site feasibility makes an Reactor Building (R/B) be buried about 40m for direct support on bed rock. For more deeply buried and completely covered R/B, cylindrical slurry wall is required to bear the ground-water and earth pressure during the construction period due to the construction feasibility. At the final stage of construction, the space between slurry wall and R/B is refilled with so called backfill materials. After construction, the expected roles of the slurry wall with backfill materials are the water tightness and absorption of seismic energy.

R/B - backfill materials - slurry wall interaction during the strong earthquake have been evaluated experimentally and analytically through the feasibility study of a twin-type Advanced Boiling Water Reactor (ABWR) and a Turbine Building (T/B). The groundwater outflow rate from the surrounding soil through the slurry wall is estimated by three dimensional flow analysis.

In the preliminary stage[1],[2], a base case layout is set up as Fig. 1. The reactor building with 104.0m diameter and with 3m backfill space is planned to be directly supported by the bed rock which is assumed to be located below 65m sediments.

Geological condition of the expected site is consists of about 65m Quaternary sediments with 10m-soft sand, 15m-sandy gravel, and 40m-silt. The water table is 4m below the ground surface. Sediments are relatively soft in terms of earthquake, and 40m silt and bed rock are relatively impermeable in terms of groundwater.

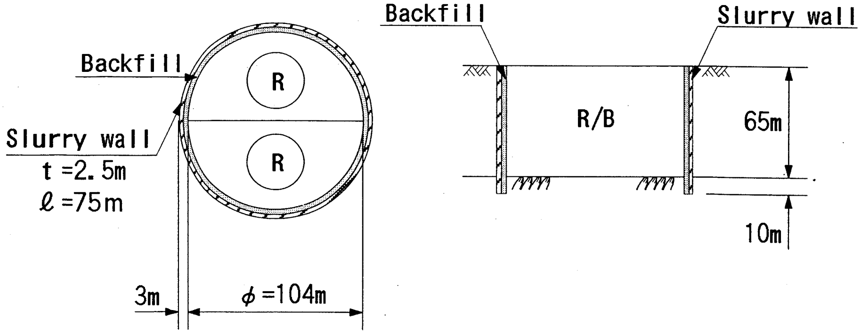


Fig. 1 Plot Plan

OBJECTIVES

One of the main objectives of the system evaluation of slurry wall and backfill material is to assess the feasibility of this system, not only during construction and operation, but also after strong earthquake. The influence of the composite system to the deeply buried R/B should be quantitatively evaluated.

In this paper, we evaluate the following items:
1) Bearing against static earth and ground water pressure and seismic load during construction phase,
2) Absorbing the seismic load to R/B during operation phase,
3) Retaining the ground water tightness inside the slurry wall to avoid the uplift pressure to R/B during operation phase, and
4) Keeping the impermeable zone of slurry wall even after the strong earthquake which is set to be an ultimate stage, so called S2 level.

Based on the above evaluation, we try to develop the design frame-work of the composite system of R/B-backfill-slurry wall.

CONDITIONS

Artificial design seismic waves (See Fig. 2), S1 (157 gal at the base of R/B) and S2 (291 gal at the base of R/B) for ultimate stage are used as input motion for the analysis.

Backfill material is parametrically treated to evaluate the most suitable one for the whole system. To set parameters, we search the material carefully and nominate three materials which each has clearly distinguished dynamic and hydrological property and has enough feasibility. Sand, gravel and man-made-rock are selected through the search.

Five cases are set for the analysis including R/B without slurry wall and dry pit (no backfill material) for comparison. The dynamic property and hydrological property of these five cases are assumed from existent data as in Table 1.

Table 1 Dynamic and hydrological properties of backfill materials

Material of backfill	Shear stiffness (tf/m^2)	Damping ratio	Hydraulic conductivity (cm/sec)
Sand	2,800	0.184	1.0E-3
Gravel	20,000-50,000	0.090	1.0E-0
Man-Made Rock	855,000	0.050	1.0E-7

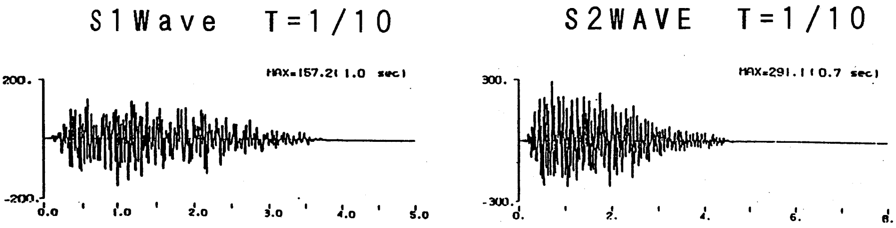


Fig.2 S1 wave and S2 wave as input motion

MODELS AND METHODS

Cases of seismic and groundwater flow analysis are listed in Table 2. Case-1 is no slurry wall model for evaluating the slurry wall effect for earthquake. Case-2, Case-3 and Case-4 have the selected three different types of backfill material respectively with slurry wall. Flow analysis is applied for Case-2 through Case-4.

Table 2 Case of Analysis

Case number	Material of backfill
Case-1	Soil without slurry wall
Case-2	Sand
Case-3	Gravel
Case-4	Man-Made Rock

1) Seismic Analysis

Case-1 to Case-4 are dynamically analyzed by axisymatric three-dimensional finite element method (code name: ABLE-3). R/B and slurry wall are modeled as shell models, and soil, rock and backfill materials as solid. Transmitting boundary is applied for the boundary condition.

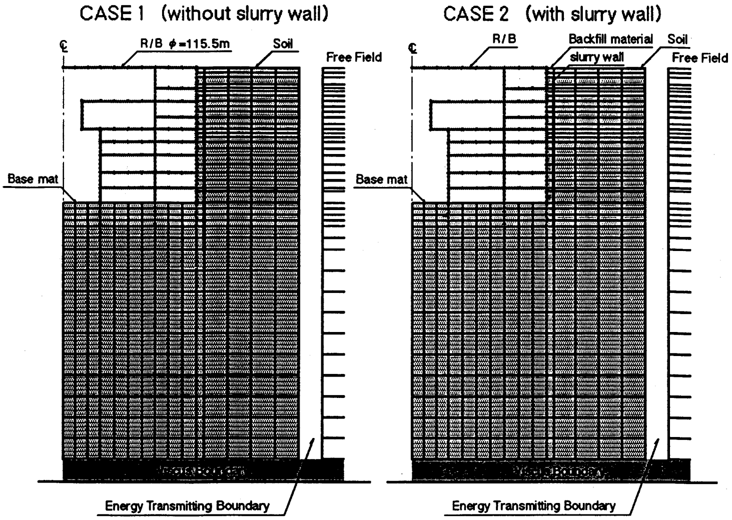


Fig. 3 Model of three dimensional seismic analysis

2) Ground water flow analysis

Flow analysis is performed with three-dimensional model which is shown in Fig. 4. Outside boundary is set to constant head. Zero head condition is set at the bottom of the R/B, because the drainage and pump-up system will be constructed at the bottom level of R/B. Hydraulic conductivity of soil and rock are assumed from former measured value.

To evaluate the hydrological property (i.e. hydraulic conductivity) of slurry wall after the earthquake loading, the hydraulic conductivity change due to the fractures by overloading is estimated by the cubic law method with following steps:

a) Preliminary design during the construction,
b) Evaluation of the overload during the strong earthquake (S2) on operation,
c) Calculation of the width of fracture opening using the overload by JCI method, and
d) Conversion of the hydraulic conductivity from width of fracture opening using the cubic law.

The cubic law method states that the flux within a fracture is proportional to the cubed effective fracture aperture. This law is based on the assumptions that the fracture can be represented by two separated, parallel plates, and that the flux is uniform within the fracture. We conservatively assumed that fracture after opening will not close any more. Realistically, it might close somehow, but degree of opening is unknown.

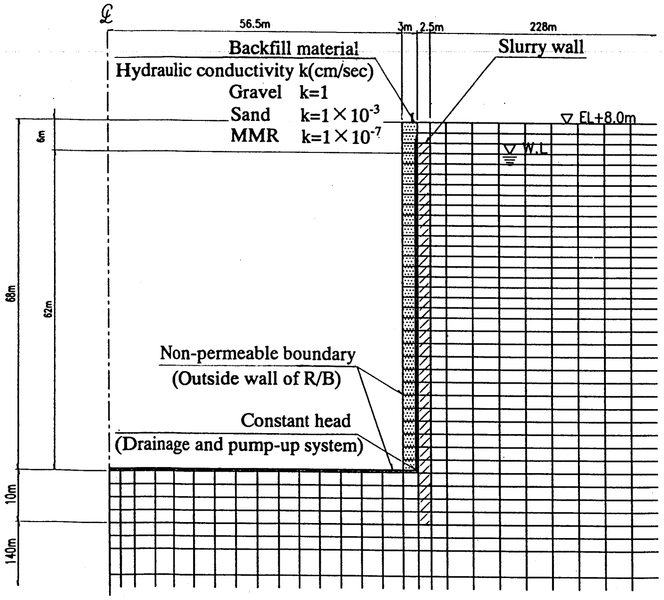


Fig. 4 Model of groundwater flow analysis

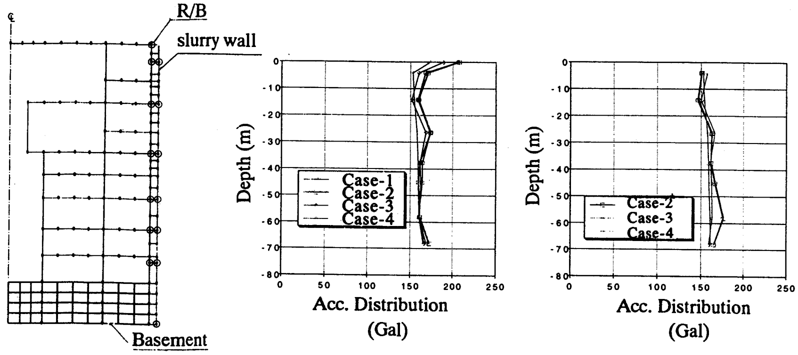
RESULTS

1) Seismic analysis

Seismic analysis results of Case-1 to Case-4 are summarized as follows:

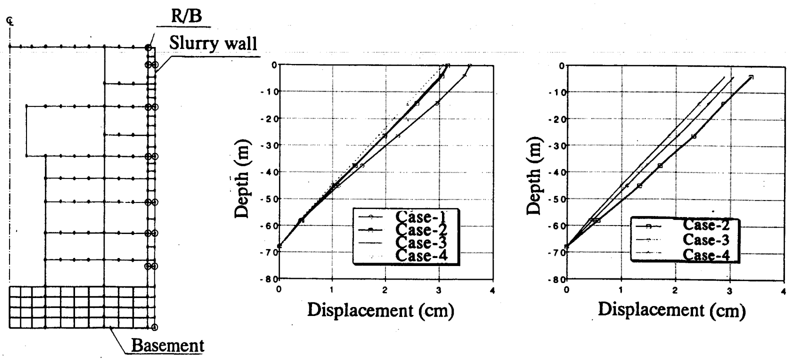
a) Dynamic behavior of R/B

According to the analytical results of R/B and slurry wall behavior shown in Fig. 5 and Fig.6, R/B is followed by the surrounded ground which behaves non-linearly during the earthquake motion. But acceleration of R/B is relatively smaller than that 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 shaking experiment which was performed with 1/100 scale using real sand[2].



Model (a) R/B (b) Slurry wall

Fig. 5 Maximum acceleration of R/B and slurry wall

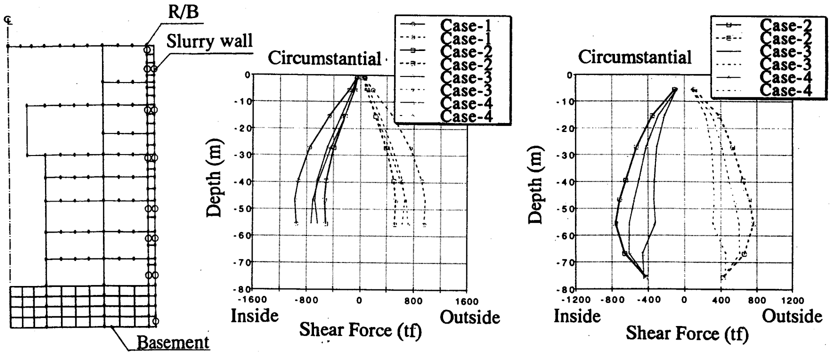


Model (a) R/B (b) Slurry wall

Fig. 6 Maximum Displacement of R/B and Slurry wall

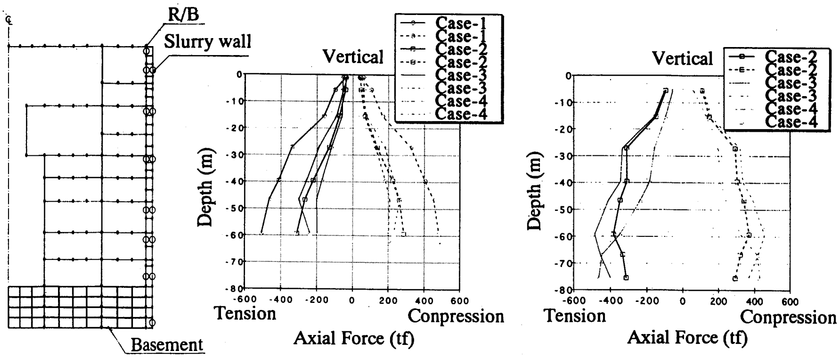
b) Force of R/B and Slurry wall

The results of shear force, axial force and moment are shown in Fig.7, Fig.8 and Fig.9 respectively. It is confirmed that all forces at R/B are decreased with backfill and slurry wall. Forces of slurry wall are increased with stiffer backfill as a reaction. This phenomena are very clear at the shear force and axial force. We measured same trend at the former experiment[2].



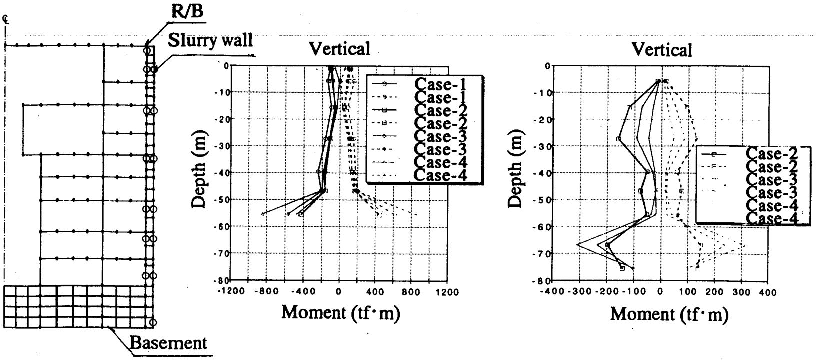
Model (a) R/B (b) Slurry wall

Fig. 7 Maximum shear force



Model (a) R/B (b) Slurry wall

Fig. 8 Maximum axial force



Model (a) R/B (b) Slurry wall

Fig. 9 Maximum moment

2) Groundwater flow analysis

The hydraulic conductivity of degraded concrete was evaluated and summarized in Table 3 from fracture opening using the three forces which was formerly estimated by seismic analysis. Table 3 shows only the case of degraded parts. Original hydraulic conductivity of concrete is assumed to be 1.0E-7 (cm/sec) from the slurry wall in-situ experiment.

Table 3 Hydraulic conductivity of degraded concrete

Depth (m)	During operation (cm/sec)	After strong earthquake (cm/sec)
13	1.0E-7	6.5E-6
21	1.0E-7	2.5E-4
40	3.0E-7	2.0E-6

The summaries of result is shown in Table 4. Changing of hydraulic conductivity of degraded concrete affect the result relatively small. This is because that the soil of outside from degraded area is silty and that it is assumed to be low permeability area (1.0E-8cm/sec). In any cases, outflow is not significant and the design of drainage system at the bottom of R/B is feasible.

Table 4 Dynamic and hydrological properties of backfill material

	Outflow rate before strong earthquake (m^3/hr)	Outflow rate after strong earthquake (m^3/hr)
R/B Basement	2	2
Slurry wall	68	80
Total outflow	70	82

CONCLUSION

We confirm that feasibility of slurry wall and backfill system for absorbing input shear force of the R/B. It means that design force, shear force and axial force of deeply buried R/B are reducible using this system. While, outflow rate from the slurry wall is conservatively estimated by the three dimensional groundwater flow analysis with considering the degraded concrete property using the cubic law.

This study integrating the above two conclusions demonstrates the design feasibility of R/B + slurry wall with backfill material. At the next step, optimum design of slurry wall + backfill material with proper drainage system will be set. Then, development of analytical model, integrating the experiment and analyses are planned for establishment of design frame work.

REFERENCES

1. Togashi K., Y. Kitagawa, T. Morita, H. Kawamura snd 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.