A Study on Seismic Feasibility of a Rationalized Reactor Building in a High Seismicity Region

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1. INTRODUCTION

The following structural features have been used in recent Japanese PWR plants in order to satisfy the design requirements of an earthquake country:

(1) Large basemat dimensions to meet the uplift criteria
(2) Symmetrical arrangement of shear walls to prevent torsional effects
(3) Well-proportioned building shapes and flat basemats to avoid local stresses in the structures
(4) Basemats which are thick enough to be regarded as rigid

In meeting these requirements, plant layouts which waste space and unnecessary thicknesses of walls, slabs and basemat in the building structures can not be avoided. Therefore these seismic requirements influence in cost increases.

In this study, a rationalized design of a building is proposed in which priority is given to equipment performance. In establishing the design of a rationalized building, two objectives must be met.
One objective is the integrity of the plant during earthquakes and the other is the reduction in the amount of the plant volume and materials. Seismic analyses of the rationalized building were carried out to evaluate these objectives. Fig. 1 shows the plant layout design flow charts both for the conventional approach and the new one.

In this study, maximum accelerations of 360 Gal for S1 and 480 Gal for S2 earthquake were used. Fig. 2 shows the spectra of the earthquake ground motion, in which the maximum acceleration is normalized to 100 Gal.

2. PLANT LAYOUT

Figs. 3, 4 and 5 show the plot plans and section of the rationalized reactor building analyzed in this study.

The features of the building can be summarized as follows:

(1) Stepped basemat
(2) Thinner basemat
(3) Unsymmetrical arrangement of shear walls
(4) Building embeddment

The first two features contribute to the reduction in the amount of plant volume and materials and the other two are concerned with the integrity of the plant during earthquakes. A large reduction in plant size and concrete volume can be achieved, if this plant is feasible in an earthquake country.

3. SEISMIC ANALYSIS AND RESULTS

3.1 Stepped Basemat

A sketch of the basemat is shown in Fig. 6. The dynamic soil spring was calculated by the boundary element method (BEM) to evaluate the stepped basemat. Soil springs based on BEM, the Barkan formula, the Tajimi formula and Admittance Theory were also calculated for the flat basemat, and compared with each other. From the comparison study, it is cleared that the soil spring values of the stepped basemat are almost equal to those of the flat basemat. Table 1 gives the calculated soil spring constants.

3.2 Basemat Flexibility

The basemat analyzed here is 5 meter thick, which is less than the conventional design thickness (8 - 10 meter). Therefore, analysis of its behaviour under earthquake conditions, using a rigid basemat model may not be sufficiently accurate.

The two-dimensional model shown in Fig. 7 was used to determine the basemat flexibility. The following results were obtained from the elastic analysis of both the rigid-basemat and the flexible-basemat models for S1 earthquake.

(a) The natural period of the flexible-basemat model is longer (0.188 sec) than that of the rigid-basemat model (0.161 sec).
(b) The difference in the maximum response accelerations in the two cases is within 5 percent.
(c) Similar floor response spectra at the operating floor of the inner concrete were obtained as shown in Fig. 8.

3.3 Torsional Response

Three dimensional response analysis was carried out to find the effect of torsional motion and the results were compared to those given by a two dimensional model. Fig. 9 shows the three dimensional analysis model.
The eccentric ratio in this study is only 10 percent of the value specified by the Japanese building standard code. From the results of the elastic response analysis under S1 earthquake conditions, it is confirmed that the torsional effects are negligibly small.

3.4 Building Embeddment

Under the seismic conditions mentioned above, the integrity of the rationalized building mainly depends on the uplift of the basemat, so that the maximum accelerations of the S1 and S2 design earthquakes are limited to approximately 360 Gal and 480 Gal to meet the uplift criteria. If the site is expected to experience more severe conditions, it is necessary to embed the building to make the rationalized building feasible. Consequently, the building embeddment was taken into account to determine its effects.
The embeddment depth was 12 meters and it is represented in the model by lateral soil springs below the ground surface.
The results show that the overturning moment at the bottom of the basemat is reduced by 15 percent compared to the case without embeddment.

4. CONCLUSIONS

It is clearly shown that reduced thickness and stepped design of the basemat of the rationalized building do not give undesirable effects to the integrity of the plant during earthquakes and they are effective in rationalizing the plant design.
Additionally, it is confirmed that the torsional effects resulting from the free arrangement of the shear walls are negligibly small.
The integrity of the rationalized building can be assured up to 360 Gal for S1 and 480 Gal for S2.

If the embeddment effect is taken into account, the maximum acceleration of the design earthquake may be increased to more than 400 Gal for S1 and 550 Gal for S2 respectively.

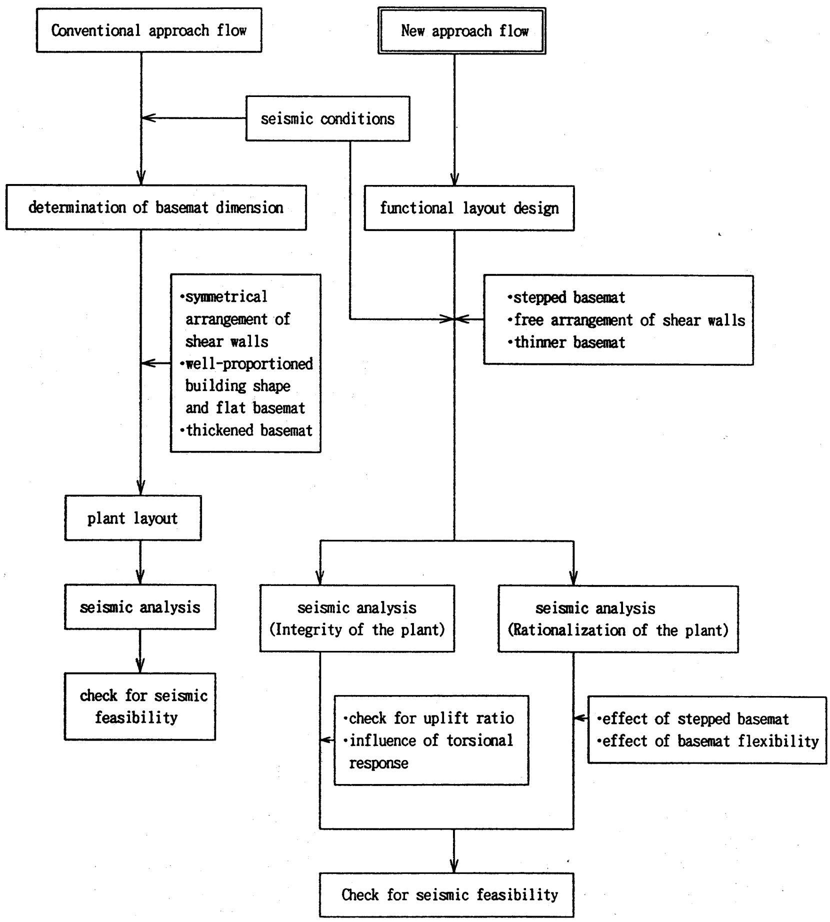


Figure 1. Comparison of the design flowcharts

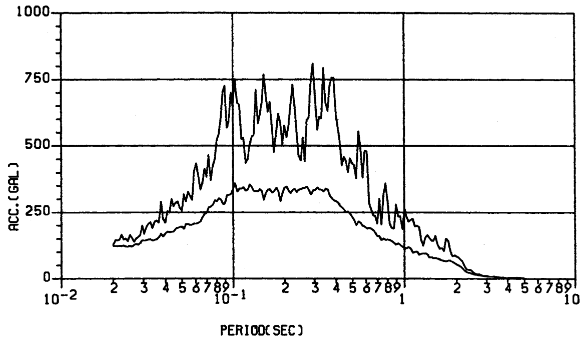


Figure 2. Earthquake ground motion (h=1%, 5%)

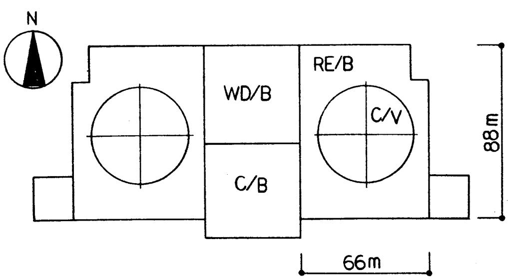


Figure 3. Plot plan

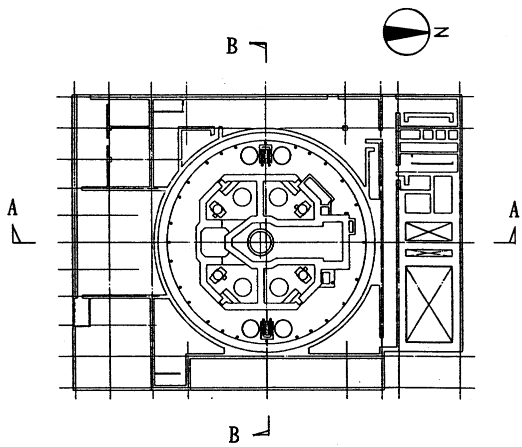
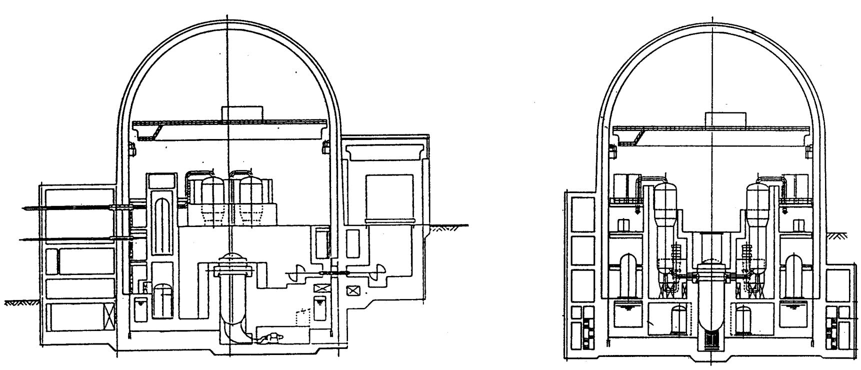


Figure 4. Plan of the reactor building



(A-A) (B-B)

Figure 5. Section of the reactor building

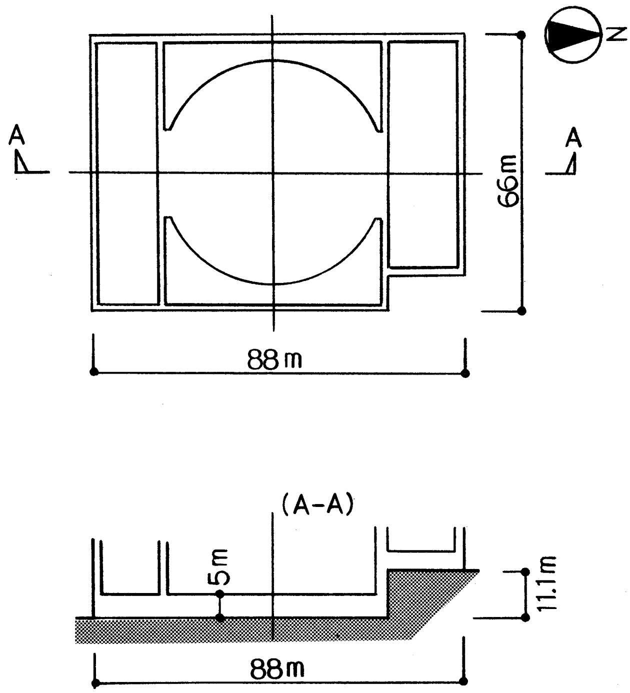


Figure 6. Sketch of the basemat

Table 1. Soil spring constants

		SWAY ($\times 10^5$t/cm)		Rocking ($\times 10^{12}$t·cm/rad)	
		NS dir.	EW dir.	NS dir.	EW dir.
BARKAN formula		18.46	19.07	27.51	18.19
TAJIMI formula		15.53	16.17	24.59	16.44
Admittance theory	0 Hz	19.77	20.07	39.21	26.05
	10 Hz	19.07	19.84	28.84	20.35
DGC	0 Hz	15.53	16.17	53.26	34.56
BEM (flat basemat)	0 Hz	16.64	19.42	45.77	29.78
	10 Hz	15.28	18.50	31.45	22.31
BEM (stepped basemat)	0 Hz	18.36	20.62	49.58	40.43
	10 Hz	16.76	19.29	33.90	29.11

DGC : Dynamical Ground Compliance
BEM : Boundary Element Method
shear wave velocity : 2000m/sec.

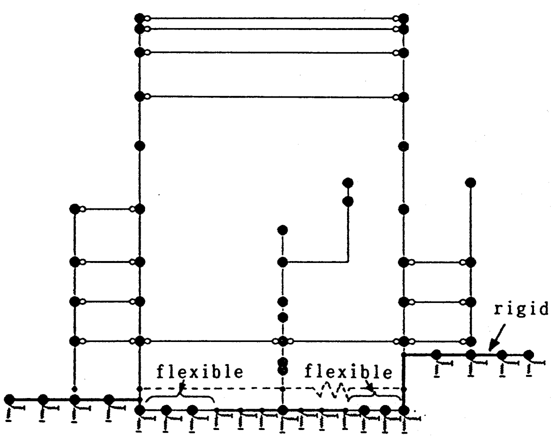


Figure 7. Two-dimensional flexible-basemat model

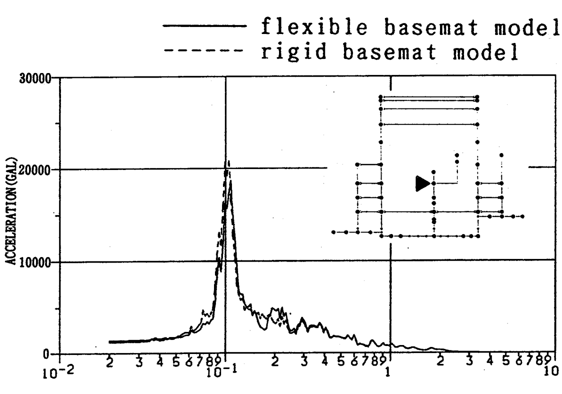


Figure 8. Floor response spectra

(Op. floor of the I/C)

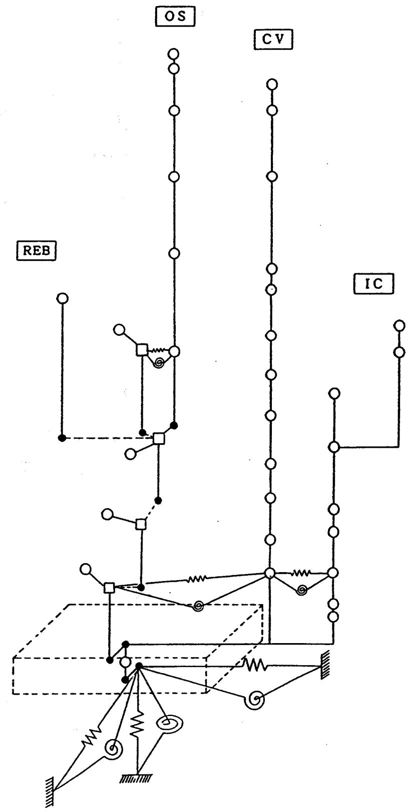


Figure 9. Three-dimensional analysis model