Transactions of the **13th International Conference on Structural Mechanics in Reactor Technology** (SMiRT 13), Escola de Engenharia - Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, August 13-18, 1995

Influences of basemat uplift on seismic response of embedded buildings

Uetake, T.[1], Hagiwara, T.[2], Ohmiya, Y.[3], Furukawa, S.[4]

1) Nuclear Power Research & Development Center, Tokyo Eletric Power Co., Tokyo, Japan
2) Power & Energy Project Division, Shimizu Corp., Tokyo, Japan
3) Office of Energy and Nuclear Engineering, Takenaka Corp., Tokyo, Japan
4) Seismic Engineering Dept., Tokyo Eletric Power Services Co., Tokyo, Japan

ABSTRACT: In this study, two varieties of non-linear seismic response analyses are performed in order to evaluate the influences of geometrical non-linearity due to basemat uplift on the embedded nuclear reactor building. The first analysis is made regarding the influences of the phenomena of separation and sliding occurring between structure and side soil during earthquake on basemat uplift. The second examination is made on the influences of the combination of material non-linearity of structural members and geometrical non-linearity due to basemat uplift.

1 STUDY CONCERNING SEPARATION AND SLIDING

Separation and sliding phenomena occur between building and side soil when a nuclear reactor building with an embedded part is subjected to a large earthquake input. These phenomena have been shown to occur through both experimental and analytical studies. Separation phenomenon of side surfaces of building is not taken into consideration in soil-structure interaction analyses being generally performed. This is because separation of side surfaces of a building is thought to have little influence on response. As for sliding, modeling is done in many cases assuming that sliding is occurring without skid friction.

The influences of the phenomena of separation and sliding occurring between building and side soil on the seismic response analyses concerning geometrical non-linearity due to basement uplift are studied.

1.1 *Analysis Conditions*

Geometrical non-linearity of basemat uplift is considered with joint elements. It is assumed that sliding will not occur at the bottom surface of the building.

Three conditions are considered concerning separation and sliding at a building side surface.

1) Type A-l: Separation Considered, Skid friction Considered
   Method considering separation and sliding phenomena at the building side surface by joint element in accordance with normal stress and transversal stress
2) Type A-2: Separation Not Considered, No Skid friction
   Method assuming separation between building and side soil does not occur, and sliding occurs without skid friction in the normal direction.

3) Type A-3: Separation Considered, No Skid friction

Method considering separation between building and side soil using joint element, and assuming sliding phenomena without skid friction in normal direction.

Seismic response analyses are performed using two-dimensional non-linear FEM models for these three conditions, and comparisons are made of ground contact ratios at the building bottom surface and building responses. The condition of Type A-3 is set for evaluation of the influences due to differences in the respective conditions of separation and sliding on making comparisons of Types A-l and A-2.

The ground conditions are shown in Fig. 1. Models for the two cases of shallow embedment (18.7 m) and deep embedment (38.3 m) are considered.

The building used in analysis is to be a BWR MARK-II type nuclear reactor building. The analytical model is shown in Fig. 2. The ground part is modeled with a plane strain element and the building part with a single-stick lumped-mass model. Joint elements are used in case of taking into consideration basemat uplift of the building bottom surface, and separation and sliding between building and side soil. The characteristics of joint elements are shown in Fig. 3. A joint element works only in a compressed state under normal stress and does not work in a tensioned state. When separation has not occurred, transversal stress in the direction of sliding will be up to τ_y of the limit of sliding. Skid friction is not produced when separation has occurred. The initial stress state at a joint element is required in order to judge the state of separation at the building side surface and uplift of the bottom surface. The initial stress state is set up carrying out static analysis separately by FEM model.

For input earthquake motion, the artificial earthquake motion shown in Fig. 4 is used as the incident wave (2E) at the bedrock of FEM model. The first 15-seconds motion is used in analysis increasing maximum acceleration to a level where basemat uplift occurs. The analytical time step is 1/1000 s for both linear and non-linear analyses.

1.2 *Analysis Results*

The minimum ground contact ratios obtained by non-linear analyses using the three conditions (A-l to A-3) concerning the side surfaces of the building are shown in Table 1. Comparisons of maximum response acceleration distribution of the building are shown in Fig. 5. Acceleration response spectra of the operation floor level of the building are compared in Fig. 6.

According to the comparison of horizontal response accelerations of the building, the influences due to differences in the respective conditions at side surfaces of the building are not very large. Vertical response accelerations differ each other according to building side surface condition. Vertical response acceleration is larger the smaller the ground contact ratio. The minimum ground contact ratios for Type A-2 are smaller than that for Type A-l. This tendency is the same for both shallow and deep embedments. The results for separation considered and no skid friction (Type A-3) are approximately the same as the results for Type A-2.

It may be seen from this that regarding the basement uplift characteristics the influence of sliding phenomena at the side surfaces of building is greater compared with whether or not separation is considered.

2 COMBINATION WITH BUILDING NON-LINEARITY

Analyses are performed using two-dimensional non-linear FEM models considering structural non-linearity and geometrical non-linearity of basement uplift. The mutual relationships of non-linear factors are investigated.

2.1 *Analysis Conditions*

The analytical model is similar to the one that is shallow (18.7 m) embedment model in the previous study (Fig. 1(a), Fig. 2). The modeling of the building and ground at side surfaces is done for Type A-2 (no separation, no skid friction), while basemat uplift is considered. The input acceleration level is proportionally adjusted 900 cm/s^2 for ground contact ratio to be about 60%.

The restoring force deformation relations of the building are represented by tri-linear type for shear stress-strain relationship (τ-γ) and moment-curvature relationship (M-ϕ). The detailed method of setting up is according to NUREG/CR-6241-1994. Analyses for the three cases given in Table 2 are performed with combinations of building non-linearity and geometrical non-linearity due to basemat uplift. Case B-1 is for when only geometrical non-linearity due to basemat uplift is considered. Case B-2 is for when non-linearity of the building is considered and geometrical non-linearity due to basemat uplift is not considered. Case B-3 is for when both non-linearity of the building and geometrical non-linearity due to basemat uplift are considered.

2.2 *Analysis Results*

(1) Basemat uplift Characteristics According to Building Non-linearity.

The minimum ground contact ratios for Case B-1 and Case B-3 are shown in Table 3. The maximum response acceleration distributions of the building are shown in Fig. 7. The vertical acceleration response spectra at the operation floor level of the building are shown in Fig. 8.

The minimum ground contact ratio is 10% higher in case of consideration of building non-linearity compared with no consideration. The times of the minimum ground contact ratio are not same. When non-linearity of building members are considered, non-liner responses become small compared with linear responses, due to absorbed building energy. Consequently, when building non-linearity is considered, it becomes difficult for basemat uplift to occur, and the ground contact ratio becomes higher.

The response properties in the vertical direction occurring due to basemat uplift differ in accordance with this difference in ground contact ratio. Vertical response acceleration spectra are of smaller values in case of considering building non-linearity (Case B-3) compared with not considering non-linearity (Case B-1).

(2) Response Characteristics of Building According to Basemat Uplift

The floor response spectra are shown in Fig. 9. Compared with the building responses when considering non-linearity of the building, the results when considering (Case B-3) and when not considering basemat uplift (Case B-2) are hardly different. The non-linear maximum response values of the building in the τ-γ and M-ϕ relationships are shown in Fig. 10. The building is considered to be in the plastic region where shear strain is about 2 x 10^{-3}, but there is hardly any difference according to whether or not basemat uplift is considered.

3 CONCLUSION

Investigation of the influences due to separation and sliding and the influences of combinations with building non-linearity is done in this study in order to evaluate the geometrical non-linearity due to basemat uplift of a nuclear reactor building having an embedded part.

The results of study on the influences of separation and sliding at the building side surfaces may be summarized as follows:

1) The condition of considering separation and sliding using joint elements is less liable to generate basemat uplift than generally performed condition. The convenient condition, no separation and no skid friction, can be available for seismic evaluation considering the basemat uplift.

The results of study on combinations with building non-linearity may be summarized as follows:

2) When building non-linearity is considered, the minimum ground contact ratio during basemat uplift becomes large compared with when not considering non-linearity, while induced vertical motion becomes small.

3) There is hardly any influence, whether or not geometrical non-linearity due to basemat uplift is considered, on the building non-linearity as indicated by building responses (response acceleration, floor response spectrum) and τ-γ and M-ϕ relationships considering building non-linearity.

4 ACKNOWLEDGMENT

This work was carried out as a part of the cooperative joint study, "A Study on the Non-linear Analysis Method of the Nuclear Power Plant Buildings", under the sponsorships of 10 electric power companies in Japan. The sponsorships and efforts made by all of the members in joint study are greatly acknowledged.

REFERENCE

NUREG/CR-6241 1994. *Technical Guidelines for Aseismic Design of Nuclear Power Plants*, Translation of JEAG 4601-1987.

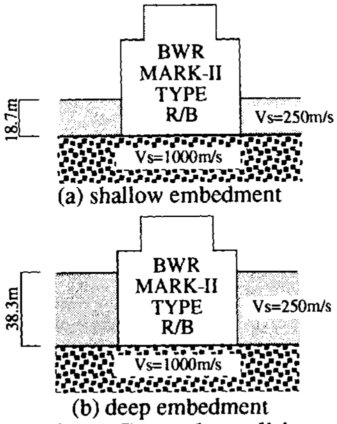


Fig. 1 Ground conditions

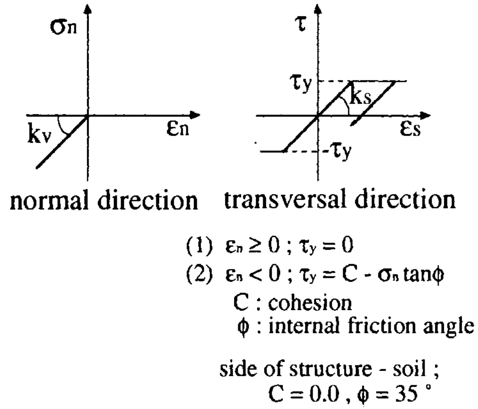


Fig. 3 Characteristics of joint elements

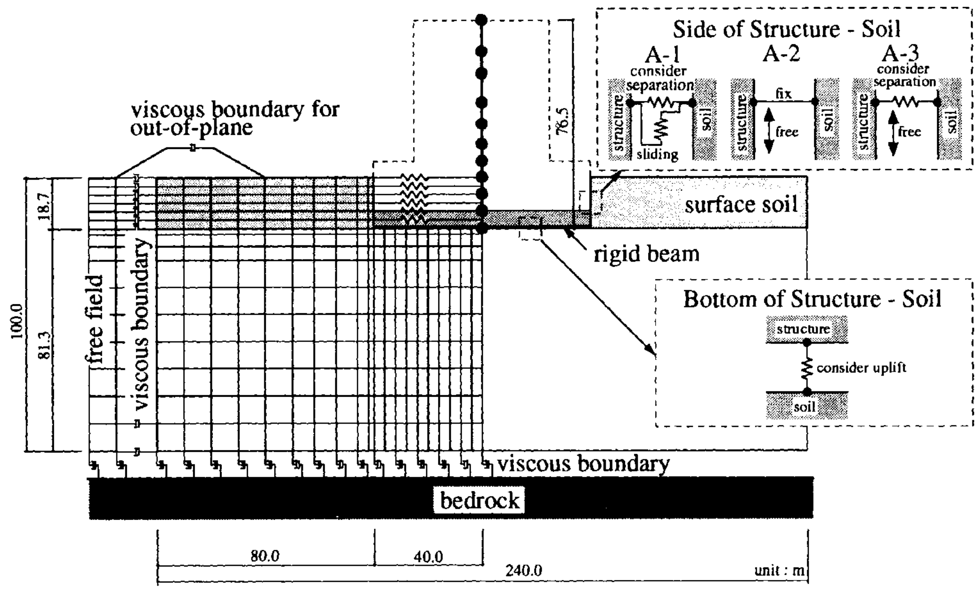


Fig.2 FEM-model (shallow embedment)

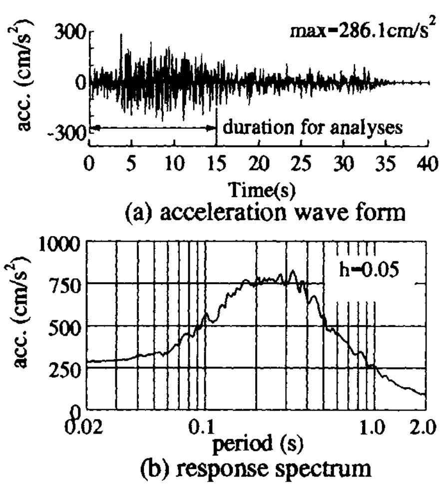


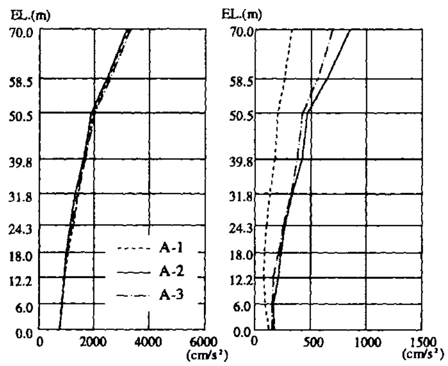
Fig. 4 Input earthquake motion

Table 1 Minimum ground contact ratio: influence of separation and sliding

type	shallow embedment	deep embedment
A-1	67.5%	85%
A-2	57.5%	70%
A-3	57.5%	75%

Table 2 Analysis cases (A-2 type)

case	structural non-linearity	basemat uplift
B-1	linear	non-linear
B-2	non-linear	linear
B-3	non-linear	non-linear



Horizontal acceleration   Vertical acceleration

Fig. 5 Structural maximum response : influence of separation and sliding (shallow embedment)

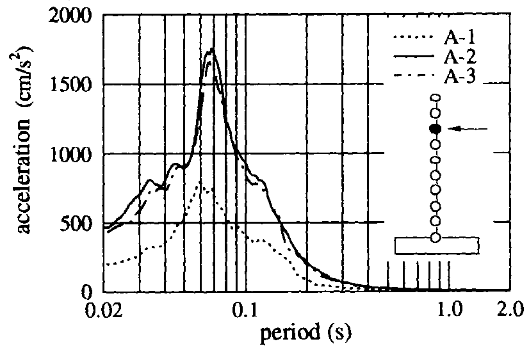
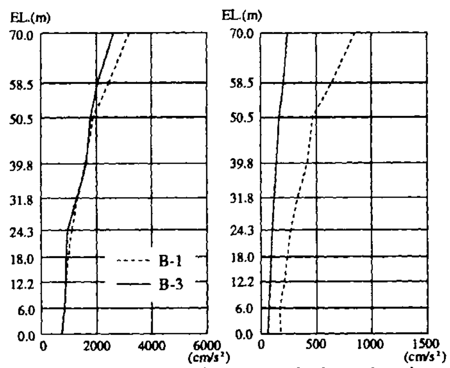


Fig. 6 Vertical response spectra: inflence of separation and sliding (shallow embedment)



Horizontal acceleration   Vertical acceleration

Fig. 7 Structural maximum response : effect of the structural non-linearity

Table 3 Minimum ground contact ratio: effect of structural non-linearity

case	contact ratio
B-1	57.5%
B-3	67.5%

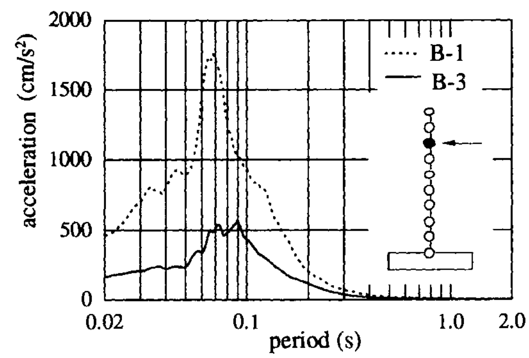
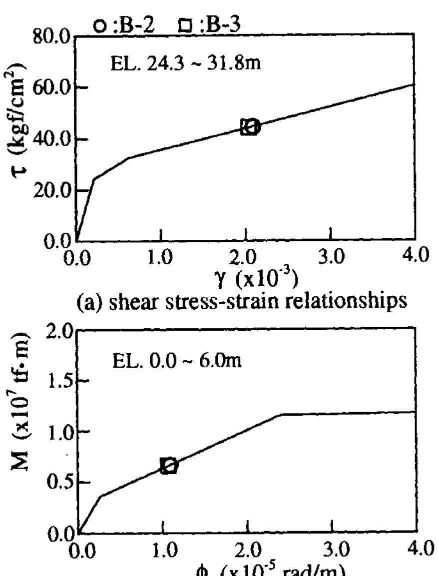


Fig. 8 Vertical response spectra: effect of the structural non-linearity



(a) shear stress-strain relationships

(b) moment-curvature relationships

Fig. 10 Structural non-linear maximum response values

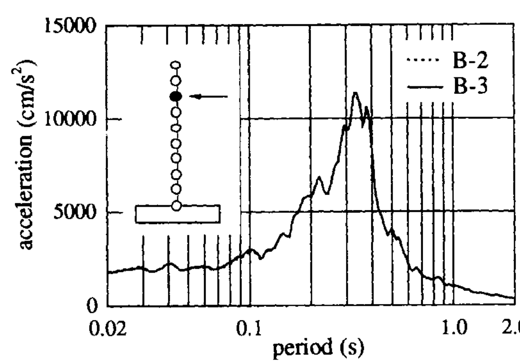


Fig. 9 Horizontal response specta: influence of basemat uplift