One Single Horizontal Seismic Analysis of FBR Core

Jing WEN[1)] and Seiji KITAMURA[2)]

1) China Institute of Atomic Energy, Beijing (at present), Japan Atomic Energy Agency, Ibaraki (past)
2) O-arai R&D Center, Japan Atomic Energy Agency, Ibaraki, Japan

ABSTRACT

In this paper the model and the method for one single horizontal seismic analysis of fast breeder reactor (FBR) core are studied. A FEM code FINAS, is used in the analysis. On the base of this study, one single horizontal seismic analysis of one row and three rows of assemblies in the China Experimental Fast Reactor (CEFR) has been performed as an example. The deformation of the core and shock forces between the assemblies are presented as a result. Comparing the results with other similar analyses and the experiments, the model and the method is reasonable and effective.

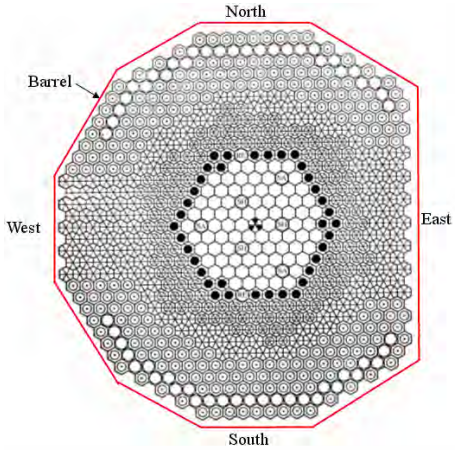
INTRODUCTION

China Experimental Fast Reactor (CEFR) is the first fast breeder reactor in China, with 65 MW thermal power and 20 MW electric power. Safety evaluation under the earthquake is one of most important issues which is being paid great attention by Nuclear Safety Bureau of China. The necessity of the seismic analysis of FBR core is showed as following: The response of the fuel assembly in the core under the earthquake leads to the change of the reactivity of the core; We should make sure that all the assemblies could be keep structural integrity; We can obtain some important data for checking of the scrambility of the reactor by the seismic analysis of FBR.

In this paper the seismic analysis on some selected assemblies in CEFR core has been carried out by using one FEM code FINAS which has been developed by Japan Atomic Energy Agency. The deformation of core, internal forces and moments, shock forces between assemblies have been acquired as a result, which provides some input data for analysises of structural integrity, variation of reactivity and the scram capability during the earthquake.

INTRODUCTION OF CEFR CORE IN BRIEF

The CEFR core comes into equilibrium status after several times of refueling. The layout of the core is shown as Fig. 1. There are 712 assemblies in the core in total, including 81 fuel assemblies (FA), 56 spent fuel assemblies(SFA), 1 neutron source assembly(NS), 336 steel shielding assemblies(SS), 230 boron shielding assemblies(BS), and 8 control rod assemblies(CR). The core is approximately axial symmetric along the east-west direction. All the assemblies are immerged in the liquid sodium. The barrel is designed around the most outside of the core.



legend	description		quantity
	FA		81
	SFA		56
	SS2	SS	37
	SS3		132
	SS4		167
	BS		230
SA	SA	CR	3
RE	RE		2
SH	SH		3
	NS		1

Fig. 1 The layout of the core of CEFR

All the assemblies have the same external hexagonal shapes. The distance between the two parallel sides of the same assembly is 59 mm. And the nominal bundle pitch of is 61 mm. The nominal total lengths of CR and NS are all 2580 mm. The nominal total lengths of the other types of assemblies are all 2592 mm. All the assemblies are inserted in the diagrid and supported by the spherical support. All the spherical support is at the same levels for all the assemblies. All the low

ends of the assemblies are inserted in the diagrid and the up ends are free. The top pad close to the up ends is designed to keep some distance between the neighboring assemblies. And middle pad is specially designed close to the middle height of FA to control the variation of the reactivity after deformation of FA. There are some certain gaps between the neighboring assemblies, between the assembly most outside of the core and the barrel, between the spike of the assemblies and the diagrid. These gaps lead to nonlinear response to the earthquake. Fluid-Structure Interaction (FSI) occurs between liquid sodium and the assemblies under the earthquake. It bring great difficulty to seismic analysis on FBR core.

PRIMARY DYNAMIC ANALYSIS OF ONE SINGLE ASSEMBLY

The analysis of FBR core is very complicated. It is necessary to carry out some simplified analysises and pre-analysis [1] on one single assembly before the analysis on multi-assembly. The following work has been finished before this paper: simplifying modal analysis of one single assembly; free vibration analysis of one single assembly; shock analysis between one single assembly and the rigid wall. By the above analyses, the minimum number of elements to simulate one assembly and the small enough time increment is determined. Meantime the method is found to simulate FSI between the liquid sodium and the assembly. It get ready for the seismic analysis on multi-assembly.

ONE SINGLE HORIZONTAL SEISMIC ANALYSIS OF ONE ROW OF ASSEMBLIES

One center row of assemblies along east-west direction are selected to be performed one single horizontal seismic analysis. The model is shown as Fig. 2. The shock between the neighboring assemblies is simulated by combination of one gap element and one spring element.

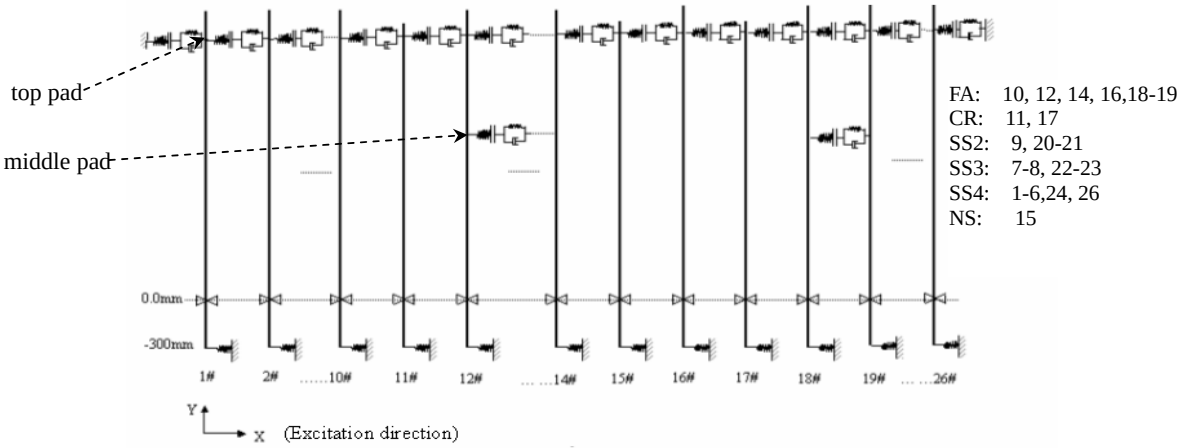


Fig. 2 One single horizontal seismic analysis model of one row of assemblies

We can not get the shock stiffness and the structural damping because of the leak of the necessary experiments. Some assumed parameters are adopted in this paper. The sensitivity analyses of the parameters have been carried out. The structural damping ratios of 0.02 for OBE and 0.04 for SSE are assumed respectively. The shock stiffnesses between the neighboring top pads of the assemblies and between the top pad and the barrel are all assumed as 2.0×10^7 N/m. The shock stiffnesses between the neighboring middle pads are assumed as 1.0×10^7 N/m.

The direct time integration of Newmark-β is adopted. The parameters δ and β are specified as 0.5 and 0.25, respectively. The time increment is selected as 0.02×10^{-3} s.

In this paper the acceleration-time histories of OBE and SSE are taken as seismic input data, which have been gotten by seismic analysis of CEFR reactor block.

Significant deformation of the assemblies under OBE is shown as Fig. 3. The up and low ends of the assemblies disperse away from the center of the core and the middle parts of the FAs concentrate to the center, which may result in the increase of the reactivity of the core. It should be paid much attention. The similar deformation occurs for SSE. The deformation of the core under the earthquake can provide input data for variation analysis of the reactivity of the core.

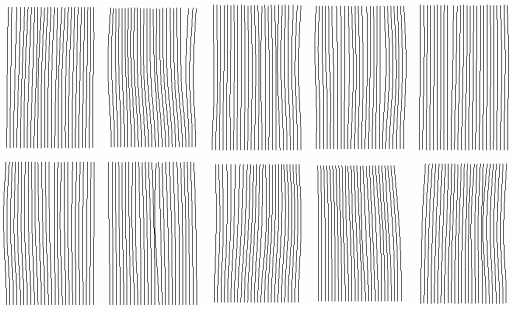


Fig. 3 Deformed shape of the core under OBE (3.1s-4.0s, interval =0.1s)

The maximum and minimum displacements of the up ends of assemblies under OBE and SSE are shown as Fig.4. The maximum of absolute values of the displacements are 9.97 mm and 11.86 mm respectively, which occurs at the up end of the assembly No. 1.

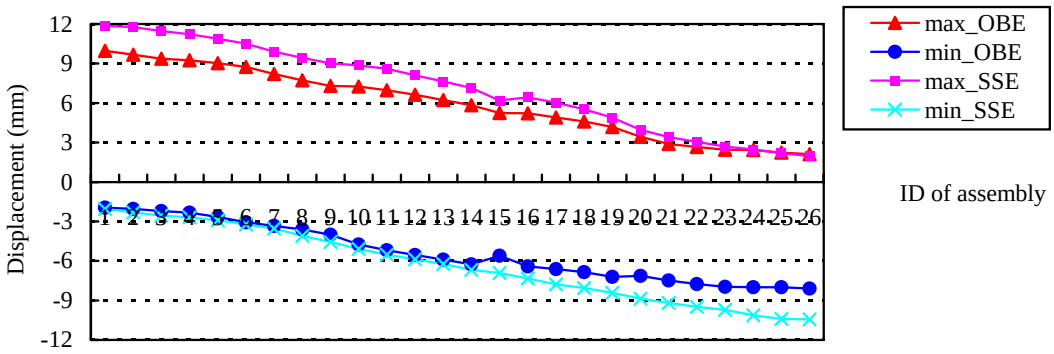


Fig. 4 Maximum and minimum displacements at the up end of the assemblies under OBE and SSE

The maximum shock forces between the pads of the assemblies under OBE and SSE are shown as Fig.5.The shock forces between the neighboring top pads and the top pads and the barrel are larger than those between the neighbor middle pads. The maximum shock forces under OBE and SSE are 6052 N and 8331 N respectively, which occurs between the side assemblies (i.e. assembly No.1 and No. 26) and the barrel.

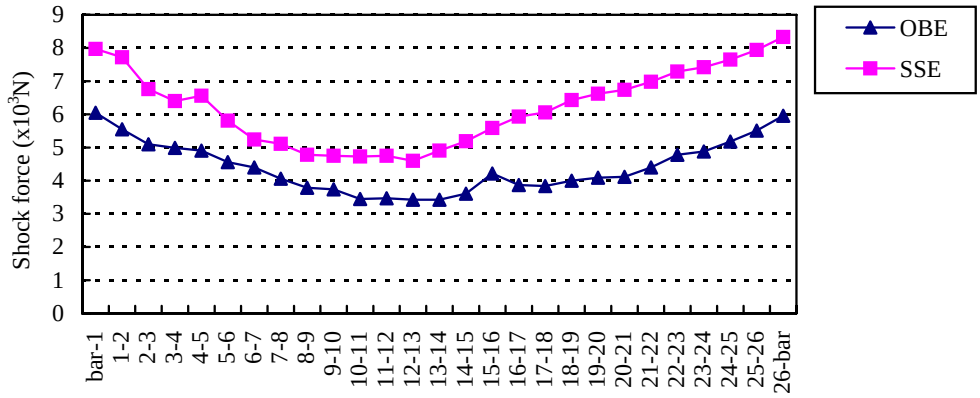


Fig. 5 Maximum shock forces between the top pads under OBE and SSE

The internal moment of the assembly varies with time. The internal moment of some cross section of some certain assembly is shown as Fig. 6. We can obtain the internal moments of any cross section of any assembly if we like. The moments are necessary to calculate the stresses of the assembly. The maximum moments of the assemblies under OBE and SSE are 294 N·m and 314 N·m respectively, which occurs at the cross section close to the spherical support of the assembly No. 2.

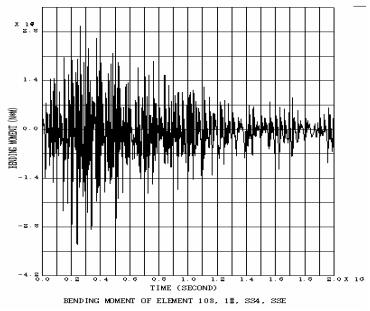


Fig. 6 Internal moment of certain cross section of one assembly

SENSITIVITY ANALYSIS OF PARAMETERS

It is necessary to take sensitivity analysis of parameters. We need to know the effect of the assumed parameters, including structural damping and shock stiffness. Here seismic analysis on one center row of assemblies for OBE has been performed as an example.

Structural Damping

The three structural damping ratios of 0.02, 0.04 and 0.20 are used in the seismic analysis. The results are compared to each other. The maximum and minimum displacements of at the top pad level of the assemblies for a set of damping ratios are shown as Fig. 7. The maximum shock forces between the neighboring top pads and between the top pad and the barrel are shown as Fig. 8. The results show that the damping ratio has less effect on the displacements and lightly more effect on the shock forces. The average maximum displacements of all the assemblies at the top pad level and the damping ratios meet the Eq. (1) approximately:

$$Disp = -0.3183Ln(d) + 3.8726 \quad (1)$$

where Disp is average displacement in mm and d damping ratio.

The average maximum shock forces and damping ratios meet the Eq. (2) approximately:

$$F = -400.2Ln(d) + 2838.1 \quad (2)$$

where F is average shock force in N and d damping ratio.

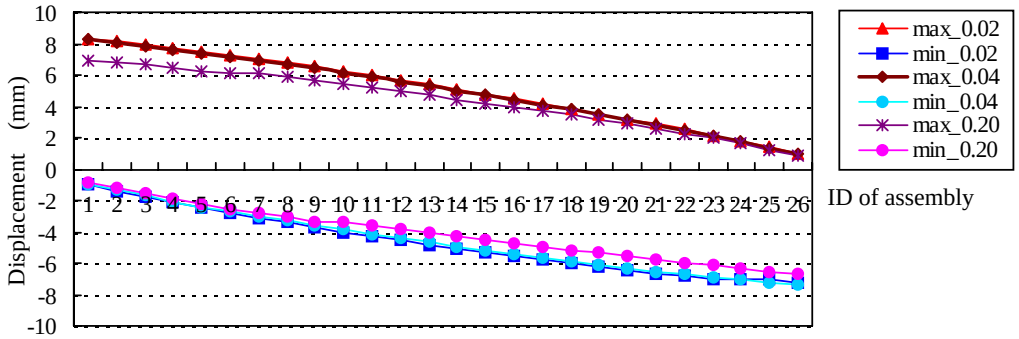


Fig. 7 Maximum and minimum displacements at top pad level for variety of damping ratios

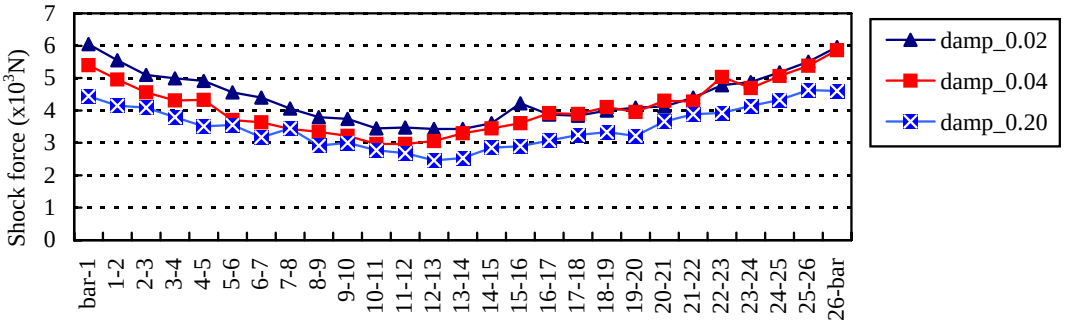


Fig. 8 Maximum shock forces between neighboring top pad for variety of damping ratios

Shock Stiffness

Three sets of shock stiffness between the neighboring top pads and between the neighboring middle pads are used for seismic analysis: a, 2.0×10^7 N/m and 1.0×10^7 N/m ; b, 4.0×10^7 N/m and 2.0×10^7 N/m ; c, 2.0×10^8 N/m and 1.0×10^8 N/m. The results to different shock stiffnesses are compared to each other. The maximum and minimum displacements at the top pad level of the assemblies are shown as Fig. 9. The maximum shock forces between the neighbor top pads and between the top pad and the barrel are shown as Fig. 10. The results show that the shock stiffness have significant effect both on the displacements and the shock forces. The maximum displacements decrease as the shock stiffness increases as well as the maximum shock forces increase as the shock stiffness increases. The average maximum displacements of all the assemblies at the top pad level and the shock stiffnesses meet the Eq. (3) approximately:

$$Disp = -0.775Ln(k) + 17.895 \tag{3}$$

where Disp is average displacement in mm and k average shock stiffness in N/m between the neighboring top pads. The maximum shock force and shock stiffnesses meet the Eq. (4) approximately:

$$F = 1863.2Ln(k) - 27132 \tag{4}$$

where F is average shock force in N and k average shock stiffness in N/m between the neighboring top pads..

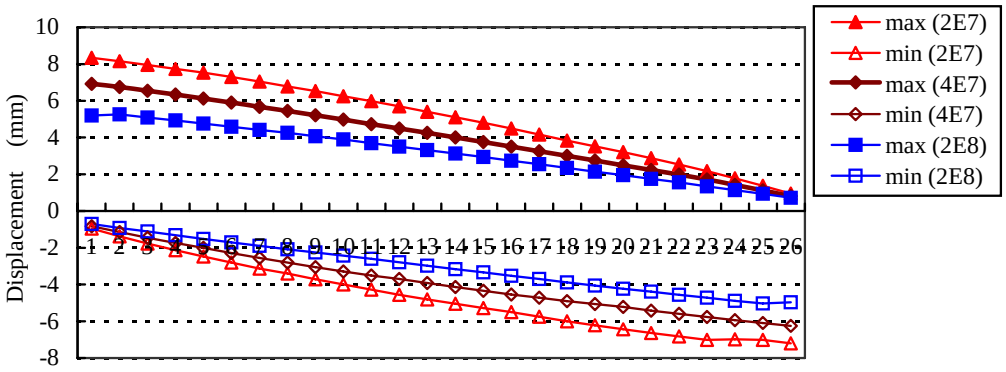


Fig. 9 Maximum and minimum displacements at top pad level for variety of shock stiffnesses

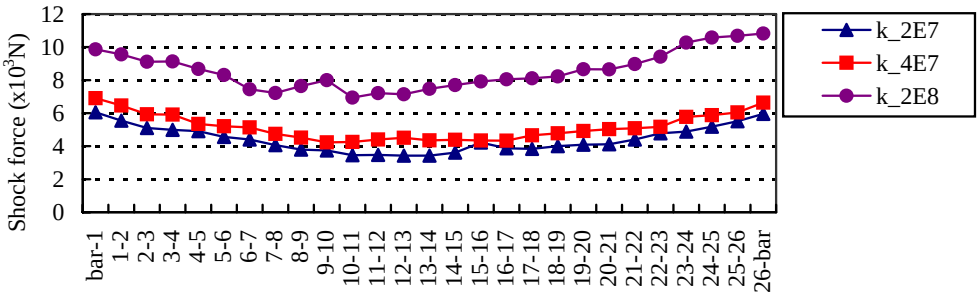


Fig. 10 Maximum shock forces between neighboring top pad for variety of shock stiffnesses

ONE SINGLE HORIZONTAL SEISMIC ANALYSIS OF THREE ROWS OF ASSEMBLIES

To take the effect of interaction between the neighboring rows into account, three neighboring center rows of assemblies are selected to carry out one single horizontal seismic analysis. Analysis model of three row mockup is almost the same as that of one row of assemblies except that interaction between assemblies on neighboring rows is taken into account. The shock in the excitation direction is modeled by a series combination of a gap element and one spring element. The shocks in the skewed direction between assemblies on neighboring rows are simulated by one gap element and two spring elements in two sets of local coordinate systems [2]. The sketch map of model is shown as Fig. 11.

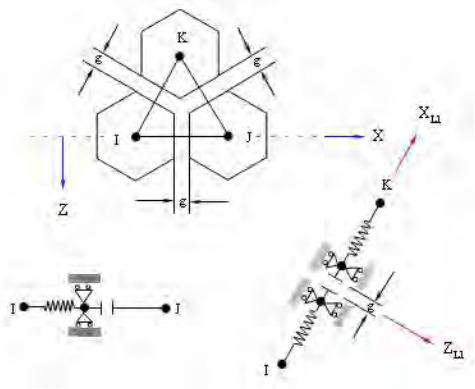


Fig. 11 Model to simulate the shock between the neighboring rows

Some displacements and shock forces response have been obtained by seismic analysis.

The maximum and minimum displacements of the up ends of all the assemblies of the center row are shown in Fig. 12. Comparing with those for one row model we can see that the displacements of all the assemblies of center row are almost identical to those in the single center row model. The two side rows have no significant effect on the center row under the single horizontal earthquake.

The maximum shock forces between the assemblies of the center row at top pad level are shown in Fig. 13. The shock forces between the assemblies in the three model are a little smaller than those in the one row model. The two side rows have slight effect on the center row. On the other word, we can estimate conservatively response of three row model or even the whole core under the single horizontal excitation by using one center row mockup model. The response of three row model agree well with that of one row model [3],[4]. It shows that the model and the analyses are reasonable and effective.

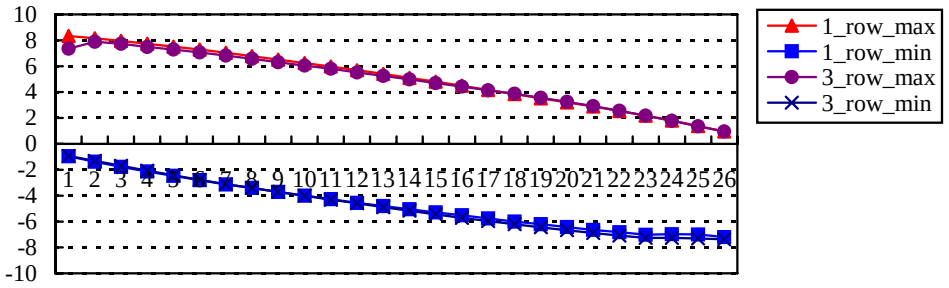


Fig. 12 Maximum displacements at top pad level for one row model against three-row model

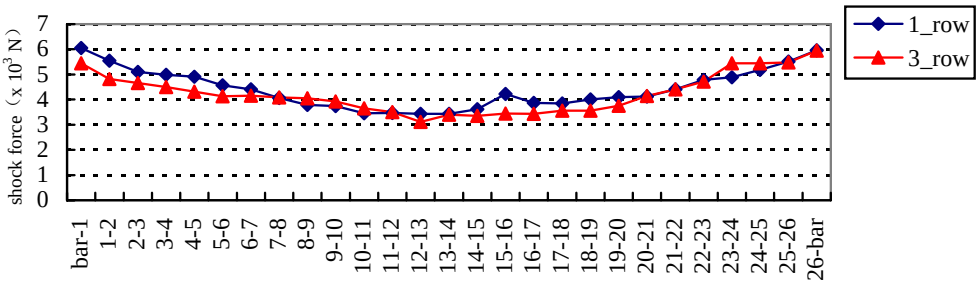


Fig. 13 Maximum shock forces between top pads for one row model against three-row model

SUMMARY AND CONCLUSION

The seismic analysis model and method of FBR core have been studied with CEFR as an example. Basing on some assumed parameters, one single horizontal seismic analysis on one row and three rows of assemblies in CEFR core has

been carried out. And sensitivity analysis of the parameters including damping ratio and shock stiffness has been finished. We can draw a conclusion as following:

a, Comparing the results of analyses with other similar analyses and the experiments, the model and the method is reasonable and effective.

b, The analyses have been carried out basing on some assumed parameters. After we get the real values of the parameters by experiments we can deduce the corresponding results by the results of sensitivity analysis.

c, Comparing the results of model consisting of three rows of assemblies with that of one row, effect between neighbor rows is very small. Roughly speaking, we can estimate conservatively the response of three-row model or even the whole core under one single horizontal excitation by using one center row model.

ACKNOLEDGEMENT

This work is done under MEXT-Nuclear Research Exchange Program between Chinese government and Japanese government. During my working in O_arai Engineering Center of Japan Atomic Energy Agency, Dr. N. Kasahara, Dr. T. Asayama, Dr. S. Okamura have done me a favor. I have benefited a lot from their good advices and discussion. Meanwhile thanks to Prof. Daogang LU from North China Electric Power University for his good suggestions.

REFERENCES

[1] Jing WEN, Daogang LU, “Single assembly preliminary analysis for horizontal seismic analysis on FBR core”, Atomic Energy Science And Technology, Vol.41, No.2, March 2007, pp.148 - 152

[2] Power Reactor and Nuclear Fuel Development Corporation, *Finite Element Nonlinear Structural Analysis System FINAS Users’ Manual Version 12.0*, TNC ZN9520, 1995

[3] T. Asayama, S. Kitamura, et al., "JNC/CEA collaborative work on core seismic study -SYMPHONY- Simulation of one-row mock-up tests with restrained configuration", Proc. of SMiRT-15, Vol. C, pp.413-420, Seoul, Korea, August 1999

[4] S. Kitamura, T. Asayama, et al., "JNC/CEA collaborative work on core seismic study -SYMPHONY- Simulation of three-row mock-up tests with restrained configuration ", Proc. of SMiRT-15, Vol. C, pp.421-428, Seoul, Korea, August 1999