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Core-seis: A code for LMFBR core seismic analysis

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ABSTRACT: This paper deals with a computer code 'CORE-SEIS' specially developed for seismic analysis of LMFBR core configurations. For demonstrating the prediction capability of the code, results are presented for one of the MONJU reactor core mock ups which deals with a cluster of 37 subassemblies (SA) kept in water.

1 INTRODUCTION

The core of an LMFBR is composed of several hundreds of SAs of different kinds such as fuel, blanket and neutron shields. They are self-standing hexagonal beams supported on rigid structure called core support structure (CSS). The core is completely immersed in liquid sodium with narrow spacings between adjacent SAs. A core configuration of a typical pool type LMFBR of 500 MWe is shown in Figure 1.

In an earthquake event, the whole cluster of SAs will be experiencing a complicated vibratory motion due to nonlinearity introduced by the collisions between SAs and dynamic interaction through fluid coupling forces. The vibratory motions of SAs are very crucial in an LMFBR due to their effects on the insertability of control rods (CRs) for tripping the reactor and the reactivity addition aspects. The possible vibratory motions in the vertical and horizontal directions as well as radially inward and outward directions cause 'vertically oscillatory', 'beam bending type' and 'flowering' modes respectively. If there is a mismatch between the control rods and crest of SAs in the horizontal direction above a certain limit (20-25mm), there may be a problem of insertability of CRs during an earthquake (Figure 2a). Since the reactor assembly of an LMFBR is vertically supported at the top, the CRs which are mounted on the top roof, will be inserted into reactor core under vertical motions resulting in an addition of positive reactivity (Figure 2b). The movements of core radially inward (flowering motions towards the central zone where neutron flux is high) as seen in Figure 2c, also cause the possibility of reactivity addition.

Since the reactivity worth of LMFBR control rods is high (~1 pcm/mm/rod), a few mm movement itself is significant. Further the neutronic events are much faster in comparison with the time scale involved in the seismic motions and because of that, sufficient time is available for the build up of reactivity due to vibratory motions of the core during an earthquake. An accurate assessment of dynamic response of the SAs and also their structural integrity is very important for ensuring safety. This requires a validated large scale non-linear dynamic analysis software. In this context, a special purpose inhouse computer software called 'CORE-SEIS' has been developed. The code has been provided with many novel features to have the capabilities to model the complex phenomenon that are associated with seismic motions of LMFBR SAs and also has ability to solve a large size problems within reasonable amount of computer time. The code has been extensively validated by the Japanese, French and Italian data supplied by International Atomic Energy Agency (IAEA) through a Co-ordinated Research Program (CRP) on Intercomparison of LMFBR Seismic analysis codes.

In this part of the paper the modelling features of CORE-SEIS have been described and its prediction capabilities are also illustrated for the MONJU core mock up data supplied by JAPAN.

2 CORE SEISMIC ANALYSIS METHODOLOGY

Seismic analysis of LMFBR core is performed in 2 phases. In the first phase, a time history analysis using spectrum compatible accelorograms is performed on the 'stick' model comprising of base raft, reactor vault, reactor containment building (RCB), reactor assembly, etc. The response time history at the top surface of CSS, is used as the input for the subsequent core seismic analysis. In this first phase of calculations, the mass inertia and stiffness values of the SAs are accounted by introducing a single composite beam. This means that the beam bending type deformation behaviour is only considered without introducing any complex nonlinear effects. In the second phase more realistic motions are computed by time history analysis, including all the possible complexities. It is to be noted that the stick model is different for horizontal and vertical excitations because of the difference in support conditions and inertial characteristics of the reactor assembly components as a whole.

2.1 Modelling features

- Each SA is treated as a 3D beam with different moment of inertia and mass per unit length depending upon the internal structures and configuration.
- The loading pads are modelled by a linear spring and a dash pot in association with the required gap (Figure 3).
- The support conditions at the foot of the SA are modelled by the springs with appropriate stiffness values so as to simulate the natural frequency values of the SAs observed experimentally (Figure 3).
- FSI effects are modelled using added mass concept both for internal and external sodium coolant.
- The global damping is introduced by defining modal damping constants, viz. α, β which are determined based on two natural frequencies of interest.

More details about modelling and associated mathematical formulations are given in ref(Chellapandi, 1994).

2.2 Analysis Procedure

As far as vertical excitations are concerned, the vibratory motions determined in the first phase using 'stick' model is sufficient for the analysis of small size rigid CSS geometry. This is because during vertical motions, interactions between SAs are negligible due to bending deformation of CSS. However for the large size CSS structure with is relatively flexible, seperate analysis for vertical excitations are required. Under this condition, the possible mode of vibration is 'flowering'. In order to have a realistic estimate, a 3D model incorporating all SAs is needed. However, a 2D analysis with the central row (Figure 4) can also give the prediction with reasonable accuracy. For the analysis of horizontal excitations, 180 deg. sector model is needed. Here also, considering the computer memory and CPU time, the central row alone is generally employed for the preliminary estimate(Morichita, 1993). The time step size is controlled by the shock stiffness values which can be estimated by an analysis of impact of a single SA on a heavy impact mass (Figure 5).

3 VALIDATION

CORE-SEIS is used to determine the seismic response of cluster of 37 SAs in water (Figure 6) which is one of the MONJU reactor core mockups. Complete validation of CORE-SEIS using the data supplied by Japan, France and Italy under IAEA-CRP, is illustrated in ref(Ravi, 1994).

3.1 Details of MONJU Reactor core mockup

The mock up SAs used for the MONJU reactor core experiments are actual sized and made of SS 316 material. The configuration of wrapper tubes are identical to the actual assemblies, while the fuel pins inside are simplified to simulate the weight distribution. Results are presented here for the case in which SAs are kept in water. Figure 6 shows the layout of configuration. Geometry, material data and input time history used in the analysis are given by Morichita, 1993. The gaps between different SAs are 0.7 mm and 1.0 mm at top and middle load pads (TLP & MLP) respectively. The gap stiffness value is 7.0E5 N/mm. The structural damping values are 3 % for the fuel and radial blanket SAs and 2 % for the neutron shielding.

3.2 Comparison of Results

The SAs are modelled with 11 nodes. Pinned support condition is assumed at the nodes corresponding to the locations of MLP & TLP. The added mass due to water present outside SA is taken equal to the mass of water in the enveloping hexagon. The Rayleigh damping parameters (α, β) are computed corresponding to the first two modes and the values are equal to 0.137332 and 0.0027966 respectively. The shock damping (Cs) was modeled from the shock stiffness (Ks) and the restitution coefficient (e) as:

$$Cs = Ks\,(1-e^2)\,\Delta t/\pi$$

where, Δt = Shock duration taken as 0.7 ms. Ks = 1200 N/mm & 7000 N/mm at MLP & TLP respectively.

The actual shock stiffness specified at TLP is equal to 7.0E5 N/mm. This requires a time step size in the order of 1-5 micro seconds for the stabe numerical solution which inturn calls for very large solution time. Further use of such a high local stiffness may also cause some numerical difficulties, which was observed for MONJU data. So calculations were performed with lower value (1200 N/mm) indicated above.

The computed maximum displacement and strain values at some selected locations as indicated if Figure 7, are compared in Table 1 and Table 2 respectively. From these tables one can see that the difference in the displacement between the experiments and the calculations is around 10 %, except at the location D3. At the location D3, the calculated maximum displacement values seems to be of the same order as the adjacent SAs. The reason for the low experimentally observed values is not known. The comparison of strain values at MLP and at the foot are good (within 20 %). At the TLP, the strain values are low. The use of lower Ks values has affected the prediction of shock forces and accelerations, particularly at TLP location.

Table 1: Maximum displacements (mm)

Location	Expt	CORE-SEIS
D1	5.2	6.12
D2	5.25	5.86
D3	2.1	4.94
D4	3.7	4.14

Table 2: Maximum strains (strain)

Location	Expt	CORE-SEIS
S1	29.0	41.7
S2	61.5	79.8
S3	17.5	1.3
S4	32.5	43.0
S5	69.2	88.7
S6	7.5	1.3
S7	36.7	47.7

4 CONCLUSIONS

An in-house finite element code 'CORE-SEIS' developed specially for the seismic analysis of LMFBR core has been described. Towards validation, calculations have been performed for the MONJU core mock up data supplied by JAPAN under IAEA/IWGFR CRP on 'Intercomparison of LMFBR core seismic analysis codes'. The displacement and strain values are generally predicted well. The difference in displacement values between the theory and the experiment is about 20 %. The strain values at lower pad locations compare well within 20 %. The strain value at top pad is generally low. The reason for the lower observed value is being studied.

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REFERENCES

Chellapandi,P., Ravi,R., Chetal,S.C & S.B.Bhoje (1994), Seismic analysis of LMFBR core: Part-I Developement of the code 'CORE-SEIS. Pıoc. 10th symposium on Earthquake engineering, Nov 16-18, Roorkee:949-956.
Morichita, M. & K. Iwata (1993), Seismic behaviour of free standing core in a large LMFBR. Nuclear engineering and design, 140: 309-318.
Ravi,R., Chellapandi,P., Chetal,S.C. & S.B.Bhoje (1994), Seismic analysis of LMFBR cores : Part-II - Validation of the code CORE-SEIS. Proc. 10th symposium on Earthquake engineering, Nov 16-18, Roorkee:957-966.

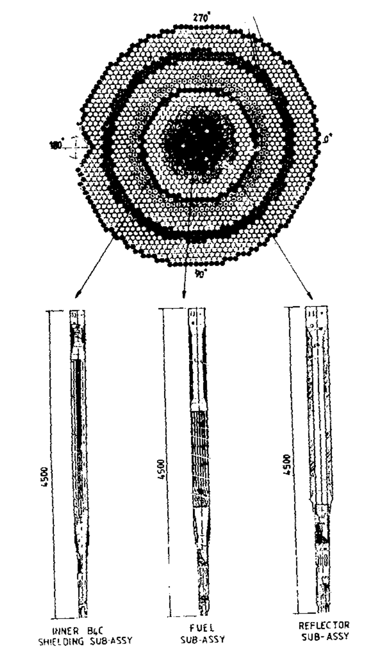

Fig. 1 Core configuration of an LMFBR

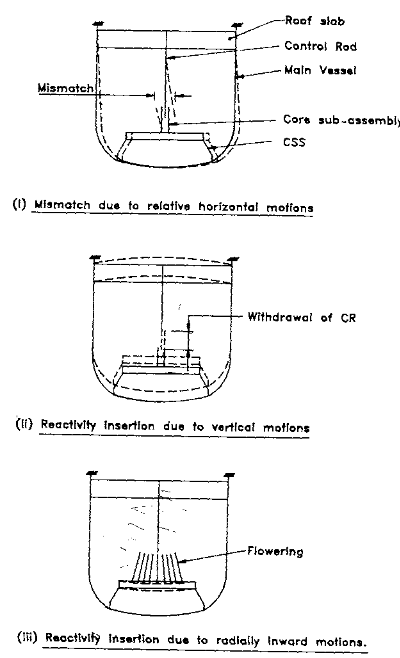

Fig. 2 Dynamic movements of LMFBR core under seismic excitations

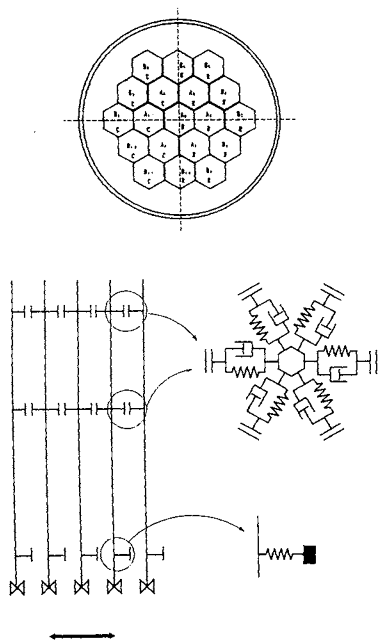

Fig. 3 Dynamic models for loading pads and end supports

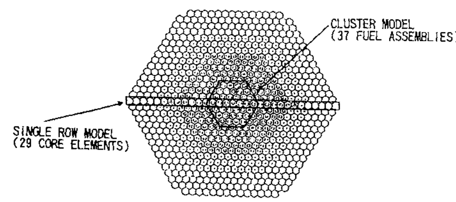

Fig. 4 Analysis models of core for seismic analysis

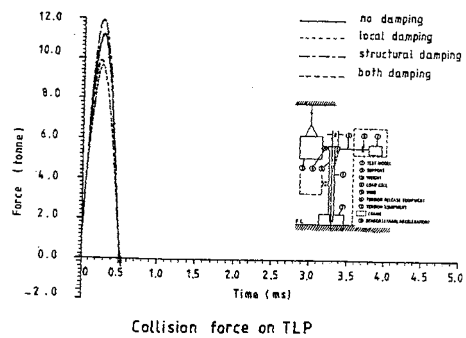

Fig. 5 Benchmark study for selection of time step

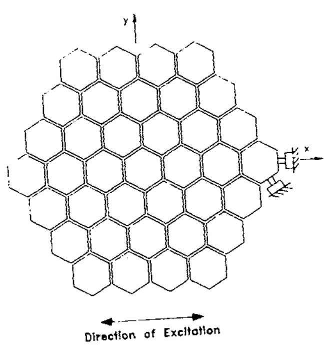

Fig. 6 37 Subassembly MONJU core mockup

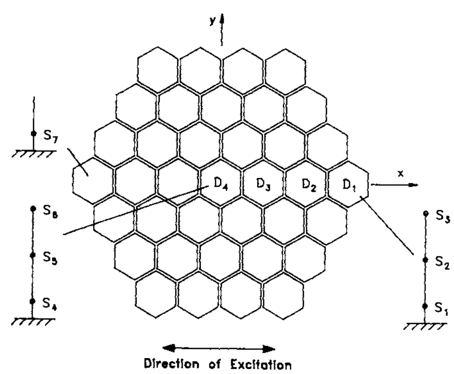

Fig. 7 Locations of displacement and strain measurements