Comparison Between a Beam and a Shell Model for the Seismic Analysis of a Reactor Vessel

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Abstract

The seismic calculation of experimental breeder reactors is usually performed using a beam model. Development has been made recently in the dynamic calculation of axisymmetric structures with fluid and accurate results can be obtained in the case of thin shells.

This paper presents the results of a comparison made between beam and shell modelings applied to the PEC reactor under horizontal seismic excitation.

To separate the shell and fluid effects an intermediate step is introduced and three models are analysed, beam,shell with added mass, shell with fluid-structure interaction.

The results given include eigenfrequencies, seismic response of the fuel elements and effects of the vertical excitation. Conclusions are drawn for the modeling of the vessel and the core.

1. Introduction

Very severe seismic conditions are applied to the PEC reactor and special attention is paid to the core design. In the loop type reactor the presence of a long suspended vessel might lead to large seismic amplification at the core supporting grid and at the piping connection.

Reactor vessel dynamic analysis has been performed using a beam model with a diagonal mass matrix accounting for the effect of fluid.

Due to the occurence of shocks between sub assemblies the core seismic behaviour is highly non linear and an equivalent linear model must be defined. This can be achieved through a step-by-step calculation of a single row of elements, extrapolated to the whole core. The transfer function between the diagrid acceleration time history and the force applied is finally obtained [1].

The core is replaced by a set of several linear oscillators with damping, matching as closely as possible the calculated transfer function.

Such a calculation can only be made by neglecting the fluid-structure interaction. In fluid the frequencies are lowered, this is understood to be an added mass effect and the mass of the oscillators are increased to simulate the core behaviour in sodium.

Recently more accurate methods has been developed for axisymmetric structures with fluid. Therefore a study was started by NOVATOME on behalf of ENEA to test the design analysis adequacy, using the computer program NOVAX described in reference [4].

To separate shell and fluid effects an intermediate step is introduced and two models are analysed : shell with added mass and shell with fluid-structure interaction.

Furthermore to evaluate the influence of core modeling two calculations have been made with simplified one-oscillator models.

In summary, three aspects have been checked :

- shell vs beam
- fluid finite element (F.E.) representation vs added mass
- fluid interaction in the core model

2. DESCRIPTION OF THE DYNAMIC MODELS

2.1. Vessel

The structure is described with two node axisymmetric conical elements. For the connection to the building floor, a special element is used to introduce the boundary condition derived from a detailed static analysis and verified by on site tests (3).

2.2. Fluid

In the added mass model the diagonal mass matrix is constructed according to the method used in the beam model : the five neutron-shields are independently represented and the lowest frequency is 16.7 Hz. The rule used can be summarized in the following way :

- in the case of a cylinder the internal fluid in an horizontal plane is directly applied to the shell by increasing its mass density,
- in the case of concentric cylinders the mass of fluid in the annulus is applied to the external shell.

In the F.E. model a detailed description of the five neutron-shields is unpractical, instead, an equivalent model was derived from a detailed analysis. This one has been adjusted on the frequency (2.1 Hz) and the participation factor of the first mode. The gap between the vessel and the equivalent shield is only 2 mm.

Four independent fluid superelements are used (see figure 1), at the free surface boundary a zero pressure condition is used and sloshing effects are not described.

The fluid inside the apparent volume of the core cannot be removed, therefore the mass density is reduced accordingly.

2.3. Core

The equivalent linear model for the core is a set of 4 damped oscillators and one residual mass. Each oscillator is modeled by a cylinder of the requested height and mass. Each cylinder is closed at the top by a rigid plate to prevent ovalisation and is connected to the diagrid. The model is derived from calculations neglecting the fluid-structure interaction. Masses have been increased by a factor close to 1.56 2 .

It could be supposed that the increase of the core mass unduly leads to overestimate the forces applied to the vessel support and the displacement of the vessel itself.

To evaluate this effect two simplified one oscillator core models were used. The first one is directly derived from the reference model, the oscillator frequency is 3.18 Hz, mass is increased by the factor 1.56. In the second model the oscillator is a cylinder of the same heigt as the core and interaction with the surrounding sodium is assumed, mass is not increased.

The frequency calculated with rigid vessel wall and diagrid is 3.20 Hz, in close agreement with the value above.

For the vertical analysis the mass of the dry core is uniformly distributed on the diagrid.

3. RESULTS AND DISCUSSION

3.1. Shell effects

Generally a shell does not behave like a beam, this effect originates from the ovalisation of conical elements of the structure when loaded by a bending moment. For example when a horizontal static force is applied at the diagrid level the displacement obtained is increased by 28 % when compared to the result obtained with the beam.

To take account of the ovalisation effect, a correction has been applied to the beam model (2).

3.2. Fluid F.E. modelisation

Results of the eigenvalue and participation factor calculation in the horizontal direction are given in table 1 for the added mass and F.E. models. Both with the four oscillator core model.

The four modes associated with the core model are practically the same in the two calculations. The only differences are introduced by the neutron-shields modelisation. They have a negligible effect on the overall results. For example, displacements at the bottom of the vessel obtained by the response spectrum method differ by less than 1 %.

A non linear analysis was performed on a single row of fuel elements with the CORALIE program using as input the time history of motion at the core diagrid. Maximum displacements obtained from three models are compared on figure 2 :

- beam (corrected for flexibility)
- shell with added mass
- shell with F.E. fluid

It was concluded that the core derived from the beam model could remain the reference.

Maximum horizontal relative displacement between the core restraint and the diagrid evaluated in the diagrid datum plane is 3 mm. This value remains small when compared to the fuel motion and needs be introduced in CORALIE calculation.

3.3. Fluid interaction in the core model

In the reference model the sodium effects are taken into account by an appropriate increase of the masses. A more precise method would use a full mass matrix coupling the core to the surrounding neutron-shields.

The simplified core model has been used to evaluate the effect of a coupled core model on the overall vessel response. Table 2 gives frequencies and participation factors of the three most significant modes.

Eigenfrequencies deviate, by less than 5 %. The participation factor of the fuel mode at 3 Hz is decreased by fluid interaction and mass reduction. The opposite effect occurs for the fundamental vessel mode at 5.4. Hz. The vessel displacement is slightly increased despite a reduction in the total mass, this can be understood as the result of a stronger coupling between the core and the vessel.

From comparison with the previous calculations it appears that a refined core model reduces forces and displacements. Therefore it is necessary to make a careful modelisation of the core behaviour and it is also justified to increase the mass to simulate the sodium effect.

3.4. Vertical response

The first frequency of vibration being relatively high (15 Hz), the response is not important.

The vertical acceleration of the diagrid being 0.22 g, there is no risk of fuel element displacement.

Differential motion between the plug and the diagrid being quite small, less than 1 mm, only negligible reactivity effects can be expected.

4. CONCLUSIONS

- The shell deformation influence on stiffness is the most important effect to be expected with a shell model as compared to a beam model.
- Fluid-structure interaction does not play an important role in the seismic behaviour of the experimental reactor PEC.
- A satisfactory evaluation of sodium effects in core equivalent linear models is made by an increase of the mass. However development of core models with complete fluid-structure interaction is desirable.

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TABLE 1 - EIGENFREQUENCIES AND PARTICIPATION FACTORS
4 OSCILLATORS CORE MODEL

	DIAGONAL MASS		F.E. FLUID	
MODE	N	Γ	N (Hz)	Γ
Neutron shield	-	-	1.115	9.2
Core	2.30	106.9	2.30	105.2
Core	2.53	37.1	2.53	36.8
Core	2.91	147.3	2.91	147.8
Core	3.21	9.1	3.21	9.4
Neutron shield	-	-	4.62	7.2
1 ST Vessel	5.31	166.8	5.35	170.2
Neutron shield	-	-	9.40	16.9
Neutron shield	12.0	142.9	-	-
2 ND Vessel	15.0	129.0	14.0	191.5
Neutron shield	-	-	15.6	10.6
External vessel	19.9	92.4	19.6	88.5

TABLE 2 - EIGENFREQUENCIES AND PARTICIPATION FACTORS
SIMPLIFIED CORE MODEL

	INCREASED MASS		FLUID INTERACTION	
MODE	N	Γ	N	Γ
Core	3.0	198.2	3.03	138.0
1 ST Vessel	5.44	153.9	5.16	190.5
2 ND Vessel	14.0	192.5	14.0	190.2

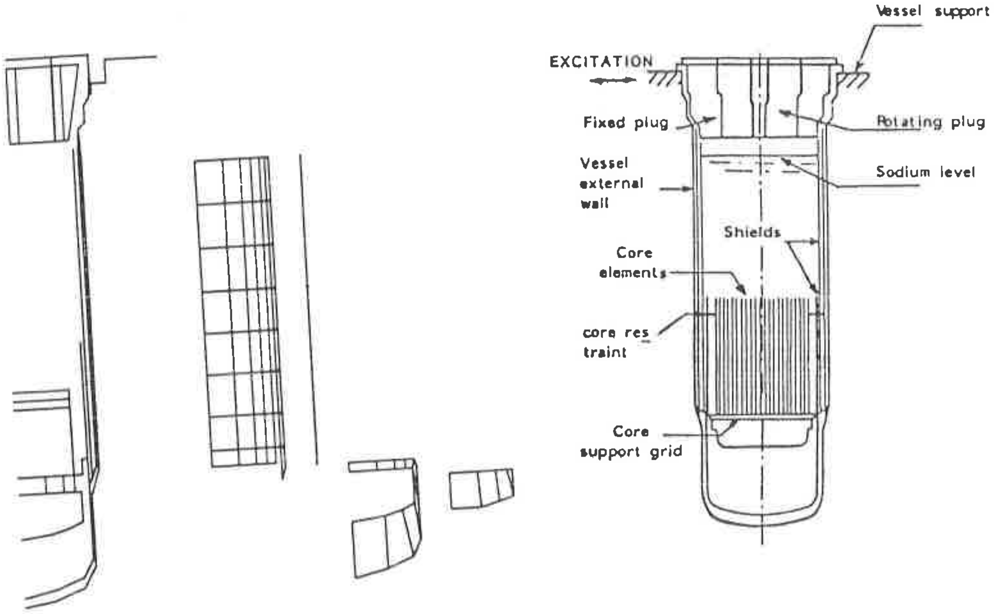

FIGURE 1 : REACTOR VESSEL MODEL

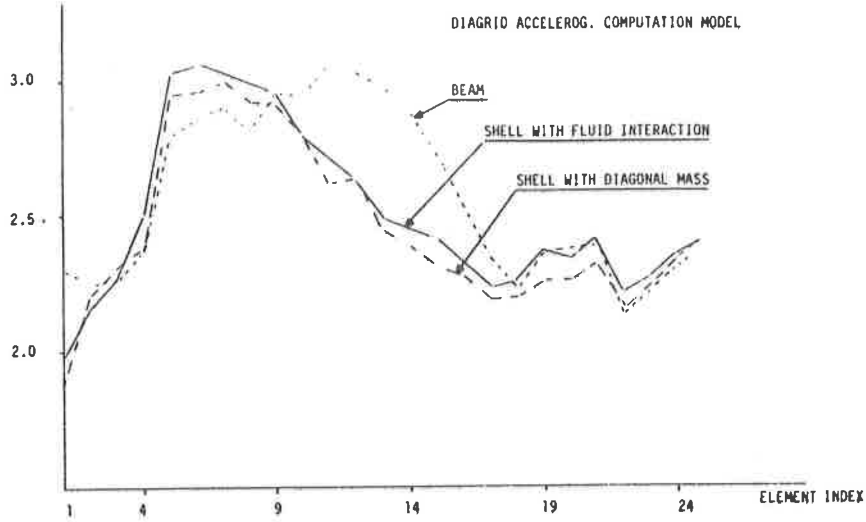

FIGURE 2 : FUEL ELEMENT MAXIMUM DISPLACEMENT (cm)