Dynamic response of PWR vessel during a blowdown

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1 INTRODUCTION

This paper presents a study of the behaviour of a 1300 PWR structures during the acoustical period of a blowdown accident, caused by a sudden break of the cold pipe at the outlet of the pump. The calculation gives displacements and pressures for many points of the vessel. Besides it gives the reaction forces in internal supports and also the loading level reached in the support device of the vessel.

This calculation was performed by the computer code TRISTANA, which uses a substructuration method on a modal basis (ref.1). This simplified method reduces computing size and time for tridimensional problems involving fluid structure interaction and sometimes localized non-linearities. It has already been validated during the calculation of the HDR blowdown (ref.2).

2 BASIC HYPOTHESIS OF THE CALCULATION

The decompression wave generated by the sudden break propagates along the discharge pipe and spreads into the downcomer. In this area, to simplify, the wave propagation is assumed to be hardly affected by the other loops. Therefore, only the vessel and the broken pipe are studied.

In this three dimensional problem, it is interesting to take advantage of the simplicity of each component: the broken pipe is a 1D structure and the vessel is an axisymmetrical one. Also it is worth while employing a sub-structuration procedure.

Moreover, in the acoustical phase of the LOCA, the internal movements are small and the structures are assumed to remain elastic. The fluid is still monophasic almost everywhere in the circuit and the flow has just started at the broken pipe. At this step, non-linearities, if they occur, are expected only at a few locations, for instance at the outlet pipe. So modal analysis can be used to represent the movement of each component.

In this study, the substructures are chosen link-free. At the connections, the substructures are isolated by the following boundary conditions:

- for mechanical links: $\vec{F} = 0$,
- for fluid links : $\overrightarrow{\text{grad}}\, p.\vec{n} = 0$

(no mass flow rate through the connection area).
So, the symmetry of the vessel can be preserved.

3 MODELIZATION

a) the discharge pipe:

As the pipe is concerned, only the movement of the fluid is represented by a set of acoustical modes of the closed pipe. The following criteria is used to truncate the modal basis: the wave front must be well represented by the modal basis. So the lower eigen period must be about a quarter of the break opening time (the greatest eigenfrequency is closed to 4000 Hz).

b) the vessel and its internals

The vessel and the core barrel are modelized with axi-symmetrical shells. The core is simply modelized by its upper and lower plates. The set of fuel assemblies is represented by added mass. An analogous procedure is used for the upper internals. Moreover the columns joining the upper core plate and the upper support plate are reproduced by an equivalent spring. The aim of this modelization is to reproduce the transverse movements of the core barrel which are excited by the decompression wave in priority.

For the fluid we use the mesh drawn figure 3. Let us remark that the set of fuel assemblies are represented by a rigid shell. The fluid contained inside the core is modelized by an annular volume located between this rigid shell and core barrel. This modelization is sufficient to represent the plane wave propagation in the core. A set of acoustical-mechanical coupled modes have been computed and fitted with some results of vibration tests performed in Paluel nuclear power plant. (This procedure allows us to estimate the rigidity of the hold-down spring which is difficult to calculate accurately).

Due to the core barrel elasticity, the wave front is smooth in the downcomer. Then, only the modes with eigenfrequency lower than 200 Hz are used in the computation.

c) Fluid connection

Two fluid connections are employed:
- the first one, to connect the downcomer and the broken pipe,
- the second one, to introduce an acoustical impedance which controls the wave reflexion on the two phase zone localized at the break.

d) Mechanical connections

The upper core plate supports and the core barrel radial support are modelized by mechanical links. During the blowdown, the gap between the structures are neglected, so the links are permanent ones.

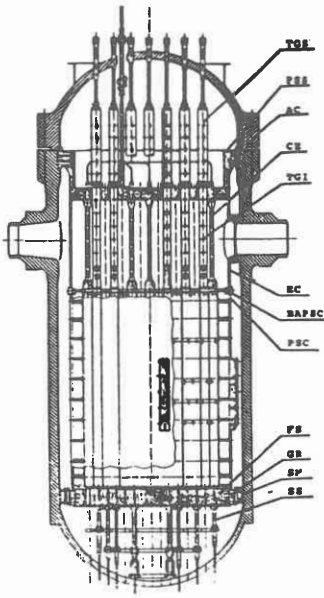

Figure 1.
PWR cross section
(1300 MW)

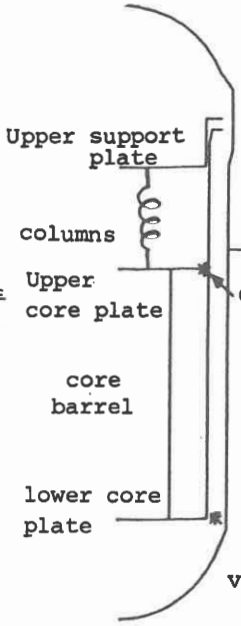

Figure 2.
Mechanical structures

Figure 3.
Mesh of the fluid.

e) Break representation

An acoustical impedance Z is used to simulate the wave reflexion on the two phase zone localized at the break. Moreover, this impedance allows to control the mass flow rate at the break. It can be seen that the mass flow rate reaches a maximum value. So, a simple way to adjust this impedance is to choose the one which gets back this maximum value. A thermohydraulic calculation has been performed with the PLEXUS code. In this computation, only the fluid is concerned. It is chosen homogeneous and in thermoequilibrium. The critical flow is given by the Moody model.

f) Loading

The break creates:
- on the fluid outlet pipe:
  an acoustical pressure source such that the pressure inside the pipe reaches the saturation pressure level,
- on the broken pipe section:
  a force due to the tension release in the pipe. The resulting efforts are applied on the junction with the vessel.

The loading time history is assumed to be a simple step reached in one millisecond.

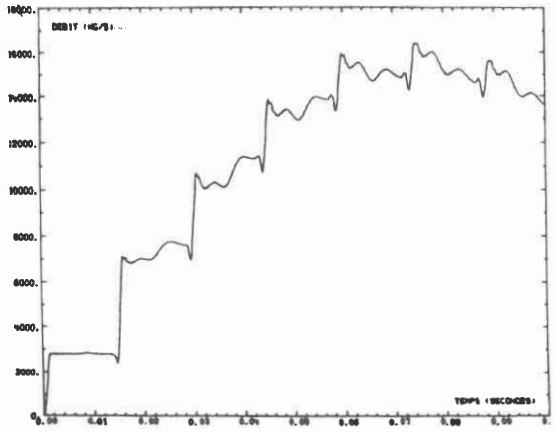

Figure 4. Mass flow rate at the break.

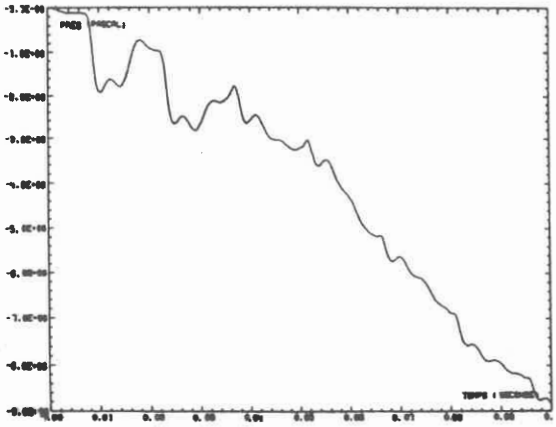

Figure 5. Pressure at the junction between the vessel and the broken pipe.

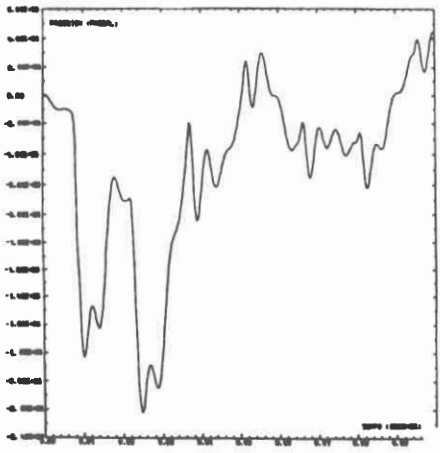

Figure 6. Differential pressure across core barrel in front of the junction.

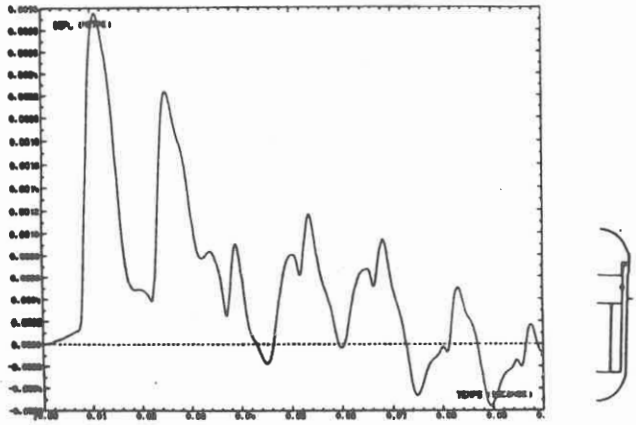

Figure 7. Radial force on a upper core plate support (90°).

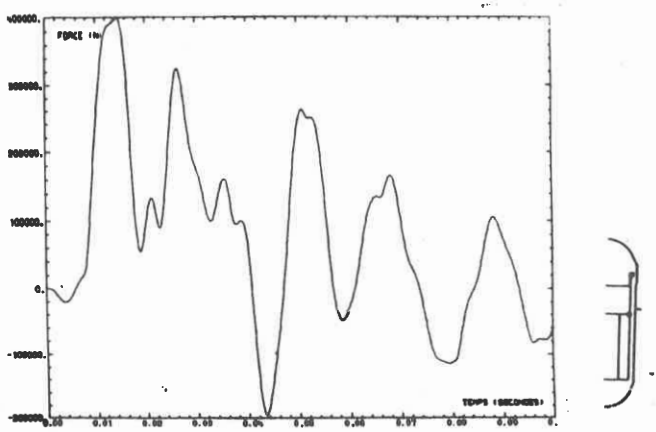

Figure 8. Radial displacement of the core barrel in front of the junction.

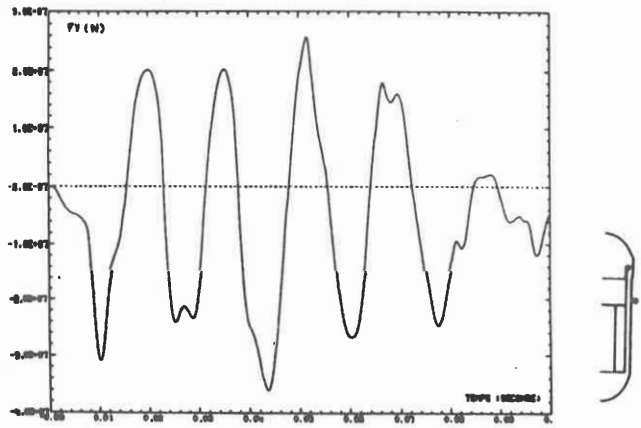

Figure 9. Resulting force on the vessel support in the y axis.

4 DISCUSSION OF THE BLOWDOWN CALCULATION RESULTS

The maximum mass flow rate reached is closed to 16,000 kg/s, the value given by the Plexus code (fig. 4).

The pressure decreases globally in the downcomer (fig. 5) with a characteristic time associated with the resonance frequency of the Helmoltz system: vessel internal volume/blowdown pipe.

When the decompression wave arrives in the downcomer the pressure starts to decrease (20 10^5 Pa).

When the pressure acting in the core barrel decreases, the core barrel starts moving towards the blowdown nozzle and the shell modes are excited.

The largest displacements are those of the core barrel in the neighbourhood of the blowdown nozzle (fig. 7). The maximum displacement is about 3 mm.

The transverse movement of the core barrel creates reaction forces on the support.

The maximum efforts observed on the upper core plate supports are tangential ones. They are closed to 2 10^6 N.

The maximum efforts observed on the radial supports are radial efforts produced by the contraction of the vessel. They are closed to 4.5 10^6 N. It seems that no plastification occurs in the supports.

The calculation also provides us with an estimation of reaction forces applied on the support device of the vessel.

The maximum force is 3.6 10^7 N and the maximum moment is closed to 27 10^6 NxM.

5 CONCLUSION

This substructuration method reduces significantly the number of degrees of freedom. Its requires few calculation compared with a finite element program dealing with fluid structure interaction in a three-dimensional geometry. However, its implementation necessitates as a preliminary a correct approach of the physical phenomena involved. Particularly, it is very important to choose a modal basis giving a good representation of those phenomena. Besides, in our case, a fitting of the model by available experimental results provide us with a reliable modal basis.

With regard to the results obtained here, the assumptions seem work reasonably well. Specially the single phase flow hypothesis remains valid during the three-quarter of the whole calculation time.

The internal modelization, somewhat difficult to perform, seems sufficient to reproduce the core movement and therefore, forces applied on upper core plates supports and on radial supports.

It is interesting to remark that efforts, excluding the compression ones due to vessel contraction are maximum within the very first instants of the accident. This point confirms the importance of the acoustical studies of the LOCA.

6 REFERENCES

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