Effects of fluid communications between fluid volumes on the seismic behaviour of nuclear breeder reactor internals

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1 INTRODUCTION

The internal structures of a breeder reactor as SUPERPHENIX are mainly axisymmetrical shells separated by fluid volumes which are connected by small communications holes. These communications can destroy the axisymmetry of the problem and their effects on the inertial terms due to the fluid are important. An equivalent axisymmetrical element based on a local tridimensional solution in the vicinity of the fluid communication is defined. An axisymmetrical modelization using this type of element is built in order to calculate the horizontal seismic behaviour of the reactor internals. The effect due to three typical fluid communications are studied and compared.

2 LOCAL TRIDIMENSIONAL EFFECT DUE TO FLUID COMMUNICATION

2.1 Introduction to the equivalent length

The influence of a fluid communication is essentially due to the inertial effect. The fluid can be assumed to have a linear and incompressible behaviour. This effect is characterized by an impedance $\mathcal{Z}$ which can be realized as in a plane wave model by an equivalent fluid column with the same cross section s of communication and an equivalent length ℓ. $\mathcal{Z}$ is defined by:

$$(1) \qquad \mathcal{Z} = \frac{p_2 - p_1}{q}$$

where q is the fluctuating mass flow rate and $p_2 - p_1$ is the fluctuating pressure gap due to the communication (see scheme 1). The equivalent tube gives us

$$(2) \qquad \mathcal{Z} = -\frac{iw\ell}{s}$$

where w is the pulsation of the fluctuation ;
ℓ strongly depends on the tridimensional velocity field (v) near the ends of the communication (see scheme 2).

Impedance $\mathcal{Y}$ then ℓ are deduced from the resolution of Laplace equation in (v). Three approaches are possible:

- use the integral equations associated with Laplace equation, making some reasonable assumptions (1),
- use a modal description of (v),
- use a finite element description of (v).

Figure 1 shows the results of the second approaches for an annular communication connected to an annular volume. The two other approaches lead to 3 to 10% variations.

Remarks

- In the example of figure 1, the communication was symmetrical. If the communication is not symmetrical (see scheme 3), it is always possible to define an equivalent symmetrical communication with an associated equivalent length.
- Equivalent lengths can be defined for n = 0 modes (vertical seismic calculation) or for n = 1 modes (horizontal seismic calculation).

2.2 Application in a finite element description

A correct modelization of the fluid communication by finite element method generally needs a lot of small elements compared to the size of the standard mesh of the fluid volumes.

The interest of the preceding analysis is to keep this standard mesh (adapted to the global fluid-structure problem) and to introduce an equivalent fluid connection element which represents the local inertial effects of the communication.

This equivalent element has the section of a face of a standard finite element (S_m) and his equivalent length ℓ_m is given by:

$$\ell_m = \frac{S_m}{s}\,\ell \qquad \text{(see scheme 4)} \tag{3}$$

ℓ is estimated from diagrams like this presented in figure 1.

3 HORIZONTAL SEISMIC CALCULATION OF BREEDER REACTOR

This part is devoted to the application to an horizontal seismic calculation of pool type breeder reactor internals.

3.1 Reference modelisation

A reference axisymmetrical modelization without fluid communication is presented in figure 2.

A modal analysis in the 0, 10 Hz frequency domain gives 22 natural modes whose the associated modal masses represent 81% of the complete structure mass (shells and fluid).

We obtain three types of modes:

1) low frequency modes of fluid sheets connected with opposite phase vibration of limiting shells (0, 1 Hz).
2) modes of core (1 Hz, 3 Hz).

3) global modes (3 Hz, 10 Hz) included seismic modes (3.8 Hz, 5.2 Hz) and (7.2 Hz, 8 Hz) (in phase vibration of shells limiting the fluid sheets).

We give in example three representative mode shapes (figure 3).

3.2 Modelisation with communication

We have three types of fluid communication represented on the figure 2:

1) Communications (1) et (2) between a large fluid volume and a thin fluid sheet.
2) Communication (3) between a large fluid volume and a large fluid sheet.
3) Communication (4) between two thin fluid sheets.

Remark: The communication (3) can be considered as the communication (1) because the effect are the same with less importance.

The modal analysis of these new models in the 0, 10 Hz frequency zone shows an important redistribution of modal masses and a strong modification of the associated fluctuating pressure fields. The frequency generally increases. When we introduce a communication at the end of the fluid sheet, we change the associated boundary conditions of the fluid, so the inertial effects are modified (generally decreased), especially the strong inertial effect due to the fluid sheet. Then the greatest influence occurs on the type 1 modes: the structure of the modes is not changed, but the resonance frequencies increase and generalized masses decrease. Concerning seismic modes as far as the fluid sheets play a role, we observe a certain influence on the inertial terms and a redistribution of generalized masses along shells (small modification of the global parameters: resonance frequency and generalized mass).

4 HORIZONTAL SEISMIC ANALYSIS

This analysis has been performed using the response spectrum method. We applied the square root of the sum of the squares (SRSS) method (modal vibrations are assumed to be statistically independent).

The maxima of the responses due to the horizontal seism for all the models including fluid communication are generally less than the responses of the reference model.

We studied pressures, displacements, accelerations and stress for structures as redans, baffles, vessels, weir and shrouds. We give two examples on the B1 baffle and the weir. The fluid communication (1) change the spatial distribution of the pressure differences acting on the B1 baffle because of the strong change of the pressure condition at the end of the fluid sheet. This communication has no influence on the pressure acting on the weir. The spatial distribution of the pressures on the B1 baffle is not modified by the other communications: the ratio between the response with communication and the response without communication is between 0.7 and 1). The same phenomena is observed on the weir: the fluid communication (2) in the vicinity of the end of the weir has an influence on the pressures on shells limiting the fluid sheet (weir, toroidal redan shroud).

We observe the same comportment concerning the displacements.

5 CONCLUSIONS

The effect due to a fluid communication has a great influence on the modes of fluid sheets, also on the seismic modes where fluid sheet effects are involved. Generally, the resonance frequencies increase and the seismic responses decrease, but for particular typical communications the spatial repartition of the pressures on the shells limiting the fluid sheet is modified. This aspect is important for the prediction of the seismic buckling stability of these shells.

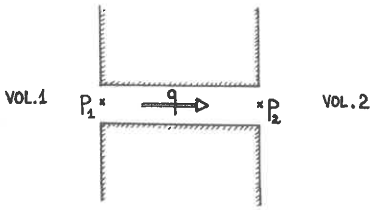
REFERENCES

(1) Baylac, G., Gibert, R.J. & M. Livolant, "La Houille Blanche", n°5, 1971.

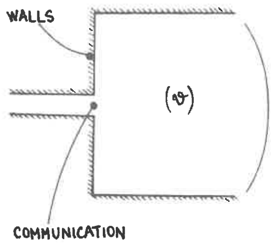
(2) Brabant, F., Billon, H., Gantenbein, F., Gibert, R.J., "Analyse 3-D d'un bloc réacteur à neutrons rapides soumis à un séisme horizontal. Calcul des modes propres en sodium", rapport DEMT/85/114 (1985).

(3) Brabant, F., Gantenbein, F., Billon, H., "Analyse 2-D d'un bloc réacteur soumis à un séisme horizontal", rapport EMT/SMTS/VIBR/80/10 (1980).

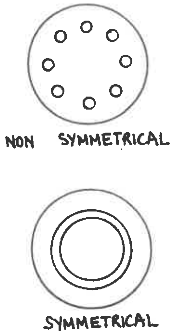
(4) Chéron, P., Desclève, P., "Detailed Representation of Fluid-Structure Interaction in Seismic Analysis", 8th SMIRT, Aug. 1985, paper E 7-9.



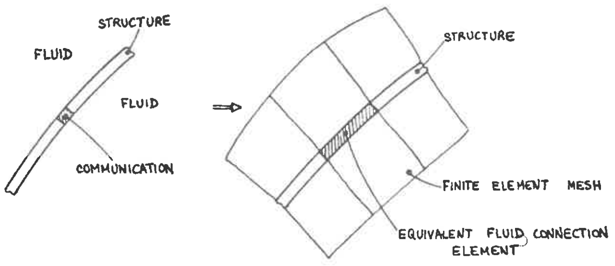
Scheme 1



Scheme 2



Scheme 3



Scheme 4

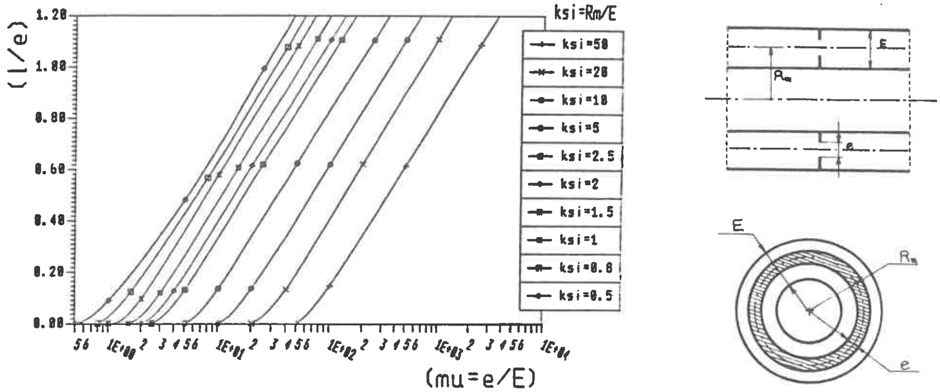


Figure 1 : Equivalent length l compared with the size e of the annular hole obtained in n = 1 mode for an annular cavity.

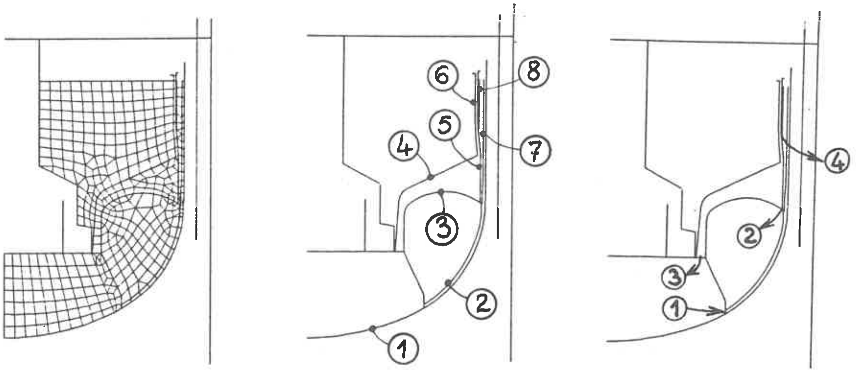


Figure 2 : Axisymmetrical modelization of the pool-type breeder reactor as SUPERPHENIX - Indication of communications.

① Main vessel
② Bl Baffle
③ Toroïdal redan
④ Conical redan
⑤ Toroïdal redan shroud
⑥ Conical redan shroud
⑦ Weir
⑧ Thermal baffle

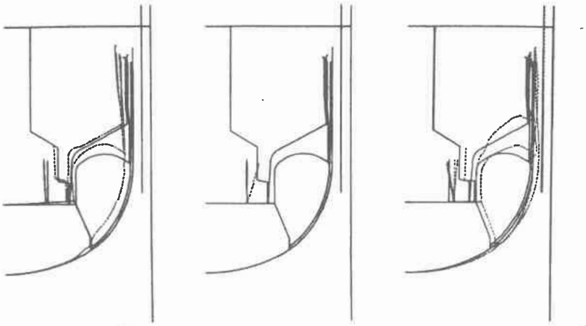


Figure 3 : Representative displacements of the structure without communication

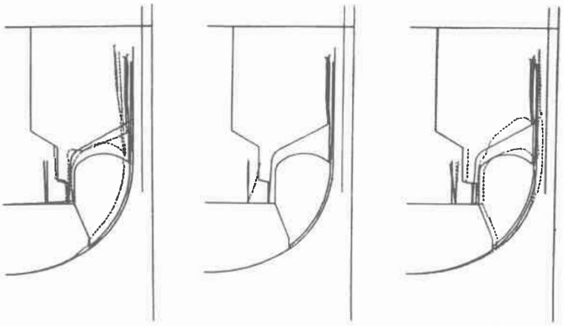


Figure 4 : Representative displacements of the structure with communication (1)

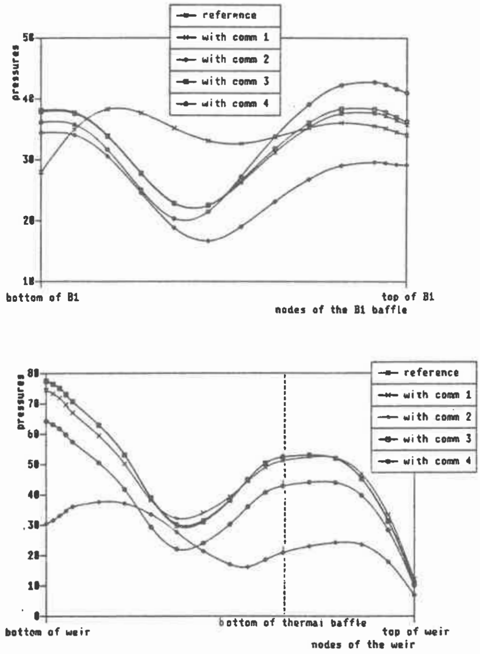


Figure 5 : Maxima of pressures differences on the B1 baffle and the weir dues to the horizontal seism

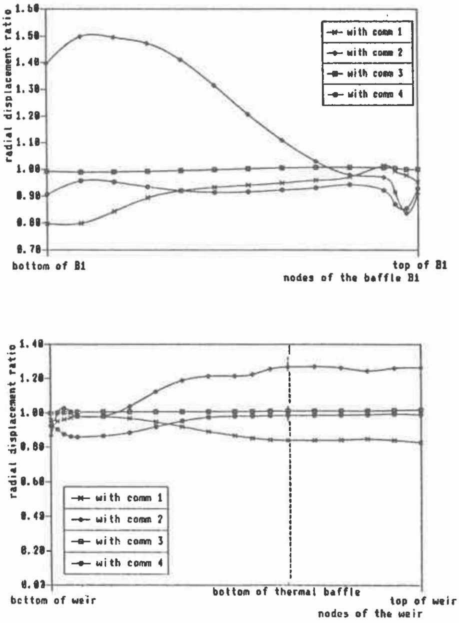


Figure 6 : Maxima of radial displacements ratio on the B1 baffle and the weir dues to the horizontal seism