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3-D Seismic Analysis of Pool Type LMFBR Structures with Fluid-Structure Interaction

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Abstract

The structures of a pool type LMFBR are composed with thin axisymmetric shells separated by narrow sodium sheets.

However the global geometry of this fluid-structure coupled system is not axisymmetric because of internal components like intermediate heat exchangers and primary pumps.

Therefore a 3D seismic modelisation has been undertaken. The great complexity of this system only allows a substructure procedure.

In a previous paper (E6-4 SMIRT 83) the principe of the method and intermediate results were given.

We present here the final results of the seismic analysis. Comparisons, made with an equivalent 2D calculation, show the 3D effects, specially on the fluctuating pressure fields generated in sodium by seismic motion which are important data of the buckling analysis.

1. Introduction

After the recall of the general principe of the method used for the seismic 3D analysis of a pool type LMFBR, we present the different steps of the horizontal seismic calculation and the final results are compared with those obtained by a 2D equivalent approach.

2. Recall of the substructuration procedure and fluid coupling formalism developped in TRISTANA computer code

The whole structure is divided into independant substructures which are defined by their natural modes calculated with free boundary conditions at the connection points. Procedure consists of assembling the substructures by link forces located at connection nodes. Complete structure modes are described by projection on the free modal basis of each substructure. The effect of neglected basis modes is corrected by using an additional flexibility matrix deduced from the static responses to forces located at each connection points. (To get more details see references (1) and (2)).

Substructures can also be connected one to another by incompressible and unviscous fluid volume (references (3) and (4)). This type of connection can be characterized by an added mass matrix coupling the free modal basis of the concerned substructures. This matrix is symmetrical ; its coefficients are calculated by resolution of the Laplace equation of the coupling fluid volume. Then they are introduced in TRISTANA code like particular links.

The system variables are the modal contributions, the connection variables are the link forces and the generalized fluctuating pressure forces.

Substructuration procedure is particularly interesting for dynamic calculation of 3D systems which can be divided into simple substructures (as axisymmetrical shells), mechanically connected at a few nodes.

Moreover, the fluid coupling method previously described permits to eliminate the displacement variables of the fluid volume in the resolution of the equations of the coupled structure.

3. Modelisation of the internal structures of a pool type LMFBR

The LMFBR internals (figure 1) are mainly composed of concentric axisymmetric vessels. Unfortunately, 8 heat exchangers and 4 primary pumps (and their crossings) are located unsymmetrically around the core and coupled to the thin shells both mechanically and by the sodium of the hot collector. These components are composed of axisymmetric shells. So the structure is divided into the following axisymmetric substructures :

(1) Heat exchanger, its two crossings, internal sodium volumes and sodium sheets

(2) Primary pump, its two crossings, internal sodium volumes and sodium sheets

(3) All the other structures of the reactor, sodium volumes and sodium sheets except the sodium volume of the hot collector.

Indeed, this volume has a strong 3D geometry and couples the different above-mentioned structures. So this fluid volume will be taken into account with the previously described method.

Moreover, we have used the following hypothesis : there are two plans of symmetry for the structure (figure 2), so only one quarter of the structure is considered with the associated boundary conditions (see the general view of the assembled substructures modelisation, fig.3).

4. Free substructures natural modes analysis

All these calculations have been carried out with AQUAMODE computer code (reference 5).

We recall that axisymmetric structure modes are characterized by an azimuthal number n ($\cos n\theta$ and $\sin n\theta$) and as meridian number m. Modes with harmonic variation $n \neq 1$ must be calculated to perform the horizontal seismic analysis because of important 3D features of the complete structure, contrary to a simple 2D approach.

Natural modes of the substructure internal structures without components have been calculated using the hypothesis that there is no soil-structure interaction (soil is assumed to be rigid).

We found a big density of modes : nearly 250 (troncation frequency is taken at 20 Hz and $n \leqslant 17$ and odd number because of plans of symmetry). Moreover, 333 natural modes of components are calculated with free boundary conditions and troncation frequency taken at 40 Hz.

5. Links modelisation

Stiffness coupling is characterized by 210 relations between components of displacements and forces at connected nodes (at the intersection of redans and crossings, components and roof slab, and pump and diagrid).

Inertial coupling by hot collector sodium is characterized by a 77 x 77 mass matrix coupling n = 1 to n = 17 modal displacement of the baffle wall and n = 0 to n = 2 modal displacement of crossings walls. Its coefficients are obtained from a 3D modelisation of the sodium volume (figure 4) : fluctuating pressure fields are calculated by BILBO computer code (reference 6) and then integrated. The analysis of these coefficients shows that they often are an important fraction of the mass of components ; consequently they will strongly act on the excitation of the n $\neq$ 1 modes of baffles.

6. Complete structure natural modes analysis

All the modes with frequencies lower than 10 Hz have been calculated by TRISTANA computer code. We have found a very big density of modes = 159 modes. The lowest frequency, $\nu = 0.33$ Hz corresponds to a movement of the conical redan shroud (with mainly an azimuthal variation in cos 3θ) and a light movement of the conical redan with driving of the external crossing of primary pumps.

The analysis of the complete structure modes shows that they are, in general, composed by :

- many basis modes (until 50) of the substructure (3), with azimuthal odd numbers n ($1 \leqslant n \leqslant 17$),
- several modes of the crossings of components with azimuthal number between 0 and 5.

This complexity of the decomposition of the complete structure modes which increases with the frequency, involves modal shapes with strong 3D features. This phenomenon is due both to the mechanical and fluid coupling between all the substructures. To put in evidence the effect of fluid coupling, a TRISTANA calculation with only stiffness links has been carried out and compared with the preceding one. We have found again a big density of modes between 0 and 10Hz, but modes have different frequencies, shapes and decompositions of the free modal basis. Comparing both calculations, we notice, for example, that the lowest frequency swinging movement of the heat exchangers is strongly coupled with shrouds and pumps crossings movements, this coupling being essentially due to the fluid connection.

The modes with a big modal mass (highly excited by the horizontal seism) have natural frequencies between 3,8 and 4,3 Hz ; 4,7 and 5,0 Hz ; 7,1 and 7,7 Hz (see figures 4 and 5 longitudinal sections of two of these modes shapes).

This modal analysis is compared to an equivalent analysis that we have carried out on a 2D classic modelisation of the LMFBR pool : the studied structure is the same, but all the components are modelised by axisymmetric oscillators hanging from the roof slab, and no coupling between components and vessels can be taken into account. 28 natural modes (n = 1) are obtained between 0 and 10 Hz from this 2D calculation. Modes with important modal mass are contained by 3,9 and 5,4 Hz ; 7,0 and 7,9 Hz ; 8,1 and 8,3 Hz. The comparison with the 3D calculation shows that these modes are located in the same frequency ranges, but, in the 3D case, they are more numerous and each of them includes not so much modal mass.

7. Horizontal seismic analysis of the complete structure

This analysis have been performed using the response spectrum method. At first we applied the square root of the sum of the squares (SRSS) method, but a sharp analysis of results showed that this method is an inadequate estimator of responses because the natural frequencies of the system are closely spaced (modal vibrations are not statistically independent). So we used the double sum combinaison (DSC) method developped by Rosenblueth, which takes into account the cross-correlations between the modal components and the time duration of "white noise" segment of seism excitation.

The comparison between the complete 3D calculation and the 3D calculation with only stiffness coupling shows that the 3D fluid coupling effects increase the seismic responses of all the substructures : in this way, relative displacements in the direction of seism are in the ratio of 1.5 to 2 for the tops of all the baffles.

The analysis of the set of 3D seismic responses and the comparison with the results obtained on the 2D modelisation described before have been carried out.

In general, we notice that the TRISTANA calculation always shows an evolution of the studied variables with the azimut strongly marked by 3D aspects (see figure 7), but the maximum (with the azimut) is sometimes greater or lower than the 2D result, according to the type of structure and the studied variable (see figure 8 the comparison of the evolution with the height of the maximum of pressure differences along the overflow).

8. Conclusion

We have presented a substructure method to calculate the seismic behaviour of complex coupled fluid-structure systems, and its application to LMFBR internals.

The results of this study show the great complexity of this problem and the importance of 3D effects on the modal and seismic analysis.

These effects have to be taken into account specially to perform a good estimation :

- of the stresses and of the displacement fields (some internal structures are separated by small gaps and then shocks can occur)
- of the fluctuating pressure fields acting on the shells which can generate buckling effects.

References

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(2) JEANPIERRE F., LIVOLANT M., "Système CEASEMT, TRISTANA - Principe. Notice d'utilisation", Rapport EMT/76/177 (1976)

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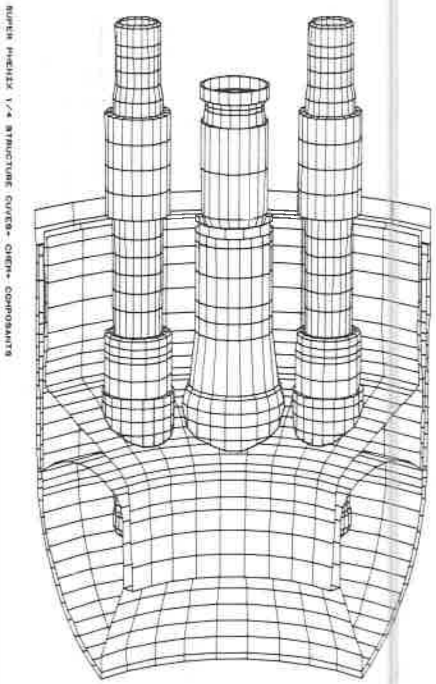

Figure 3 - General view of redans, shrouds, crossings and components (quarter of structure) = mesh

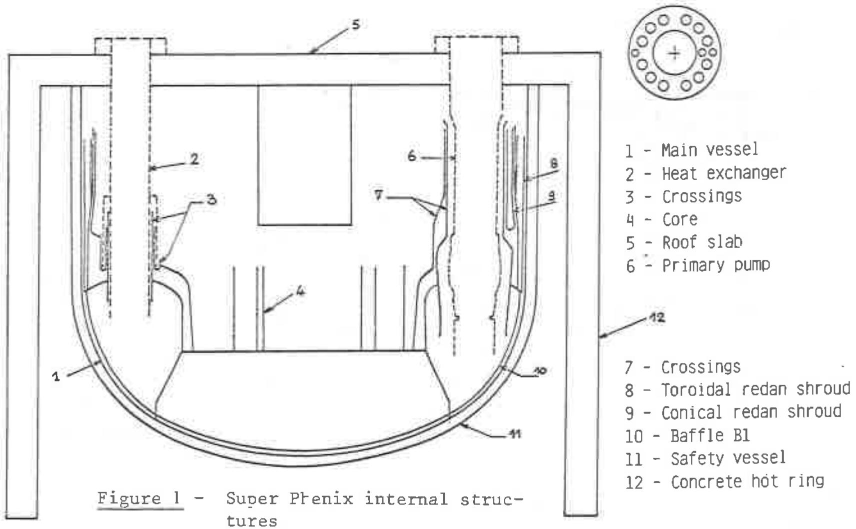

Figure 1 - Super Phenix internal structures

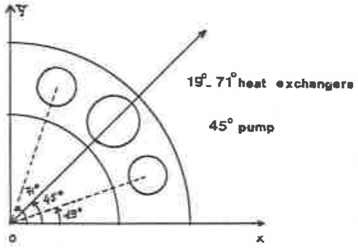

Figure 2 - Super Phenix geometry : Plans of symmetry.

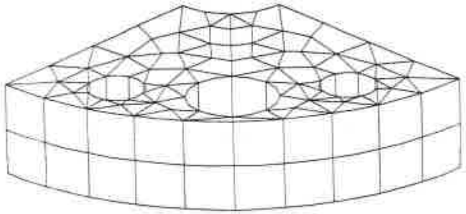

Figure 4 - Hot collector sodium volume (quarter of structure) = mesh

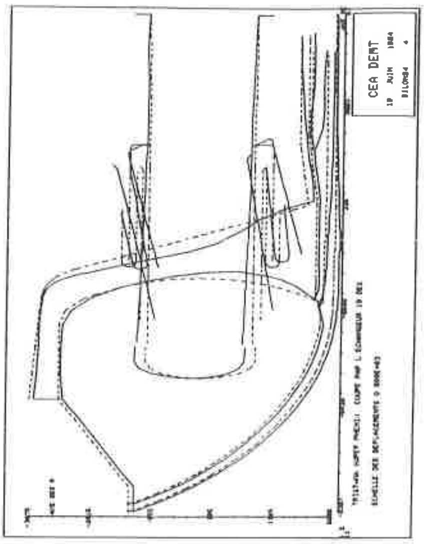

Figure 5 - Shape of the natural mode at 4.3 Hz : meridian section by the heat exchanger located at 19°

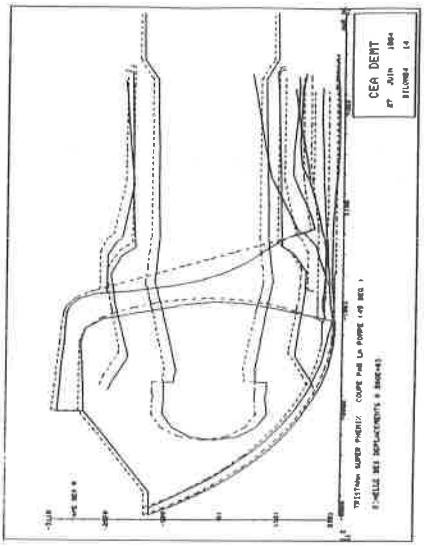

Figure 6 - Shape of the natural node at 5,0 Hz : meridian section by the primary pump.

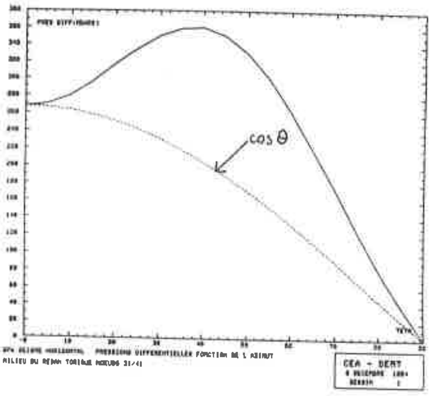

Figure 7 : Pressure differences on the toroidal redan dues to the horizontal seism : evolution with the azimut (0°⩽θ⩽90°)

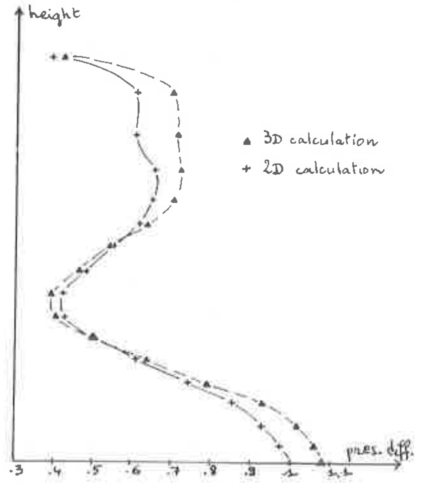

Figure 8 - Comparison between 2D and 3D calculation : maxima of pressure differences on the overflow dues to the horizontal seism (maximum of the 2D calculation is normed to 1)