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A STUDY OF STRUCTURAL ATTACHMENTS OF A POOL TYPE LMFBR VESSEL THROUGH SEISMIC ANALYSIS OF A SIMPLIFIED THREE DIMENSIONAL FINITE ELEMENT MODEL

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H. Ahmed and D. Ma

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Argonne National Laboratory

Argonne, Illinois

ABSTRACT

A simplified three dimensional finite element model of a pool type LMFBR in conjunction with the computer program ANSYS is developed and scoping results of seismic analysis are produced. Through this study various structural attachments of a pool type LMFBR like the reactor vessel skirt support, the pump support and reactor shell-support structure interfaces are studied. This study also provides some useful results on equivalent viscous damping approach and some improvements to the treatment of equivalent viscous damping are recommended. This study also sets forth pertinent guidelines for detailed three dimensional finite element seismic analysis of pool type LMFBR (to be published in a separate paper).

I. Introduction

Three-dimensional finite element stress analysis of reactor systems under seismic loadings presents numerous problems. In order to overcome the difficulty imposed by computer capacity, the substructuring technique can be used which will allow detailed modelling of the structure. The difficulty to handle required complexities in the analysis such as the fluid-structure interaction and fluid sloshing, hydrodynamic effects in various annulus and gaps in the structure, the incorporation of an equivalent viscous damping approach and many other features in the analysis cannot be fully described in one paper. There are added difficulties such as time and funding limitations which impose serious limitations on accomplishing what is practical often at the cost of what is required.

Three-dimensional finite element analysis using the substructuring technique for the above-mentioned purpose was attempted during a study at Argonne National Laboratory. It was decided that such an analysis can only be accomplished through careful individual handling of all complexities involved in the analysis. In this connection the work involving fluid-structure interaction and fluid-sloshing is the subject of Ref. (1) and other papers awaiting publication. This study also concluded that if substructuring technique capability of computer program such as ANSYS (a wave front program) for solving a massive problem such as the one described above can be handled with ease. Fig. I.1 shows the handling of vari- ous internals of a pool type LMFBR in conjunction with the required dynamic degrees dling of all complexities involved in the analysis. In this connection the work involving fluid-structure interaction and fluid-sloshing is the subject of Ref. (1) and other papers awaiting publication. This study also concluded that if substructuring technique capability of computer program such as ANSYS (a wave front program) for solving a massive problem such as the one described above can be handled with ease. Fig. I.1 shows the handling of various substructures of a pool-type LMFBR in conjunction with the required dynamic degrees of freedom in accordance with the available wave front capabilities of ANSYS program.

In the following, an equivalent viscous damping approach to be used in conjunction with the substructuring method of analysis was also developed in the above-mentioned study. A simplified three-dimensional finite element model was developed to test the working of this proposed equivalent viscous damping approach and to perform some initial studies on critical structural attachments in a pool-type LMFBR which was chosen as an application problem in the above-mentioned study.

This equivalent viscous damping approach was developed by the author in conjunction with Ref. (2) and (3).

II. Equivalent Viscous Damping Approach

The procedures used to determine the equivalent viscous damping for the seismic analysis are consistent with the criteria given in "U. S. Nuclear Regulatory Commission Standard Review Plan" Section 3.7. Appropriate critical damping values for structures or components will be selected from Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants." Table II.1 shows the damping ratios for different materials within each substructure of a pool-type LMFBR. Composite modal damping values will be determined based on an energy proportional damping method.

A procedure using the ANSYS computer program to obtain the response spectrum analysis of a substructured system which includes composite modal damping is outlined in this paper. The analysis is done in two parts: (1) to obtain frequencies and mode shapes and (2) post processing to combine modes for total response.

Only one spectrum is used for the frequency analysis. Based on the frequency, a modal damping factor is calculated for each mode and is then used to obtain the response for the correct damping value in the modal summation.

Modal damping factors are calculated in two steps. First, an equivalent damping factor is calculated for each mode of each substructure by using strain energy as a weight function and proportioning critical damping factors for each material in the substructure. These substructure damping factors are then proportioned to obtain the equivalent damping factors for each mode, using either substructure strain energy or kinetic energy as the weight function.

The final response is obtained by modal summation using POST 7. A linear factor is applied to each modal response to account for its correct equivalent Viscous damping. The detailed procedure is shown as follows:

A. Assumptions

1. One response spectrum is used for ANSYS frequency analysis.

2. ANSYS calculates and prints the total strain energy and kinetic energy for each mode for all elements having the same material number. Although the same material will be used in more than one substructure, a different material number will be assigned for

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A. Assumptions

1. One response spectrum is used for ANSYS frequency analysis.

2. ANSYS calculates and prints the total strain energy and kinetic energy for each mode for all elements having the same material number. Although the same material will be used in more than one substructure, a different material number will be assigned for that material in each substructure to obtain the strain energy and kinetic energy for each substructure.

B. Calculation of Equivalent Viscous Damping Factors

1. Equivalent viscous damping factors are calculated for each substructure using the strain energy proportion in Equation II.1 for each mode considered in the analysis.

$$D_{KR} = \frac{\sum_{j=1}^{nm} \sum_{i=1}^{ne} E_{ijR} d_j}{\sum_{j=1}^{nm} \sum_{i=1}^{ne} E_{ijR}} \qquad \text{(II.1)}$$

where

D_{KR} = equivalent viscous damping factor for R^{th} mode for the K^{th} substructure;

E_{ijR} = strain energy ($\Phi^T K \Phi$) for i^{th} element of finite element mesh and j^{th} material of the K^{th} substructure;

d_j = fraction of critical damping for j^{th} material of the K^{th} substructure;

ne = number of elements;

nm = number of materials;

Φ = modal vector obtained from frequency analysis of the entire system.

ANSYS computes and prints D_{KR} for each substructure for every mode. Note that $D_{KR} = d_j$ for substructures consisting of one material.

2. Equivalent viscous damping factors are calculated for each mode of the entire system, using a strain energy proportion (Equation II.2) or a kinetic energy proportion (Equation II.3).

$$D_R = \frac{\sum_{K=1}^{nK} SE_{KR} D_{KR}}{\sum_{K=1}^{nK} SE_{KR}} \qquad \text{(II.2)}$$

$$D'_R = \frac{\sum_{K=1}^{nK} KE_{KR} D_{KR}}{\sum_{K=1}^{nK} KE_{KR}} \qquad \text{(II.3)}$$

where

D_R = equivalent viscous damping factor for R^{th} mode of the system based on strain energy approach;

D'_R = equivalent viscous damping factor for R^{th} mode of the system based on kinetic energy approach;

SE_{KR} = substructure strain energy obtained from ANSYS for R^{th} mode in the K^{th} substructure;

KE_{KR} = substructure kinetic energy obtained from ANSYS for R^{th} mode in the K^{th} substructure;

D_{KR} = equivalent viscous damping factor for R^{th} mode in K^{th} substructure calculated by Equation II.1;

nK = number of substructures.

substructure;

D_{KR} = equivalent viscous damping factor for R^{th} mode in K^{th} substructure calculated by Equation II.1;

nK = number of substructures.

C. Total Response Calculation

The system response is obtained using modal summation contained in the POST 7 post processor of ANSYS. Using the damping factors in Part B and Equation (II.4), linear factors are calculated which are used to scale the response for the correct damping in a given mode.

$$F_R = \frac{U_{DR}}{U_{OR}} \quad \text{(II.4)}$$

where

F_R = the linear multiplier for R^{th} mode;

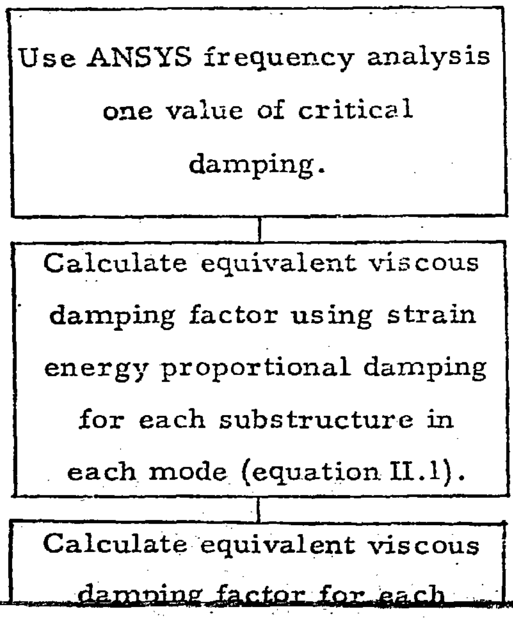
U_{DR} = the spectral value corresponding to frequency of R^{th} mode and damping D_R (or D'_R);

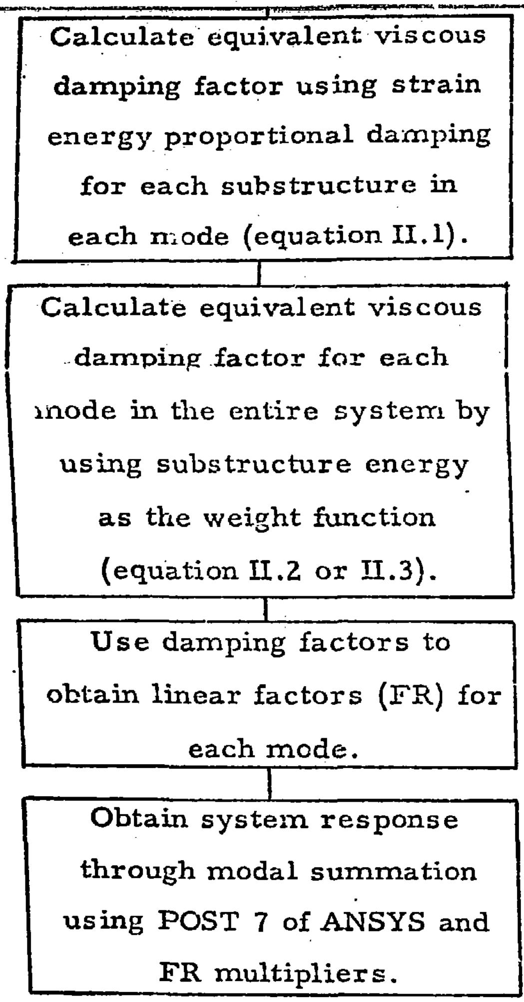
U_{OR} = the spectral value corresponding to frequency of R^{th} mode and damping D_O;

D_O = percent critical damping for response spectra used in ANSYS frequency analysis;

D_R, D'_R = damping factors defined by equations II.3 and II.4, respectively. U_{DR} and U_{OR} may be obtained from the response spectra for multiple damping values as illustrated in Fig. II.1.

D. Response Spectra Analysis Flow Using ANSYS and Energy Proportional Damping




Calculate equivalent viscous damping factor using strain energy proportional damping for each substructure in each mode (equation II.1).
Calculate equivalent viscous damping factor for each mode in the entire system by using substructure energy as the weight function (equation II.2 or II.3).
Use damping factors to obtain linear factors (FR) for each mode.
Obtain system response through modal summation using POST 7 of ANSYS and FR multipliers.

III. Seismic Analysis of a Pool-type LMFBR by Simplified 3-D Finite Element Model

A simplified three-dimensional finite element model of a pool-type LMFBR was developed to serve the purpose of obtaining scoping results of the seismic analysis to aid in establishing guidelines to the detailed three-dimensional finite element analysis outlined above. The simplified three-dimensional finite element model can also be used as an initial test for the equivalent viscous damping procedure.

The 180° simplified three-dimensional pool-type LMFBR finite element model is shown in Fig. III.1. The substructures included in the system are: 1) concrete wall, 2) skirt support, 3) deck structure, 4) primary vessel, 5) IHX's, 6) pumps, 7) removable reactor and 8) fixed reactor (not shown in Figure). The concrete wall (84 ft OD, 60 ft high, 3 ft thick) supporting the primary vessel and deck structure was modeled by the solid elements. The skirt support is composed of 2 in. thick steel plates for transmitting the heavy weight of the reactor vessel to the concrete wall. The skirt support was modeled by 3-D quadrilateral shell elements. The 10 ft thick deck structure is composed of radial ribs and circumferential ribs which are covered by horizontal plates. The deck was simplified to be modeled by the 3-D quadrilateral shell elements and pipe elements. The primary vessel which is 69 ft in diameter and 61 ft in height has wall thickness from 1.6 in. to 2 in. It contains all of the components of the heat generating system, i.e., fixed reactor, IHX's, pumps. The primary vessel was also modeled by 3-D quadrilateral shell elements. There are two pumps and four IHX's within the 180° model. They were simplified to be modeled by pipe elements. The removable reactor was also simplified to be modeled as pipe elements at the center of the model. Spring elements were used at several locations along the skirt support to represent components of the heat generating system, i.e., fixed reactor, IHX's, pumps. The primary vessel was also modeled by 3-D quadrilateral shell elements. There are two pumps and four IHX's within the 180° model. They were simplified to be modeled by pipe elements. The removable reactor was also simplified to be modeled as pipe elements at the center of the model. Spring elements were used at several locations along the skirt support to represent the stiffness of the reactor building which is not included in the model.

A linear transient dynamic analysis of the simplified 3-D finite element model was performed by using the ANSYS program. The spectrum-compatible modified EL CENTRO acceleration time history enveloping the 0.2 G, 2% damping NRC design response spectrum was used as input motion. The dynamic response of various structural attachments were obtained. The post processor (POST 28) of ANSYS was employed to generate the response spectra at various spots in the system. The 2% damping response spectra at skirt support and pump support generated by POST 28 along with a pump support response spectrum (OBE, 2% damping) for a large scale LMFBR (Ref. 4) is shown in Fig. III.2. Fig. III.2 shows that the spectrum at skirt support has peak acceleration 3.55 G occurring at 7.5 Hz with 0.32 G rated at high frequency range. The spectrum at pump support has 4.8 G peak value with 0.41 G rated at high frequency range.

IV. Conclusions

In this paper a procedure for the determination of equivalent viscous damping in conjunction with a substructuring technique is presented. A simplified three-dimensional finite element model using ANSYS program is presented which provides initial test of the use of this equivalent viscous damping procedure. This simplified three-dimensional finite element model also serves the purpose of obtaining scoping results of the seismic analysis of a pool-type LMFBR to aid in establishing guidelines to the detailed three-dimensional finite element analysis. Some initial studies of critical structural attachments such as reactor vessel skirt support and pump support are made using this simplified three-dimensional finite element model.

REFERENCES

[1] Leonard, J. W., Ahmed, H. U., and Swanson, J. A., "Application of ANSYS Fluid Elements in Fluid-Structure Interaction Problems" Division B4/6, Proceedings of 5th International Conference on Structural Mechanics in Reactor Technology, August 1979.

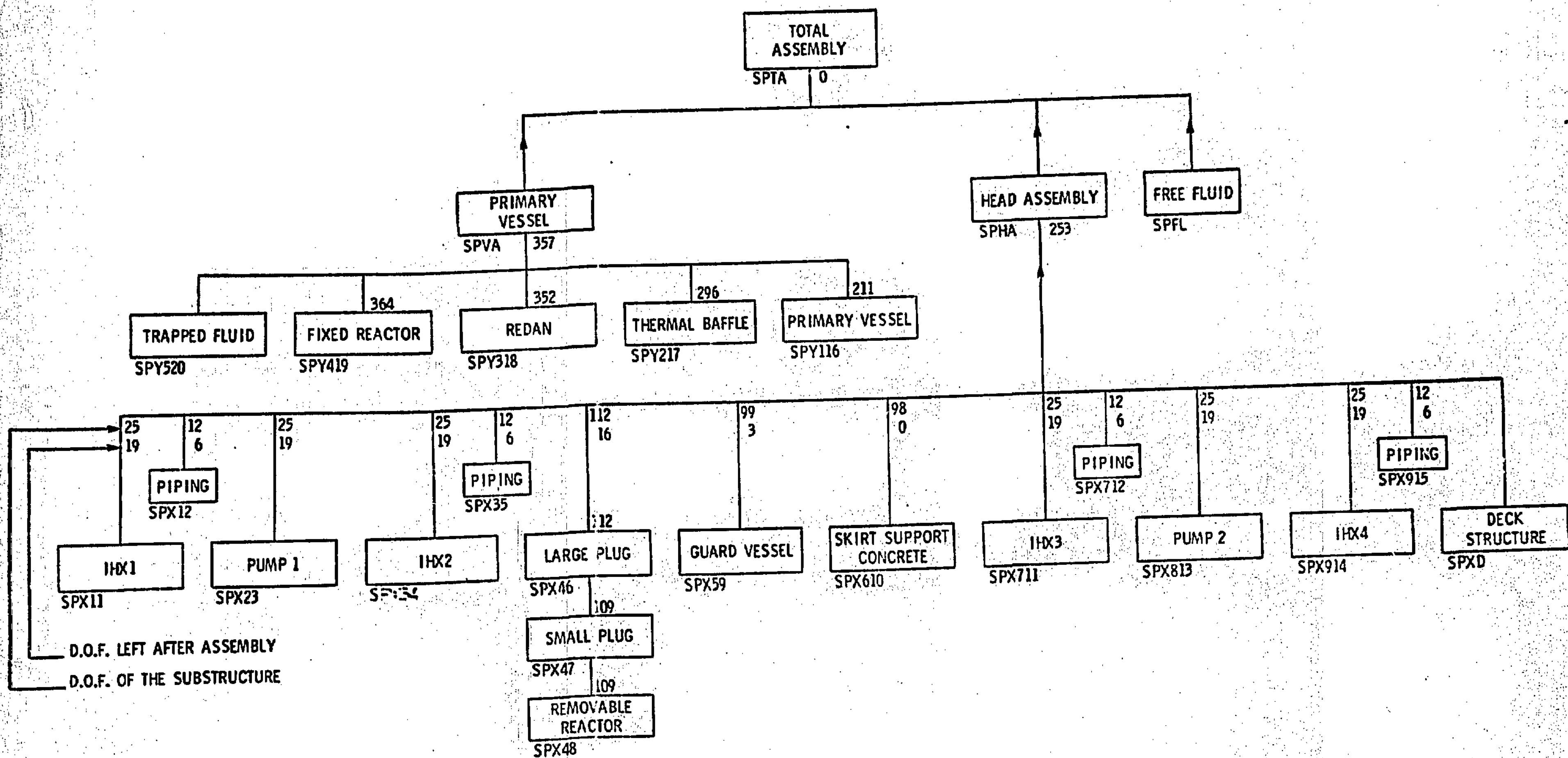
[2] Werner, S. D., and Reddy, D. P., Equivalent Viscous Damping for Seismic Analysis of Nuclear Plants, Agbabiean Associates, El Segundo, California, April 1, 1975.

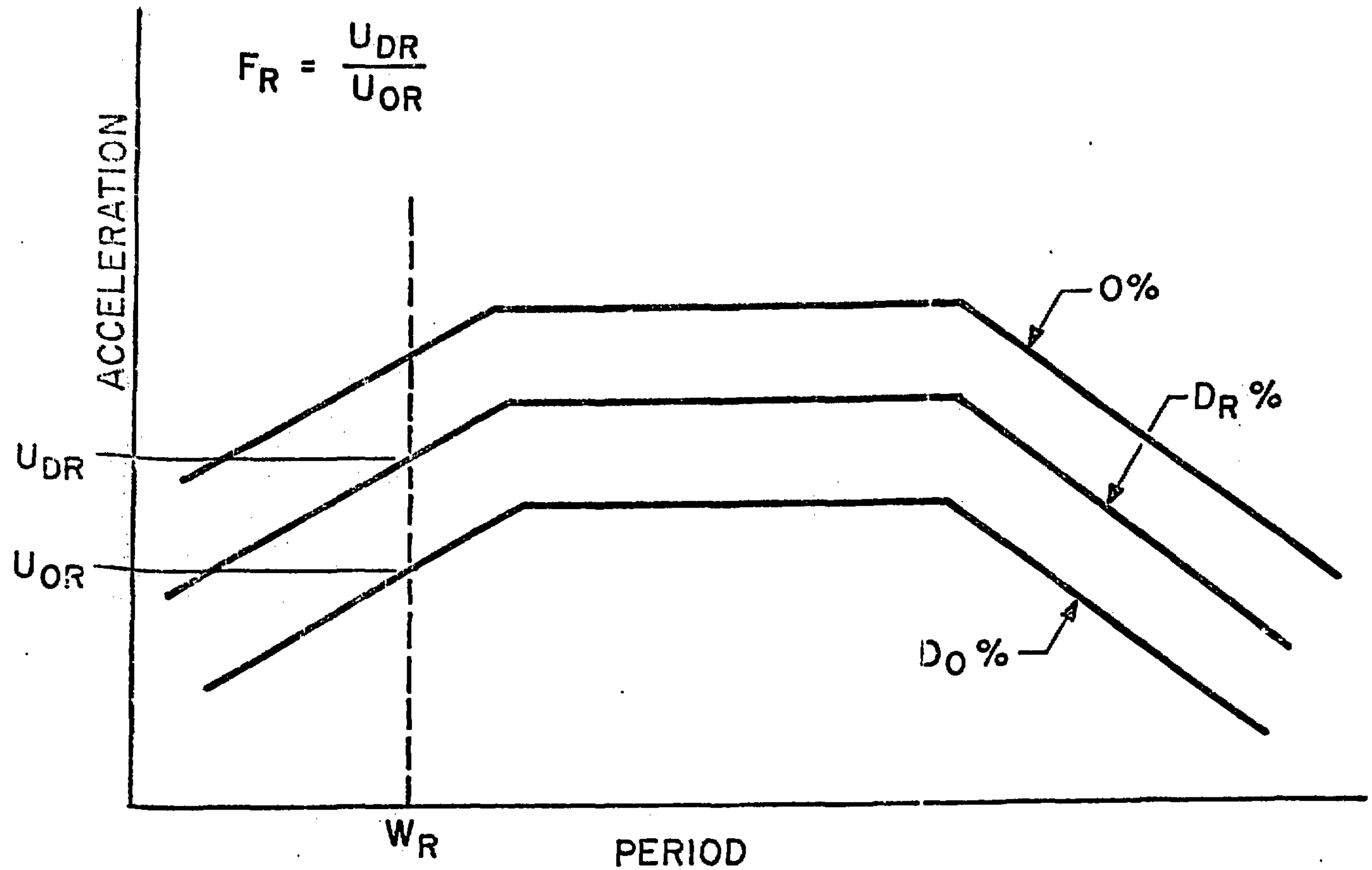
[3] Discussions with Structural Mechanics Division of Sargent and Lundy Co. and Swanson Analysis Systems.

[4] Byror Jackon Equipment Specification #PS-9001 for Intermediate Pump Drive System (Sodium Pump for Large Scale LMFBR Plants), dated 17 Aug 1977.

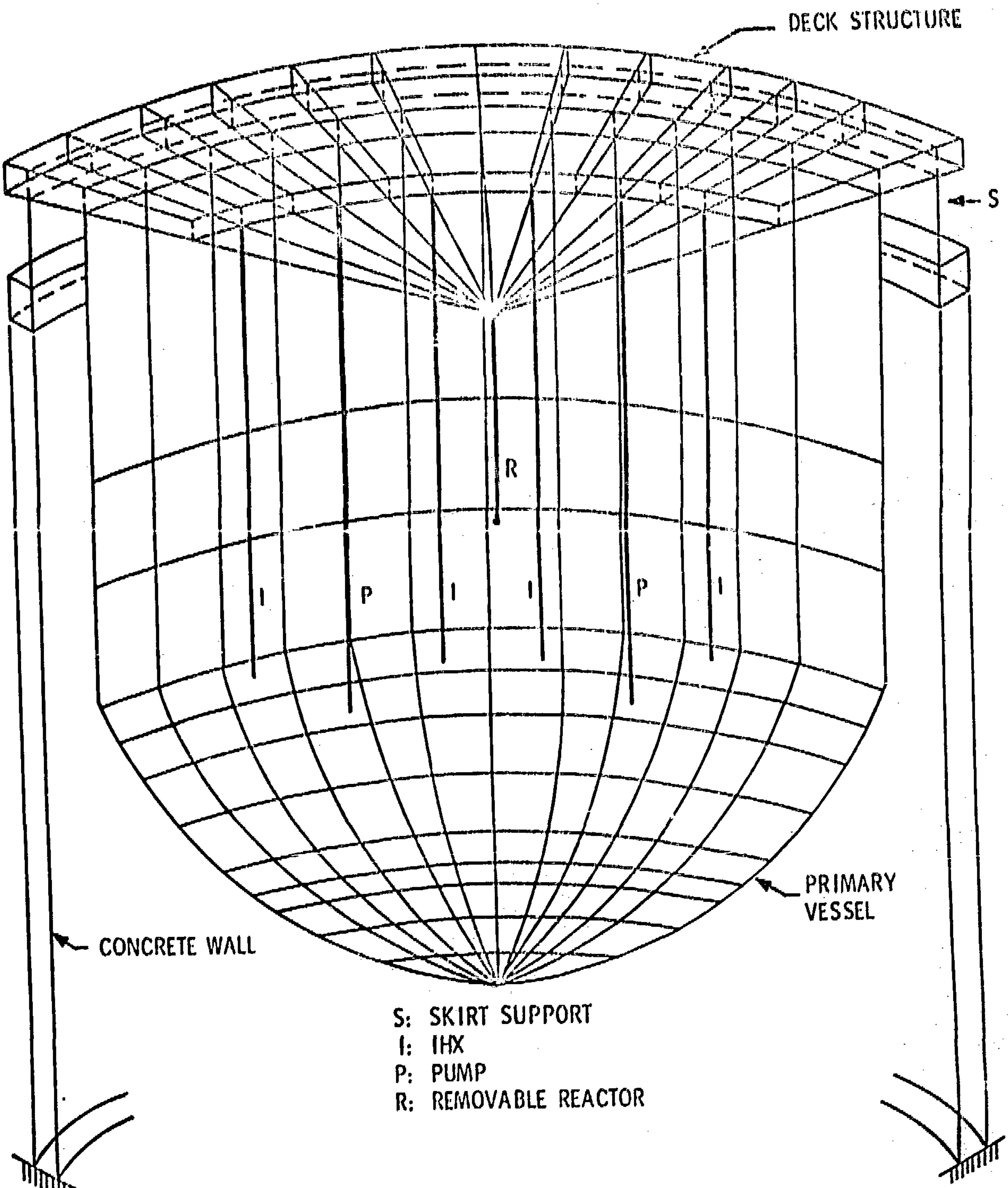
TABLE II.1. Components Damping Values in a Pool-type LMFBR

ubstructure Name	Matrix No.	Structure	Damping Ratio (%
SPXD	0	Deck Structure	4
SPX11	1	IHX1-Bolt Conc/Steel/Fluid	7/4/10
SPX12	2	Piping of IHX1	2
SPX23	3	Pump 1-Bolt Conc/Steel/Fluid	7/4/10
SPX34	4	IHX2-Bolt Conc/Steel/Fluid	7/4/10
SPX35	5	Piping of IHX2	2
SPX46	6	Large Rotation Plug	4
SPX47	7	Small Rotation Plug	4
SPX48	8	Removable Reactor	4
SPX59	9	Guard Vessel	4
SPX610	10	Skirt Support/Reinforced Concrete	4/7
SPX711	11	IHX3-Bolt Conc/Steel/Fluid	7/4/10
SPX712	12	Piping of IHX3	2
SPX813	13	Pump 2-Bolt Conc/Steel/Fluid	7/4/10
SPX914	14	IHX4-Bolt Conc/Steel/Fluid	7/4/10
SPX915	15	Piping of IHX4	2
SPY116	16	Primary Vessel	4
SPY217	17	Thermal Baffle	4
SPY318	18	Redan	4
SPY419	19	Fixed Reactor	4
SPY520	20	Trapped Fluid	10
SPFL	21	Free Fluid	10


TOTAL ASSEMBLY
SPTA 0
PRIMARY VESSEL
SPVA 357
HEAD ASSEMBLY
SPHA 253
FREE FLUID
SPFL
TRAPPED FLUID
SPY520
364
FIXED REACTOR
SPY419
352
REDAN
SPY318
296
THERMAL BAFFLE
SPY217
211
PRIMARY VESSEL
SPY116
25 19
IHX1
SPX11
12 6
PIPING
SPX12
25 19
PUMP 1
SPX23
25 19
IHX2
12 6
PIPING
SPX35
112 16
112
LARGE PLUG
SPX46
109
SMALL PLUG
SPX47
109
REMOVABLE REACTOR
SPX48
99 3
GUARD VESSEL
SPX59
98 0
SKIRT SUPPORT CONCRETE
SPX610
25 19
IHX3
SPX711
12 6
PIPING
SPX712
25 19
PUMP 2
SPX813
25 19
IHX4
SPX914
12 6
PIPING
SPX915
DECK STRUCTURE
SPXD
D.O.F. LEFT AFTER ASSEMBLY
D.O.F. OF THE SUBSTRUCTURE



$F_R = \frac{U_{DR}}{U_{OR}}$
ACCELERATION
U_{DR}
U_{OR}
0%
D_R %
D_O %
W_R
PERIOD


DECK STRUCTURE
S
R
I
P
I
I
P
I
PRIMARY VESSEL
CONCRETE WALL
S: SKIRT SUPPORT
I: IHX
P: PUMP
R: REMOVABLE REACTOR

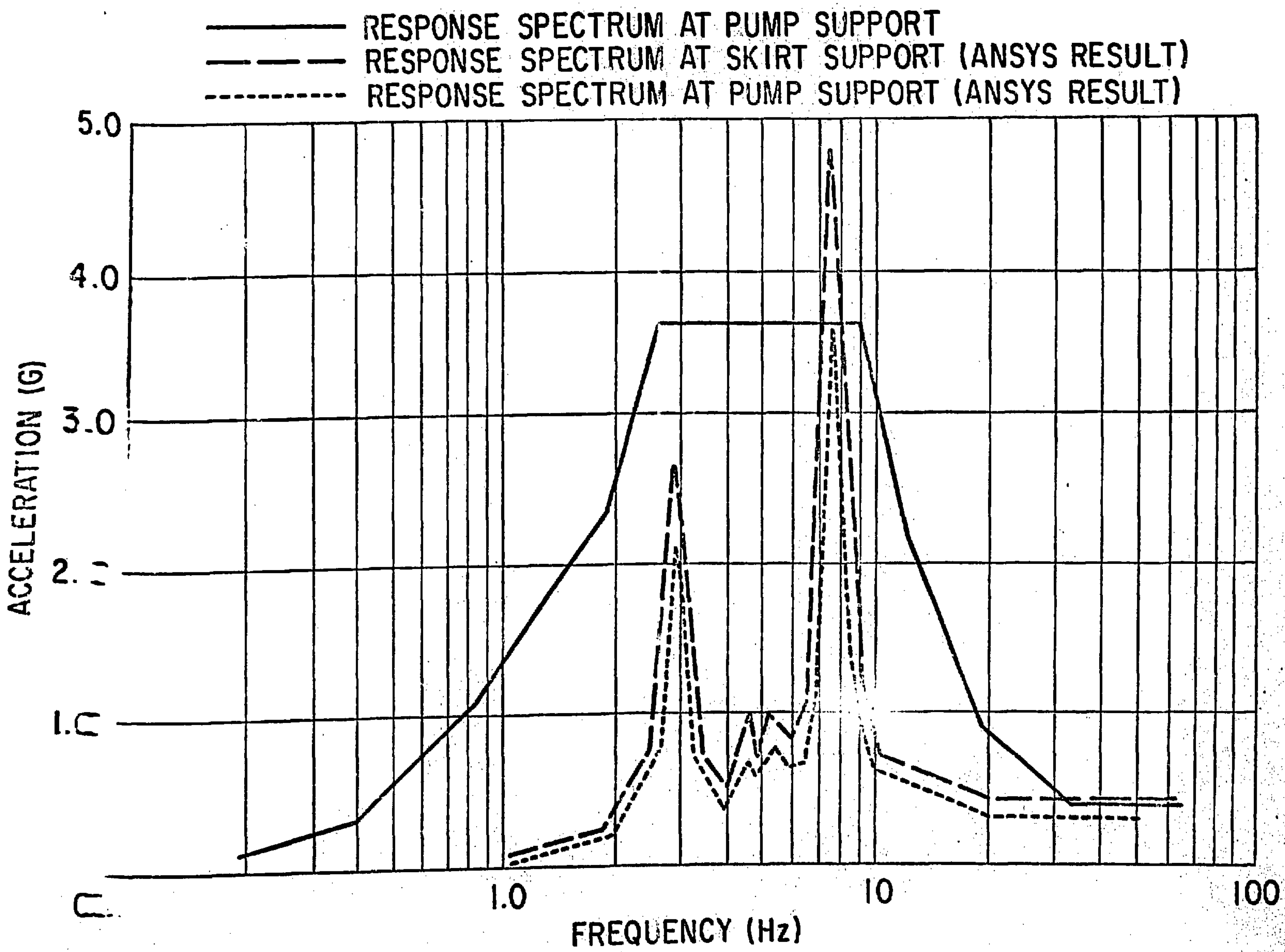

RESPONSE SPECTRUM AT PUMP SUPPORT
RESPONSE SPECTRUM AT SKIRT SUPPORT (ANSYS RESULT)
RESPONSE SPECTRUM AT PUMP SUPPORT (ANSYS RESULT)
5.0
4.0
3.0
1.0
ACCELERATION (G)
1.0
10
100
FREQUENCY (Hz)

Fig. I.1. Substructures Assembly with Dynamic Degrees of Freedom and Wavefront Requirements for a Pool-type LMFBR 3D-Model

Fig. II.1. Graphical Representation of Method to Obtain Linear Multipliers Required for Modal Superposition

Fig. III.1. Simplified Three-dimensional Finite Element Model of a Pool-type LMFBR

Fig. III.2. Response Spectra at Pump Support and Skirt Support (2% Damping)