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CALCULATION OF THREE-DIMENSIONAL BUBBLE LOADS FOR
THE MARK I HYDRO-STRUCTURE INTERACTION ANALYSIS

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INTRODUCTION

The Nuclear Test Engineering Division has completed an analytical research program for the U.S. Nuclear Regulatory Commission (NRC) which investigated the qualitative effects of hydrodynamic/structural interaction of impulsive pressure loading in boiling water reactor (BWR) pressure suppression systems(1). As part of this program, a series of three-dimensional linear analyses of a General Electric Mark I pressure suppression torus under nominal safety relief valve (SRV) discharge loading was conducted using the finite element code SAP4(2). SAP4 is the LLL version of the SAPIV code developed at the University of California, Berkeley, by Bathe, Wilson, and Peterson(3) and is used for static and dynamic analyses of linear elastic structures. Systems can be modeled using beam, pipe, plate and shell, and two- or three-dimensional solid elements.

The analytic model used for the 3D SRV analyses (Figure 1) represents a right circular cylinder partially filled with water with a spherical bubble cut by the two planes of symmetry in the model. The inner surface of the bubble is loaded by a nominal pressure pulse representing the injection of air into the suppression pool during a safety relief valve discharge. Proper definition of the time-dependent load at the bubble surface was, of course, an important part of the analysis and was accomplished using the finite element mesh generator OASIS(4).

OASIS was adapted from INGEN(5), a general-purpose two- and three-dimensional mesh generator developed by W. A. Cook at the Los Alamos Scientific Laboratory. Although OASIS is primarily a mesh generator, it has additional capabilities that make it valuable in helping the user construct input files for finite element calculations. For example, OASIS can establish boundary conditions, generate surface tractions, and present output in several different formats compatible with various finite element codes.

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Figure 1 Three-Dimensional SR, For a Finite Element Mesh

SAP4 LOAD DEFINITION

In static SAP4 analyses, pressure loads are usually directly specified on a surface because the conversion to nodal loads is internal to SAP4. However, the current version of SAP4 has no similar software that allows the user to directly specify a time-dependent pressure on a surface. Instead, the forcing function is specified as a set of time-varying load components at each node defining the surface considered. A load component is applied for each degree of freedom at each node following the relationship

$$F_{n,i}^m(t_n) = P_i^m \times p(t_n) \quad (1)$$

where the magnitude of the force F at the node i for degree of freedom m at time t_n equals the product of the time function $p(t)$ at t_n and a load multiplier P_i^m .

Definition of the time function (i.e., the nominal SRV pressure pulse) is straightforward, essentially reducing the dynamic load problem to one of calculating the multipliers P_i^m . It was originally intended to use the computer code PR3D(6) to accomplish this task; however, the node numbering scheme used for the three-dimensional torus mesh generated by OASIS is incompatible with PR3D(7). It was subsequently determined that OASIS could be used instead of PR3D to generate the required load multipliers.

OASIS can convert finite element surface loads to nodal loads for a number of different codes, including SAP4. SAP4 pressure loads are generated by OASIS in the nodal load format used for static analyses. Unfortunately, SAP4 requires a different load format for dynamic analyses, an inconsistency, unaccounted for by OASIS, which disallows

direct generation of the load multipliers in a SAP4 format. However, the finite element code ADINA(8), also covered by OASIS, requires that surface pressures be input as nodal loads in an identical format for both static and dynamic analyses. Furthermore, this input format is similar to that used for the SAP4 dynamic load multipliers, implying that OASIS could generate the multipliers indirectly.

OASIS was used to reform the torus mesh in an ADINA format with a unit pressure applied to the inner surface of the bubble. The resulting "loads" output by OASIS corresponded to the desired SAP4 multipliers once components for fixed degrees of freedom had been removed and minor format changes had been made by simple text editing. Because a unit pressure was specified, no scaling of $p(t)$ was required when the multipliers were incorporated into SAP4 input.

OASIS MODIFICATIONS

Using OASIS to convert a surface pressure to nodal loads proved to be more complicated than was originally expected. Initially, OASIS did not calculate the loads correctly and it therefore became necessary to start a debug procedure to isolate the problem. The major problem proved to be trivial in that one of the main data arrays was misdeclared. This allowed OASIS to calculate loads correctly for simple sample problems, but not for the more complex torus mesh. The problem was traced to the LOADS subroutine, one of several INGEN subroutines that had been written into OASIS without modification. After studying in detail how LOADS worked, it was discovered that modifications made to the OASIS data structure were

incompatible with the LOADS ROUTINE. The particular modification that created the incompatibility was the "merge" option, which merges points within a specified distance of one another together as a single point. As long as no merging was performed, correct loads were calculated. However, because the torus mesh required merging, it was necessary to redefine the internal data structure of OASIS. As a result, OASIS now correctly converts surface pressures to nodal loads.

CONCLUSIONS

This load definition method was validated by a series of three-dimensional plane-strain calculations described in detail in (1). In these analyses, an earlier two-dimensional model of the SRV torus was expanded to three dimensions and was analyzed using SAP4 as a check on details of the full torus model. Close agreement between two- and three-dimensional plane-strain displacements and pressures was observed, indicating that the 3D bubble loads had been defined properly.

Definition of the 3D SRV bubble loads provided a useful test problem for further development of the OASIS mesh generator. As a result, the OASIS and SAP4 software package now represents a more versatile and a more user-oriented tool for the analysis of complex dynamic systems.

References

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