ELEMENT TECHNIQUE USED IN
CONTAINMENT STRUCTURAL ANALYSIS

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APPENDIX 5G

DESCRIPTION OF THE FINITE ELEMENT TECHNIQUE USED IN CONTAINMENT STRUCTURAL ANALYSIS

1.0 ANALYTICAL METHOD

The finite element technique is a general method of structural analysis in which the continuous structure is replaced by a system of elements (members) connected at a finite number of nodal points (joints). Conventional analyses of frames and trusses can be considered to be examples of the finite element method. In the application of the method to an axisymmetric solid (e.g., a concrete containment vessel), the continuous structure is replaced by a system of rings of triangular cross-sections which are interconnected along circumferential joints. Based on energy principles, force equilibrium equations are formed in which the radial and axial displacements at the circumferential joints are the unknowns of the system. A solution of this set of equations is inherent in the solution to the finite element system.

There are many advantages to the finite element method, when compared to other numerical approaches. The method is completely general with respect to geometry and material properties. Complex bodies composed of many different materials are easily represented; therefore, in the analysis of the containment, concrete, and foundation material can be realistically considered. Also, arbitrary thermal, mechanical and gravity loading can be analyzed.

It can be shown mathematically that the method converges to the exact solution as the number of elements is increased; therefore, any desired degree of accuracy may be obtained.

2.0 COMPUTER PROGRAM

The initial development of the computer program used in the analysis of the containment vessel was conducted at the University of California at Berkeley, in 1962, under a National Science Foundation Grant. Since that time, the program has been further modified and refined by Dr. Edward L. Wilson. The validity of the specific program used in the containment vessel analysis has been established by the analysis of axi-symmetric solids with known exact linear solutions. It is noted that the results of a finite element analysis always satisfy statics, since the equations solved within the computer program are based on force equilibrium requirements.

3.0 COMPARISON WITH KNOWN SOLUTIONS

An exact analysis of the containment structure under consideration is impossible by classic methods. A preliminary approximate analysis of the structure was conducted, based on classical shell theory. In addition to the difficulty in representing the steel liner, reinforcing rings and foundation material, shell theory neglects thickness and shear deformations. Since the finite element approach includes thickness and shear deformation, an exact comparison with shell theory cannot be expected. However, gross section forces obtained from the finite element method at sections not near rings or the foundation does agree with the results based on shell theory.

The attached Figure 5-G-1 illustrates a comparison of the results of a finite element analysis with an exact elastic theory solution of an infinite cylinder subjected to an internal pressure. Three different finite element analyses were performed. Except for the very coarse mesh, agreement of the radial and hoop stresses with the exact solution is excellent.

An analysis of a containment structure has been done according to general shell theory for homogeneous surfaces of revolution. The matrix of influence coefficients (the unknown forces - deflections, moments and rotations for the dome, ring, and cylinder) was solved for the condition of equal deflection and rotations. Similar analysis methods were used for the intersection of the base slab and the cylinder wall. The base slab was analyzed as an elastic plate on a rigid foundation.

The results thus obtained are within five percent of those obtained by a more rigorous finite element program for ring girder, dome and cylinder wall of a similar containment structure.

For the base slab analysis, using the finite element program, the matrix was extended into the ground approximately 160 feet below the base slab and modulus of elasticity of the soil was considered in the analysis.

For determining the anchorage zone stresses as well as the stresses in the nearby region of anchorage caused by hoop prestressing forces, plane strain analysis has been carried out using finite element methods for the buttress. As the problem is three dimensional, plane strain analysis is a better approximation than plane stress analysis. However, as the program is prepared for plane stress analysis, modulus of elasticity, E, was changed to $\frac{E}{1-\nu 2}$ and Poisson's ratio, ν, $\frac{\nu}{1-\nu}$ in order to have plane strain effect. For the analysis, a cylindrical quandrant with unit thickness and with one buttress at the center of this quadrant has been considered. Since the anchorage areas are quite close, and one above the other, they can be approximated by a vertical line load. The effects of a prestress were applied as concentrated forces at the anchorages and the loads were uniformly distributed according to the curvature of the tendons.

Guyon's method, or the "standard" treatment, is relatively much more approximate and empirical than the above method used in our design. However, it will be used as a check method in confirming the design.

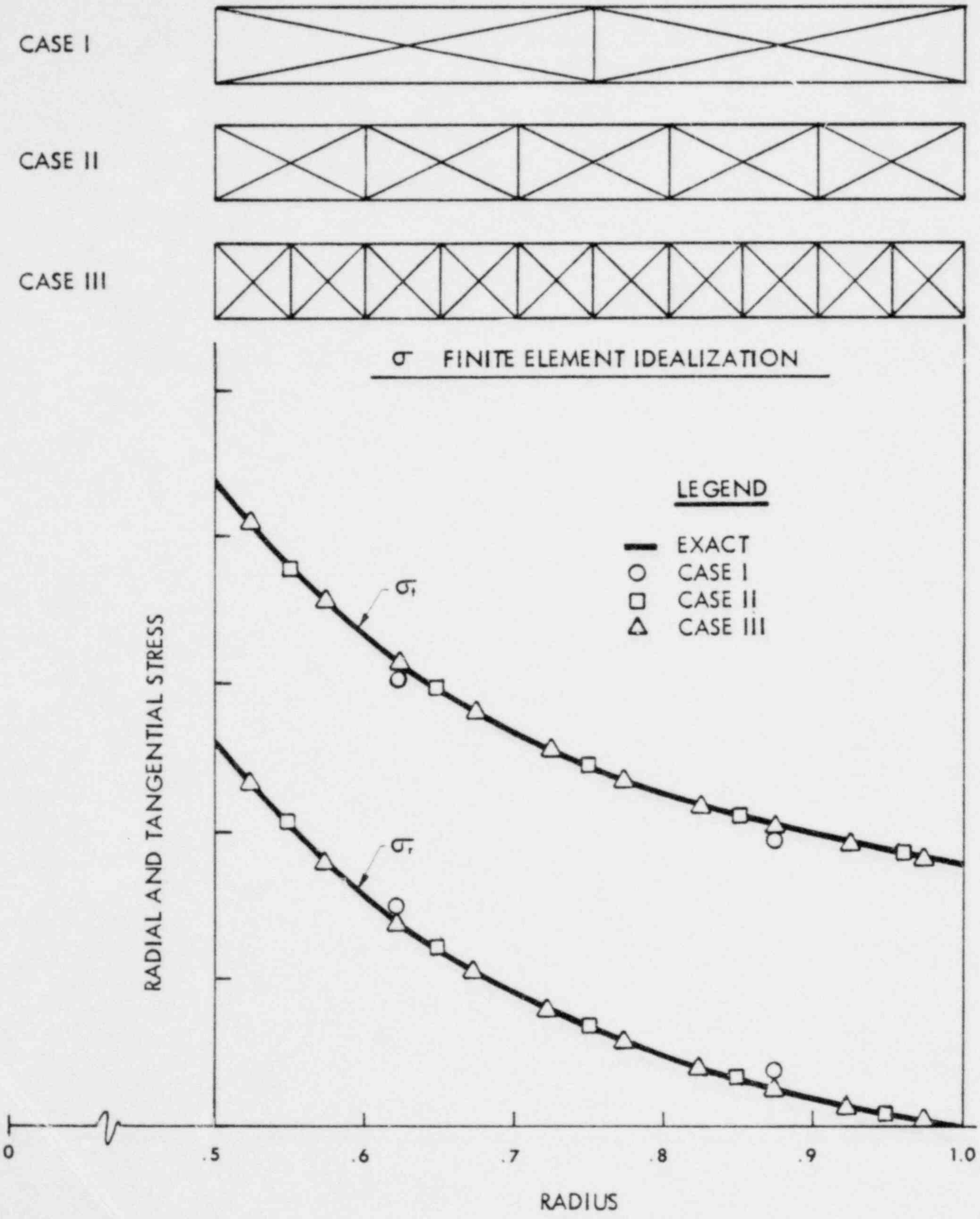

FIGURE 5G-1
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