APPROXIMATE AND DETAILED ANALYSES FOR STRUCTURES OF REACTOR CONTAINMENT BUILDINGS, USING THREE-DIMENSIONAL COMPUTER PROGRAM

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SUMMARY

Structural finite element programs are commonly used in the design of nuclear reactor building structures. In several cases, the usual two-dimensional and axis-symmetrical programs did not prove to be adequate for the analysis of non-symmetrical structures or non-symmetrical loadings. Three-dimensional programs were developed and proved to be fast and reliable tools for the analysis in each phase of the design.

During the design of nuclear power plants, there are several occassions when approximate analyses are sufficient:

— In preliminary designs;
— In selections between more proposed alternates;
— In detailed analysis to provide boundary conditions;
— In case of independent checking analyses;
— In test analyses with simplified models.

Short descriptions and size of models used are given for the following analyses:

1. Preliminary analysis for all structures of a BWR reactor containment building.
2. Preliminary analysis for selection of structural solution of a reactor pedestal structure.
3. Independent checking analysis for the primary containment structures of a BWR.
4. Independent checking analysis of a reactor shield structure.
5. Test analysis with a simplified model for the seismic response analysis of a reactor drywell structure.

In the detailed analysis of complex structures, the use of a three-dimensional program is indispensable. Description of analysis and model sizes for two complex structures is given:

6. Building structure of a breeder reactor with detailed non-linear analysis of the internal support structure for 30 million pound hypothetic accident loads. Model sizes: 1570 and 1032 nodes respectively.
7. Drywell structure, which serves as a primary containment and also carries the weight of the upper fuel pools. Loading conditions include internal and external pressures, thermal, seismic, and other loads. Model size: 1350 nodes.

Conclusions

The three-dimensional structural programs are useful tools in every phase of the design of nuclear power plants.

Non-linear and dynamic analyses may be also performed with three-dimensional models.

Test analyses with simplified models are the best way to test and learn a structural program.

The plotting subprograms facilitate the creation of the mathematical model and the evaluation of the output of loading analyses.

Familiarity of the engineer with a three-dimensional program increases the speed and effectiveness of the design.

1. INTRODUCTION

Finite element computer programs are widely used in analysis and design of major structures in the reactor building. In the past these structures were analyzed using two-dimensional, axisymmetric programs. Some of these programs can analyze the non-linear behavior of reinforced concrete structures resulting from axisymmetrical loads, including thermal loads. Others may be used to analyze non-axisymmetrical loadings. In spite of these capabilities, the above programs have several limitations in the area of non-symmetrical structures, boundary and load conditions.

To solve the limitations of the axisymmetrical programs, more and more three-dimensional programs became available during the last few years. Some of these are linear elastic programs; some can analyze the non-linear behavior of these structures. Some have well developed pre- and post-processing features; others have fast equation solving methods. All have a wide range of element library.

This paper describes the experiences obtained from the approximate and detailed analyses using three-dimensional computer programs and provides guidelines for the selection of their use.

2. Approximate analyses with three-dimensional models

During the design phases of the containment buildings and internal structures, there are several occasions when approximate analyses are sufficient:

- In preliminary designs.
- In selections between proposed alternatives.
- In interconnected structures to provide boundary conditions for detailed analyses.
- In structures with dimensions determined by shielding rather than stress requirements.
- In analyses with simplified models to test and become familiar with a computer program.
- In independent checking analyses.

The following subsections provide information on the approximate analyses performed on structures utilizing the three-dimensional programs. The described analyses provided timely results: a maximum of only ten engineering workdays were expended for each analysis.

2.1 Preliminary analysis with three-dimensional model of boiling water reactor (BWR) containment building. (Figure 1.)

This analysis includes a simplified half model of 316 nodes and includes all the important structures within the containment. A load-run was conducted with three load-cases. The model was further developed for the design analysis of the base mat, and in another development for seismic response analysis. A model with the same form and size as that of the original model was created using another three-dimensional program to compare the results and for a test of both programs. Although this analysis resulted in comparable stresses and displacements, it revealed important differences in the capability of the two programs.

2.2 Preliminary analysis of a reactor pedestal structure. (Figure 2.)

This analysis utilized a full circular model consisting of one layer of plate elements representing the pedestal and another layer the shield wall. The reactor pressure vessel is also modeled so that concentrated forces and moments resulting from the reactor vessel can be applied. This model included 301 nodes. The detailed model of the same structure utilized 1,214 nodes. The coarse model provided valuable information for the selection of the detailed model geometry.

2.3 Independent checking analysis for the primary containment of a BWR (Figure 3.)

A half model of 342 nodes is used for the analysis of the structure subjected to an internal pressure of 84 psi (6.0 kgf/cm^2). The modulus of elasticity of the highly tensioned concrete elements was modified to simulate the decreased stiffness of the cracked concrete structures based on the stress output. The modified model was loaded and modified again. Three cycles resulted in the completely cracked structure which gave good comparison to the results of an axisymmetrical non-linear analysis.

2.4 Independent checking analysis of a reactor shield structure. (Figure 4.)

A half model of 393 nodes was created for the independent checking of this composite steel-concrete structure. Plate elements were used for the external and internal steel shells and cube elements were used for the concrete. Two critical load cases were investigated: internal pressure of 94 psi (6.7 kgf/cm^2) and a local jet load from vessel rupture of 1,330 kips (603 tons). The resulting stresses were in close agreement with the predicted stresses resulting from the axisymmetrical shell analyses.

2.5 Seismic response analysis of a drywell structure.

This analysis was performed to learn the capabilities of the three-dimensional program to provide seismic response. The masses are lumped acting in two main directions (one horizontal and vertical) on the simplified half model of 75 nodes. Total number of dynamic degree of freedom is 62. The Householder dynamic analysis resulted in 20 mode shapes. Seismic response analysis was conducted using ground motion response spectrum curves. The overturning moment was within 5 percent of a two-dimensional seismic analysis.

3. Detailed analyses of three-dimensional models for complex structures.

In cases where rectangular and cylindrical or other rotated shapes are structurally integrated, the use of three-dimensional programs is even more advantageous. The following describes the analyses for two complex structures.

3.1 Building structures for a breeder reactor. (Figure 5.)

Special loadings, technology, shielding and space requirements resulted in a very complex non-symmetrical structure. A six degree of freedom model of 1,570 nodes and 2,500 plate elements was used in two alternates with different boundary conditions for the full structure. The stress outputs of twenty-three load combinations and the plots of deformed shapes were evaluated and the required reinforcing was calculated in 250 critical locations. The analysis revealed that in certain locations more reinforcing was required when compared with results of different analyses.

A partial detailed model was prepared for the cylindrical reactor support structure. (Figure 6.) The cracking behavior of the concrete was taken into account on the detailed, three degree of freedom model of 1,032 nodes. The main loadings of the analysis were the 30 million pound (13,600 tons) hypothetical accident loads acting up and down. The final cracked model was reached in four and three complete cycles respectively. The analysis proved that the reinforcing provided using axisymmetrical model was not always sufficient.

3.2 Design analysis for the complete drywell structure of a Mark III BWR. (Figure 7.)

The main part of this structure is a cylindrical wall enclosed by a horizontal roof slab. This wall also carries the loads of the upper fuel pool and other connecting rectangular structures. Two-dimensional or axisymmetrical programs are not suitable for the analyses of the structure. Therefore a three-dimensional model was utilized. This model consists of the full structure and has 1,350 nodes and 1,450 plate elements. The load conditions include: dead and live loads; service and accident loads generated in the suppression pool; internal, external pressures; vertical and horizontal seismic responses. The moments and forces acting on the elements as resulted by the various loading combinations were used to determine the amount of necessary reinforcement.

4. RECOMMENDATIONS

The following factors should be considered in the selection of a three-dimensional program:

- Availability of the program, user manual, computer facility, program support.
- Capability of the program: linear - non-linear, static-dynamic, available elements, boundary conditions, possible model sizes.
- Economic factors:
  In engineering time: fast model creation, data preprocessing, easy output evaluation with selective post-processing.
  In computer time: fast equation solving, dynamic core allocation, output selectivity, data saving on tapes.
- Familiarity of the engineer with the program, training possibilities of new users.

Sometimes it is necessary to use different programs in the various stages of design as preliminary, detail design or checking.

Users of new programs should always be prepared to find errors in them. The use of simplified test models before an important analysis is highly recommended.

5. CONCLUSIONS.

5.1 Three-dimensional structural programs are available and they are useful tools in every phase of the design of the nuclear reactor building structures.

5.2 Some of the programs provide non-linear analyses with non-linear properties of its elements. Non-linear behavior of cracked concrete may be simulated by modifying the member properties step-by-step.

5.3 Prestressed concrete containment structures may be accurately modeled using cube- and sliding bar elements.

5.4 Many of the programs offer dynamic analysis. Seismic response analysis of dome type or cylindrical structures is not accurate by stick- or two-dimensional models.

5.5 Simplified models of the full or half structure may be used in fast approximate analyses. None of the approximate analyses presented in Section 2 required more than ten engineering work days.

5.6 Geometry plotting and other preprocessor features help for creation of the mathematical model. Plotting of deformed shapes or stress contours helps for evaluation of the computer outputs.

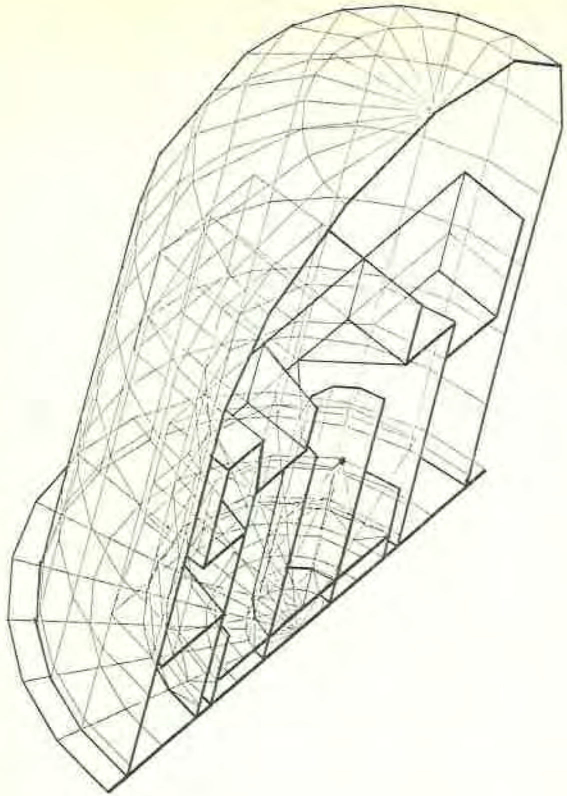

Figure 1 Model for preliminary analysis of a BWR containment building structure. Model also used in seismic response analysis.

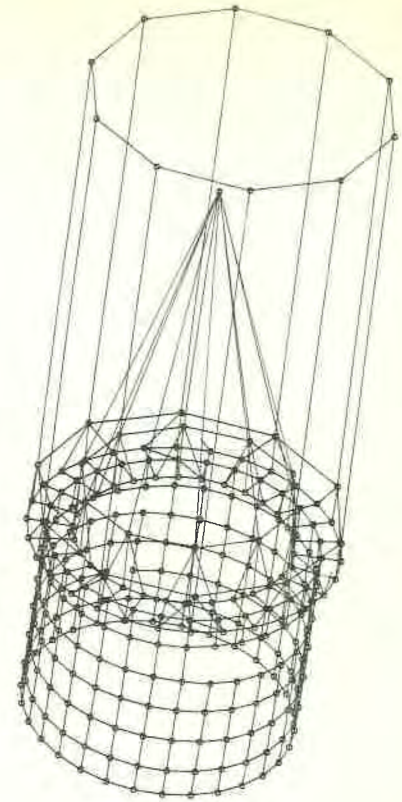

Figure 2 Model for preliminary analysis of structural solution of a reactor pedestal.

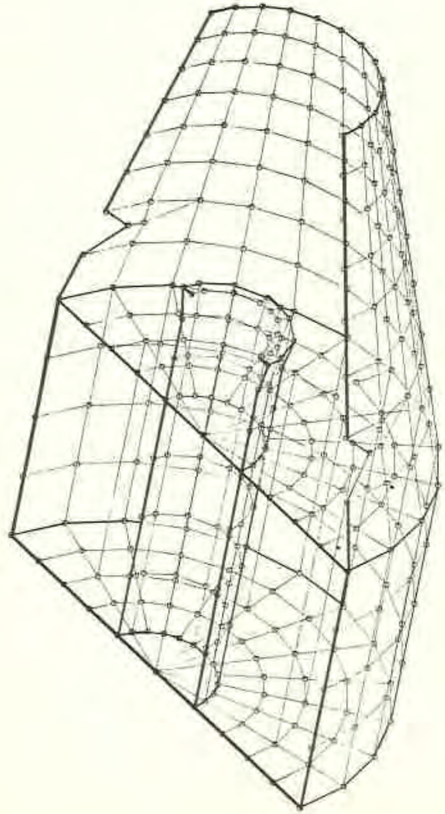

Figure 3 Model for independent checking for the primary containment of a BWR. Model also used in non-linear analysis.

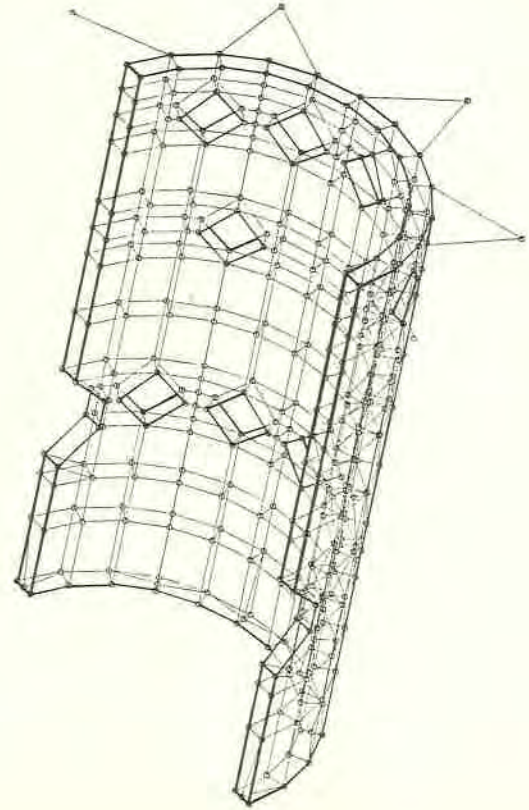

Figure 4 Model for independent checking analysis of a reactor shield structure.

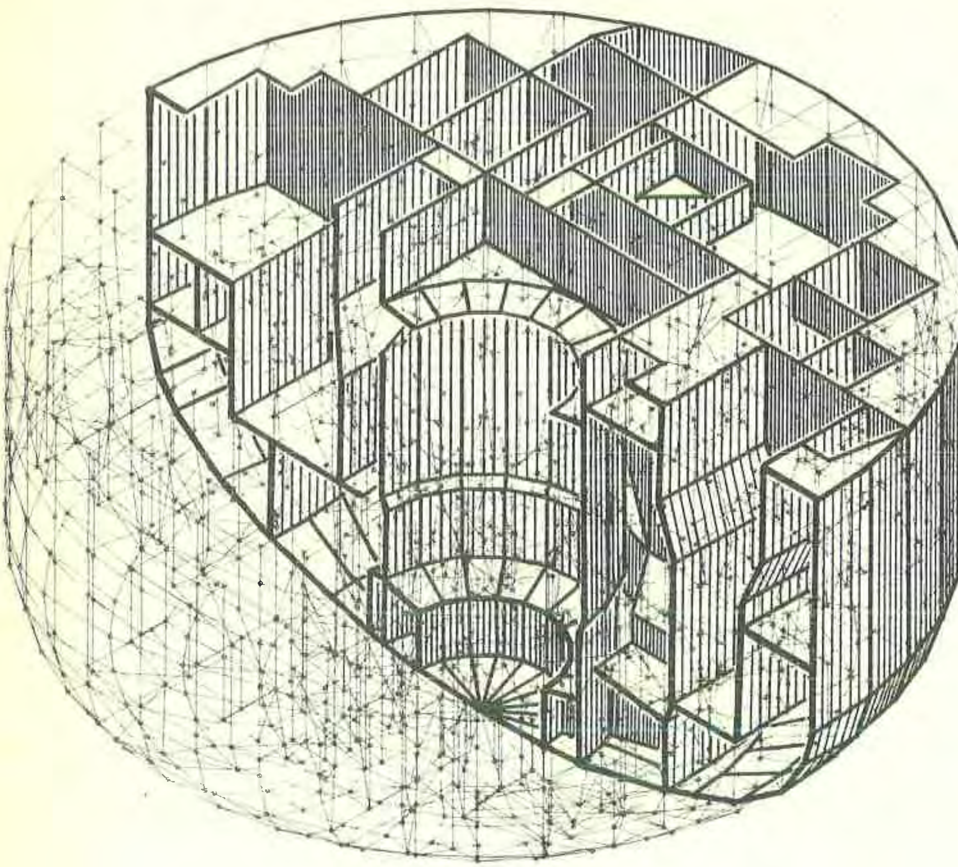

Figure 5 Complete model for analysis of building structure of a breeder reactor.

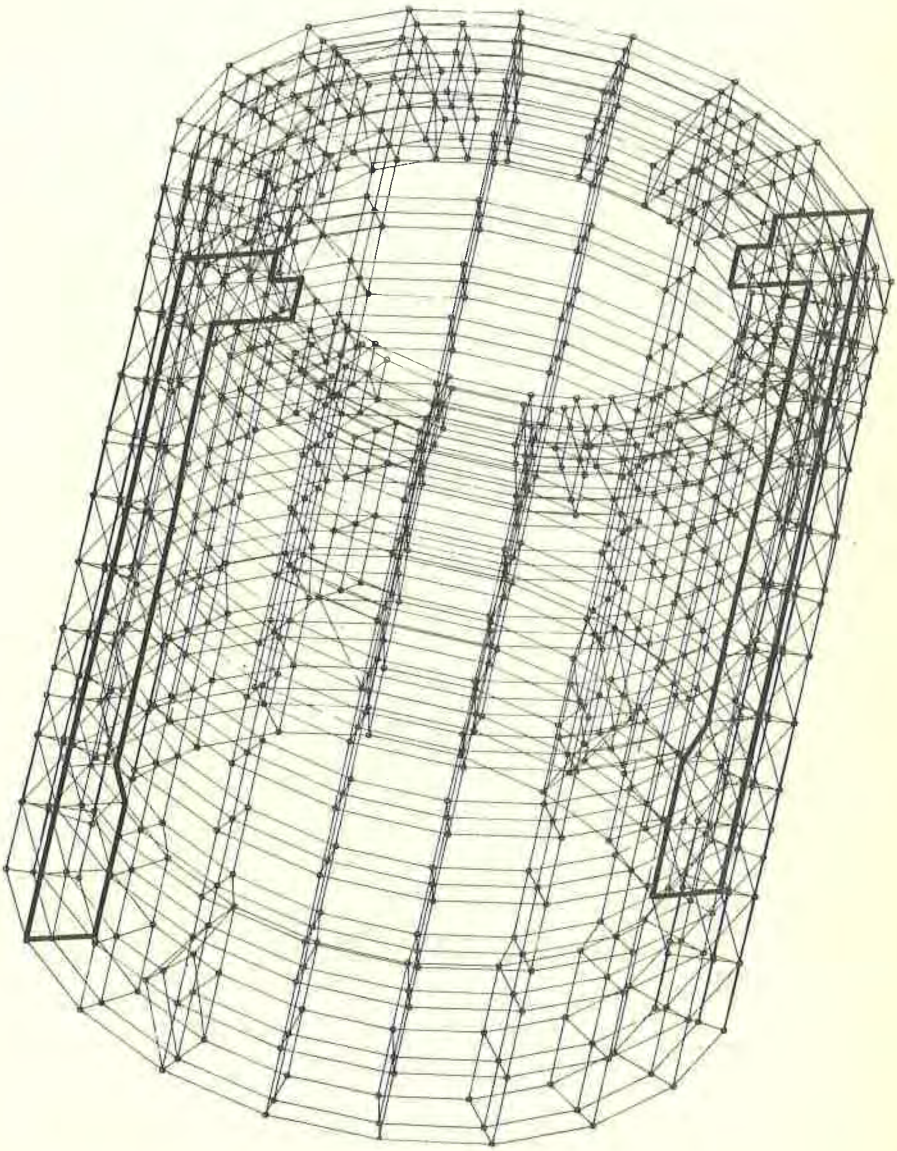

Figure 6 Detailed model used for non-linear analysis of the internal support structure of a breeder reactor.

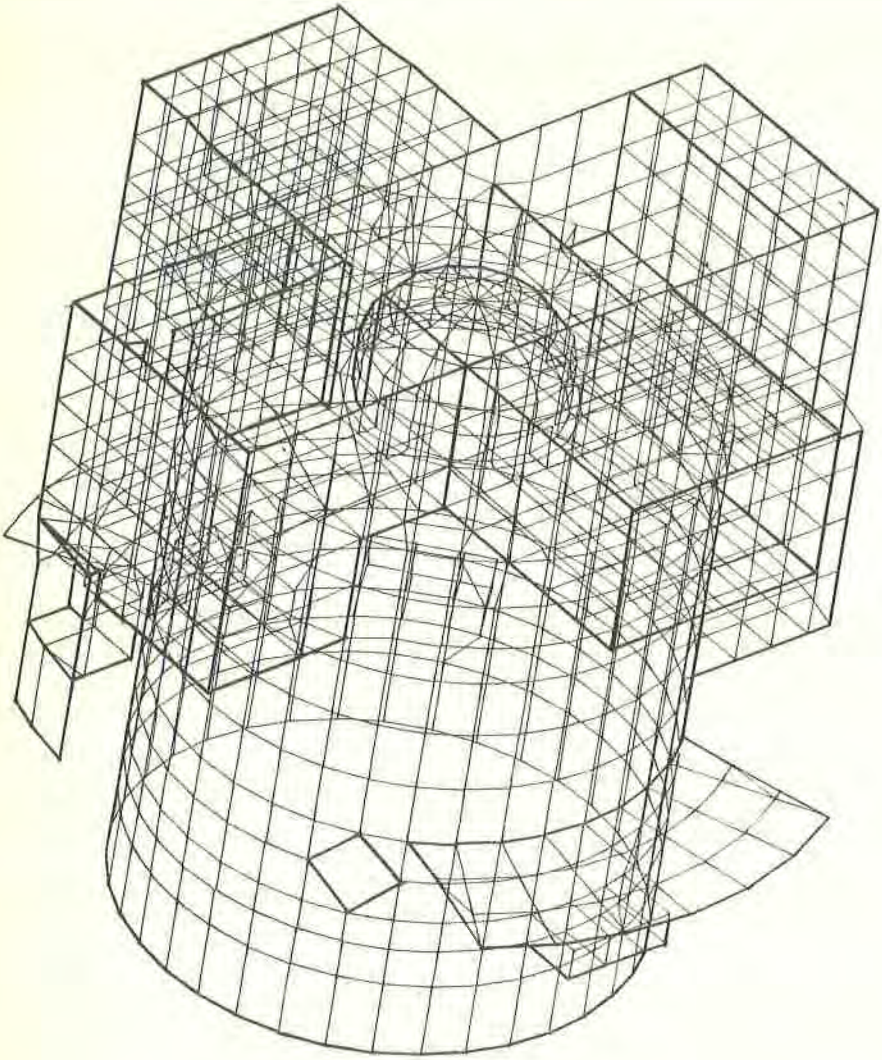

Figure 7 Complete model for analysis of the drywell structure of a BWR.