Structural design of nuclear power plants using very large finite element models

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1 INTRODUCTION

The design of reinforced concrete structures of nuclear power plants requires the utilization of special calculation methods, in order to be possible the handling of the large amount of input data and results. The various loading types, different possibilities of application of the prescribed loadings (concerning places, directions, intensities, time instants, etc.), combination rules, design rules and design safety factors, must be studied for a large amount of structural elements. Since these structural elements are interconnected, the analysis through individual finite element models can cause a formidable task, if the effects of the structural coupling would be realistically evaluated. Therefore the best way to tackle the problem is to analyse the structure as a whole, considering at the same time all the intervening structural elements. For this purpose the consideration of very large finite element models is absolutely necessary. This paper shows how the models are created, analysed, and afterwards how the results are postprocessed through a battery of computer programs.

It will be of practical interest to see how large these models can be formed, in order to be possible the investigation of the structural peculiarities but at the same time to limit the complexity of models, in a way that the numerical treatment can still be done economically.

It should be mentioned additionally that the automatic procedures can cause a reduction of steel expenditure in reinforcement steel for the concrete structures, due to a series of inherent features of the coupled model as well as due to the automatic economic design which can be performed by the design procedures of the programs.

The obtained experience comes from the design of the Angra NP Plants, which are being built in Brazil at mid course between the cities of Rio de Janeiro and São Paulo. Two units of 1300 MW each are foreseen, which are designed according to the KWU architecture. The main designer is the Brazilian state company NUCLEN, and the responsable for the reinforced concrete design is Promon Engenharia S.A.

2 DESCRIPTION OF THE MODELS

Herein only the Reactor Building of the Angra NPP will be treated.

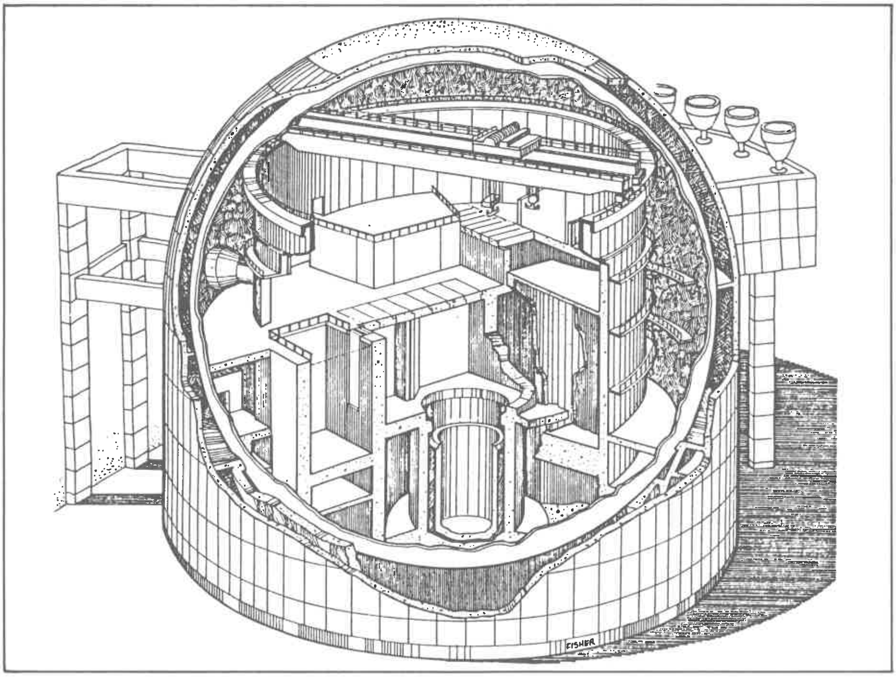

Figure 1. General arrangement of the Reactor Building.

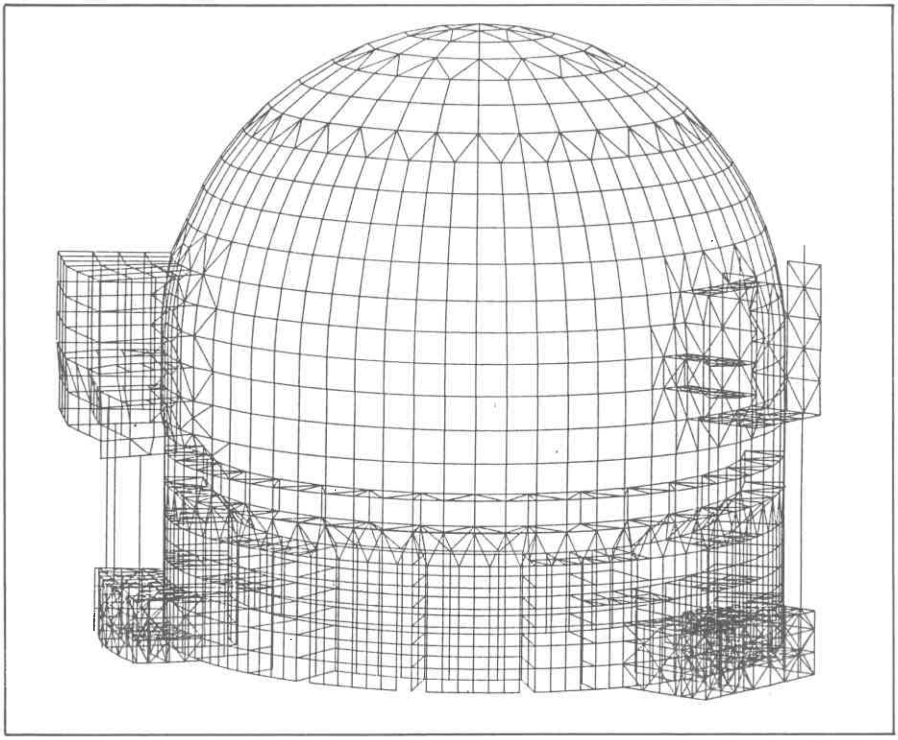

Figure 2. Model for the analysis of the external concrete shell.

As shown in Figure 1, the main structures of the Reactor Building can be subdivided into three large structures: the external containment shell, the spherical cap and the internal structures. These three large structures are formed by different types of single elements including beams, plates, shells, etc. The structural connection between the different elements is almost complete, since the reinforced concretes of the building, in most cases, do not present any sort of hinge support or something similar.

The external shell model represents:

a. the concrete shell itself

b. the walls and slabs of the annulus of the Reactor Building

c. the walls, slabs and columns of the Main Steam and Feedwater Valve Compartments.

The spherical cap model includes the following parts:

a. the spherical cap, which supports all the internal structures of the Reactor Building

b. the steel containment shell

c. the ring wall, which supports the spherical cap and transfers the loads to the base plate

d. the slabs, which are connected to the ring wall.

And finally, the model of the internal structures is defined. It represents the existing structures in the internal part of the Reactor Building, delimitated by the steel containment shell.

The three models have the following amount of degrees of freedom, nodes, beam elements and plate elements:

Model	Degrees of freedom	Nodes	Beams elements	Plate elements
External Shell	9237	1830	328	2467
Spherical Cap	8372	1862	921	2832
Internal Struc.	5432	1178	395	1932

Figure 1 shows the arrangement of the different parts of the Reactor Building. The spherical cap in this figure can not be seen.

Figure 2 represents the mathematical model used for the external containment shell.

The model of the spherical cap is depicted in Figure 3. It should be explained that the spherical cap itself is modeled through three shells:

a. the lower concrete cap with a thickness of about 1,5m

b. the intermediate steel shell about 25mm thick, which forms the internal containment

c. the upper concrete cap presenting a thickness of about 1,5m.

This model permits the consideration of the non linear effects, due to existent friction between the three spherical caps, in the design of the Reactor Building for the Angra NPP, Unit 3.

The Figure 4 shows a view of the model utilized for the internal structures. In order to decrease the size of the model, some parts of the building, located outside of the missile protection cylinder have not been modeled. The corresponding loads of these parts were included in the analysis by means of acting forces.

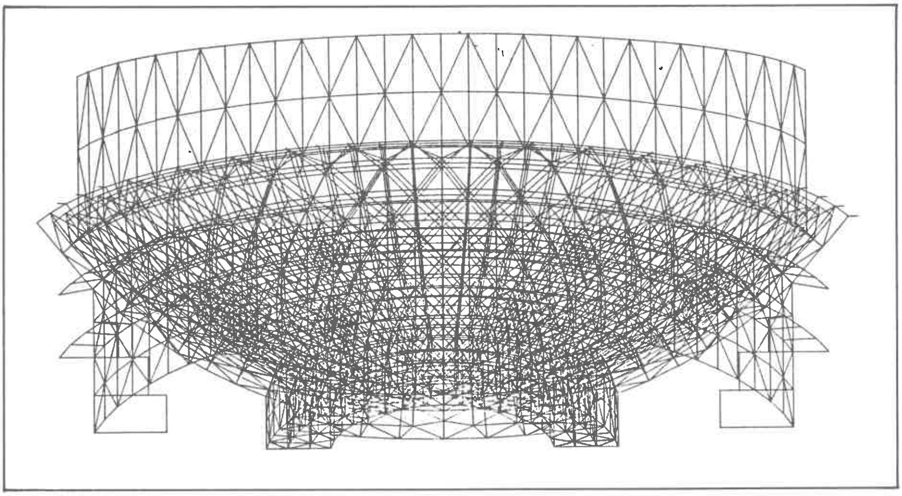

Figure 3. Model for the analysis of the spherical cap.

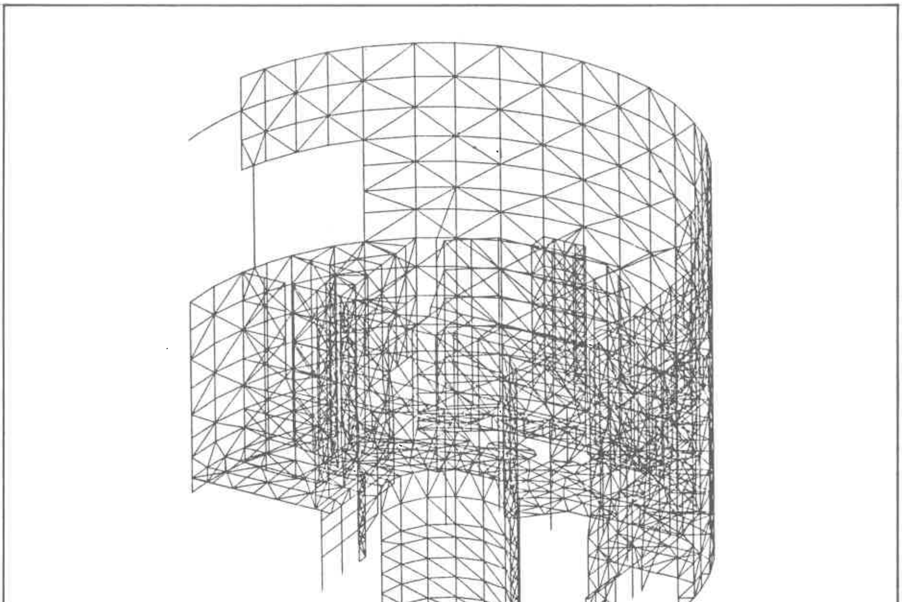

Figure 4. Model for the analysis of the internal structures.

3 CONSIDERATION OF THE LOADS

The Reactor Building is subjected to a multitude of loads, which can be summarized into: dead loads, loads due to deferred deformations of the concrete (creep, shrinkage), loads due to TNT explosions, operation loads (equipment, pressure, temperature, traffic, etc.), environmental loads (wind, OBE earthquake, SSE earthquake, temperature, bouyancy) and the loadings related to the postulated internal accidents (equipment reactions, piping reactions, jet pressure, jet impingement, pressure, temperature, fall of equipments, etc.).

In order to handle all this individual loads with help of analysis programs, it is necessary beforehand to define some practical concepts for the necessary bookkeeping of the data. Thus, the definitions regarding computed loadings, basic loadings and combinations will be given. The computed loading corresponds to the actual loading processed by the analysis program. The basic loading is correspondent to an acting loading, which is identified through its cause, such as, dead load, wind from north, earthquake from east, postulated accident in the cold leg of the primary loop, and so on. In order to reduce processing each basic loading, represented by the vector {B} is determined from the computed loadings, represented by the vetor {P}, with help of the transformation matrix [BP] through the expression:

(1) $\{B\} = [BP]\ \{P\}$

This allows the use of different models since the combination of internal forces can be performed, as long as, the numbering system of the individual elements be mantained. For the computation of the internal forces for each combination, it is necessary to define the combination rule by means of the combination matrix [CB]. The data of each combination are obtained by:

(2) $\{C\} = [CB]\ \{B\}$

in which {C} represents the vector of the internal forces for each combination. From expressions (1) and (2) can be obtained:

(3) $\{C\} = [CB]\ [BP]\ \{P\}$

Since the combination of internal forces is performed by independent programs, the analysis programs will not perform the combinations. It is interesting to note that for large models, the analysis output data are utilized in the design in partial steps, since the structural design must be developed according to the construction sequence. Therefore it is out of the question to try to combine all the internal forces for the design in a single step. The combinations of internal forces are performed in phases, which is highly dependent on the structural element, and on the part whose design is necessary for construction.

It is interesting to show herein the number of single computed loadings processed for each model and the number of combinations utilized in the design of some structural parts.

Model	Number of computed loadings	Number of basic loadings	Number of combinations
External Shell	22	28	20
Spherical Cap	14	24	21
Internal Structures	195	289	182

4 DESIGN OF REINFORCED CONCRETE ELEMENTS

The determination of the reinforcement of the concrete members, such as columns, beams, plates and shells, must be performed in a defined area of the overall structure, for all the defined combinations. This is caused by the different design rules pertaining to each combination. Therefore the computer program has not only to process the different combinations of internal forces, but take into consideration the different safety factors and inherent peculiarities of each design rule to determine the reinforcement for every particular member and for each loading combination.

It was verified during the reinforcement design that it was feasible to use design procedures which determine for each load combination the most economical reinforcement in the longitudinal direction. This was possible since most of the members could be designed as a plate element, for which only the axial forces and bending moments are necessary. A special design procedure chooses the most adequate top and bottom reinforcement so that the total reinforcement is a minimum.

After that, another program must be processed to investigate which is the critical reinforcement for an area of the structure, for which the reinforcement must be the same.

It has been verified that the computed reinforcement, in comparison with other designs, was substantially reduced due to: the large redistribution of forces, the precise and reliable design and the optimization design procedures.

5 ADDITIONAL ADVANTAGES

The use of large models has presented additionally a few important advantages: better control of the calculation, reduction of man-hours for the analysis of the structures, a more real representation of the internal forces of the structure, more efficient design due to the reliable previous analysis work, and so on.

6 CONCLUSIONS

It has been shown that it is possible to use large finite element models in the design of nuclear power plant structures, with various advantages such as: reduction of steel expenditure, better reliability in the calculations, better possibility of design control and reduction of the design man-hours.