Seismic response of a reactor building on rocky foundation

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1. INTRODUCTION

The significance of rational evaluation of seismic response of a reactor building is well recognized from the point of view of structural safety under high seismic conditions. The reactor building is a complex structure composed of various subsystems such as outer and inner shells, foundation raft and cellular roof slab having widely differing individual dynamic characteristics. A simplified mathematical model such as an axisymmetric finite element idealization can be employed for seismic response analysis. Such a model can lead to useful results for design and is less expensive compared to three dimensional model. The axisymmetric finite element model is undoubtedly superior to conventional beam method because of several reasons, particularly the ability of the former approach to consider both meridonal and cricumferntial vibrations (Chandrasekaran 1985). Consequently the stress predictions in the structure with this method of modelling is more realistic. The seismic response of the building is greatly influenced by the type of foundation rock (Thakkar 1983; Deq 1985). The foundation-structure interaction effect in the case of rock is less pronounced because a stiff structure like a nuclear reactor building tends to interact little with the stiff foundation medium. Nevertheless, the elasticity of foundation has an important role in the seismic response evaluation and must be considered.

The nuclear reactor building resting on a rocky foundation is considered here. The two dimensional axisymmetric finite element harmonic analysis is carried out under horizontal and vertical ground motion. Various aspects such as the base fixity, variation of foundation rock properties, stiffness of internals, and inertia of foundation are considered and their influence on seismic response is studied. The natural time periods, displacements stresses and bending moments are obtained as a result of dynamic analysis. The response of one mode alone is found to be significant in the case of rocky site. The fixed base analysis of reactor building has demonstrated that the foundation-structure-interaction on rocky foundation has relatively small contribution to the total response.

2. ASSUMPTIONS

The finite element model of a reactor building on a rocky foundation is shown in Figure 1. The following assumptions are made in the idealization:

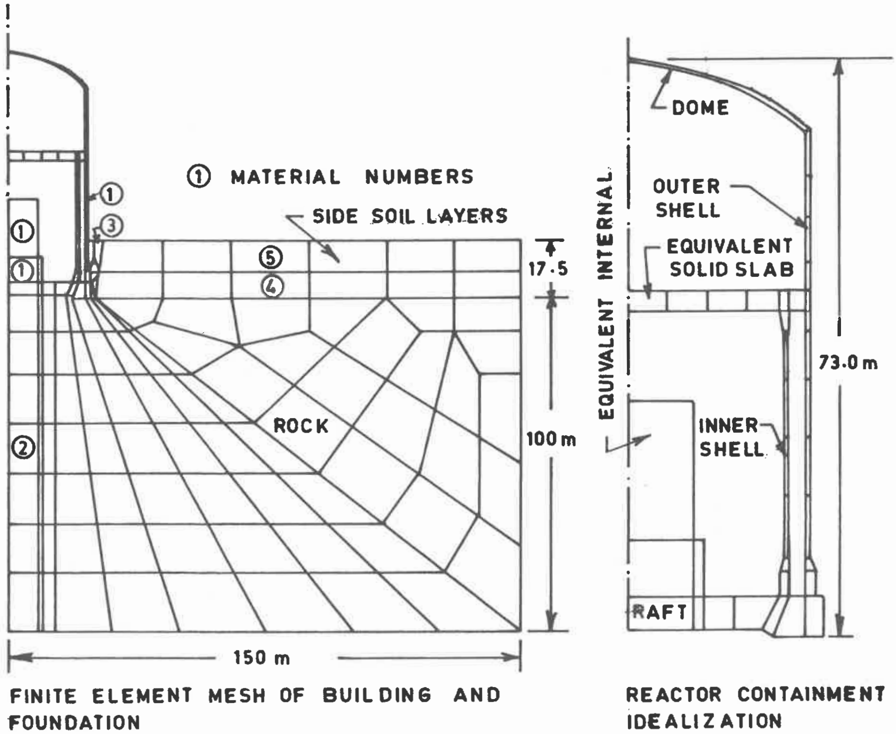

FIG.1_FINITE ELEMENT MODEL OF REACTOR BUILDING

a. The outer and inner shell, the foundation raft and cellular roof slab and the foundation medium are represented by eight noded isoparametric axisymmetric solid elements.

b. The internal structure though non axisymmetric is represented by an equivalent solid cylindrical body. The basis of the equivalence is the flexural sigidity.

c. The inertia of foundation is not considered.

d. The structure is analysed for both horizontal and vertical ground motions.

e. Modal damping is considered as 7 percent of critical in all the modes.

3. FORMULATION FOR DYNAMIC RESPONSE

The earthquake motion applied to an axisymmetric structure results in a non symmetric inertia loading. The analysis of an axisymmetric body for such a loading is made by Fourier expansion of both loading and displacements. The resulting solution is obtained by superposition of harmonic solutions. The detailed formulation is presented in the text book on finite element method (Zienkiewicz 1979). The salient features of the procedure are described below.

3.1 Displacement Components

The radial, tangential and vertical components of displacements (u,v,w) are expressed as:

$$u = \underline{N} \text{ Cos } n\theta \, \underline{u}_{ne}$$

$$v = \underline{N} \text{ Sin } n\theta \, \underline{v}_{ne}$$

(1) $$w = \underline{N} \text{ Cos } n\theta \, \underline{w}_{ne}$$

where $\underline{N}$ represent shape functions, n denotes the harmonic number, $\underline{u}_{ne}$, $\underline{v}_{ne}$, $\underline{w}_{ne}$ are the nodal displacement vectors of an element.

3.2 Stiffness matrix

The element stiffness matrix $\underline{K}_e$ is a function of harmonic number n. When n = o, the standard axisymmetric case is retrieved. The stiffness matrix is obtained from the following relationship,

(2) $$\underline{K}_e = \int_V \underline{B}^T \, \underline{D} \, \underline{B} \, dv$$

3.3 Equations of motion

The dynamic equilibrium equations in the finite element formulation are of the following form:

(3) $$\underline{M}\ddot{\underline{u}} + \underline{C} \, \dot{\underline{u}} + \underline{k} \, \underline{u} = \underline{f}(t)$$

where $\underline{M}$, $\underline{K}$ and $\underline{C}$ are harmonic dependent mass, stiffness and damping matrices respectively, $\underline{f}(t)$ is the external force vector.

3.4 Earthquake motion as harmonic loading

It is observed that n = 1 and n = 0 exactly represent the horizontal and vertical components of ground motion respectively. The ground acceleration components are represented as follows:

(4) $$\ddot{\underline{a}}_h = \{a_{gh} \text{ Cos}\theta, \, a_{gh} \text{ Sin}\theta \, , \, O\}^T$$

(5) $$\ddot{\underline{a}}_v = \{O, \, O, \, a_{gv}\}^T$$

The solutions are obtained separately for the two motions.

3.5 Method of solution

The dynamic response to earthquake motion is obtained by timewise mode superposition method. The first three modes of vibration for both n = 1 and n = 0 are considered. The maximum stresses at the Gauss points, displacement at the nodes and bending moments are obtained as a result of seismic analysis.

4.0 BUILDING PARAMETERS

Figure 1 shows the axisymmetric finite element idealization of the building with foundation. The properties of materials 1 to 5 along with variations considered are described in Table 1. The side layers of soil providing embedment to the building is relatively of smaller stiffness. A range of material properties of the backfill in contact with the outer containment is considered. In order to consider the variation in the soil properties, three cases (1, 2, 3) are considered. The aspects particularly studied in this paper are (i) base fixity, (ii) inertia of foundation, (iii) stiffness of internals, and (iv) foundation rock properties.

TABLE - 1

MATERIAL PROPERTIES USED IN THE ANALYSIS

Material No.	Case	Modulus of Elasticity $\times 10^6$ t/m^2	Poison's ratio	Mass density (t-sec^2/m^4)	Description of Structure
1	-	3.00	0.20	0.255	Reactor building
2	-	1.50-3.0	0.30	0.255	Foundation rock
	1	0.0208	0.30	0.183	
3	2	0.0052	0.30	0.183	Backfill
	3	0.0052	0.30	0.183	
	1	0.15	0.20	0.203	
4	2	0.15	0.20	0.203	Top side layer
	3	0.25	0.20	0.203	
	1	0.50	0.15	0.203	
5	2	0.50	0.15	0.203	Bottom side layer
	3	0.75	0.15	0.203	

The properties of material No. 1 and 2 remain same in all the cases.

5.0 RESULTS OF SEISMIC ANALYSIS

As a results of seismic analysis, the time periods of vibration of the structure in the horizontal and vertical directions, the stresses, displaceemnts bending moments are obtained. In the finite element analysis the bending moment in the shells is worked out from vertical stresses at the Gauss points on the basis of beam analogy. The results of analysis are described below.

5.1 Time periods

The time periods in three modes in different cases are presented in Table 2. It is observed that the variation of properties of side soil layers and backfill affect only the fundamental mode (n=1). The vertical modes are not affected by different soil properties. The comparison of time periods for n = 1 with the fixed base condition, that is, reactor building fixed at the base of the raft shows that the periods are shortened by 6, 18 and 0.8 percent respectively in first, second and third mode. The consideration of foundation inertia causes elongation in periods, in some cases it is observed even more than 55%. Variation of foundation rock modulus of elasticity from 1.5 x 10^6 to 3.0 x 10^6 t/m^2 causes decrease in time periods by 3.44, 7.38 and 0.595 percent in first, second and third mode respectively. The increase in the stiffness of internals hundred times does not affect time periods in the first and third mode, the period in second mode is shortened by about 33 percent.

TABLE - 2

TIME PERIODS OF STRUCTURE

Type of Analysis	Case No.	Horizontal vibration T1	T2	T3	Vertical vibration T1	T2	T3
Finite	1	0.226	0.149	0.0835	0.165	0.0932	0.0828
element	2	0.232	0.149	0.0839	0.165	0.0932	0.0831
analysis	2	0.231	0.149	0.0838	0.165	0.0932	0.0830

T1, T2 and T3 are the time periods of vibration in seconds in first, second and third mode.

5.2 Bending moments

Table 3 shows the bending moments at the base of outer and inner shells and bottom of the raft. It is observed that the case 2 gives the maximum values. The bending moments in the structure are found by the combination of three modes as well as based on single mode only in the horizontal direction. It is observed that the second and third mode has a negligible contribution to the base moments.

TABLE - 3

BASE BENDING MOMENT IN THE REACTOR BUILDING

Type of analysis	Case No.	Raft base (x 10^6 t-m)	Top of raft (x10^6 t-m) External shell	Internal shell
Finite	1	0.465	-	-
element	2	0.537	0.274	0.220
	3	0.534	-	-

5.3 Vertical stresses

It is observed that the vertical normal stress at the base of outer and internal shell due to horizontal ground motion is of the order 136.0 and 85.0 t/m^2 in the case 2 when foundation rock elasticity is considered. Considering the building fixed at the base causes reduction in the stresses by 2.3 to 10.14 percent. Consideration of inertia of foundation can cause increase in the stresses at the base of shells by 3 to 4 times than when the inertia is not considered. By doubling the elasticity of foundation the stresses at the base of shells are decreased by 4.5 to 10.0 percent. Increasing the stiffness of internal does not cause appreciable change in the vertical stresses. This is primarily due to the dominance of first mode in the total response.

5.4 Displacements

The horizontal displacements at the top of dome under fixed base condition and with foundation elasticity effect is found to be 9.50 mm and 11.46 mm respectively. Doubling the elasticity of foundation causes the horizontal displacement at the top of the dome to decrease by about 10.0 percent.

6.0 SUMMARY AND CONCLUSIONS

The seismic response of a reactor building on a rocky foundation has been studied by the finite element model. The influence of base fixity, inertia of foundation, stiffness of internal structure and foundation rock properties is studied on the seismic response. The conclusions of this study are summarised as follows:

1. The response due to one mode alone is found to be significant in the case of rocky foundation.
2. The foundation - structure interaction has relatively small contribution to the total response.
3. The consideration of inertia of foundation may lead to very high seismic responses. More realistic method of considering inertia effect of foundation is therefore necessary.
4. The increase in the elasticity of foundation by one hundred percent does not cause variations in vertical stresses in the outer and inner shells by more than 10 percent.

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