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SOIL-STRUCTURE INTERACTION EFFECTS ON SEISMIC RESPONSE OF CONTAINMENT SHELL

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ABSTRACT

In recent years seismic analysis of axisymmetric structures, such as cooling towers, chimneys, pressure vessels, reactor containments, etc., subjected to dynamic loading has attracted considerable attention, specially in the analysis of nuclear power plant structures. The structural safety of nuclear reactor building during expected earthquake motion is of great importance in view of possibility of radiation hazards. These massive structures interact with the surrounding soil, leading to a further modification of the seismic motion at the base. Thus, the structural response may be affected by the interaction with the soil. Also, there will be a feedback from structure into the soil. It is thus not appropriate to analyze the structure alone. Instead, the total system consisting of the structure and the soil should be analyzed. It is necessary that modern methods of dynamic analysis using numerical methods and high speed digital computers are employed for predicting theoretical response of structures. Besides other factors, the accuracy of results of dynamic analysis is dependent on the type of mathematical model employed.

KEYWORDS

Earthquake analysis; nuclear reactor; soil-structure interaction; modal damping.

ASSUMPTIONS

The structure and underlying soil remain bonded through out the period of ground shaking. The motion at the base of foundation is assumed to be the free field ground motion. The soil surrounding the structure is assumed to be linearly elastic. The soil is assumed to be massless and only flexibility of soil is considered. The modal damping is evaluated based on weighted damping considering strain energy as weighted bases.

METHODOLOGY

The earthquake motion applied to the base of axisymmetric structure results in a non-axisymmetric inertia loading. The analysis of an axisymmetric body for such a loading is made by Fourier expansion of both loading and displacement (Zeinkiewicz,1979). The salient features of the procedure are described below :

Displacement Function

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

$$u = N \text{ Cos } n\theta \,.\, u_{ne}$$

$$v = N \text{ Sin } n\theta \,.\, v_{ne}$$

$$w = N \text{ Cos } n\theta \,.\, w_{ne}$$

where N = Shape function,
n = harmonic number (0,1,2,...)
u , v , w = nodal displacement vector of an element and e stands for element.

Stiffness matrix

The element stiffness matrix, K, is a function of harmonic number n. It is given as :

$$K = \int B^T D B dv$$

where B is strain-displacement relationship matrix and D is the elasticity matrix.

Equation of motion

The dynamic equilibrium equations in the finite element formulation are as follow:

$$M\ddot{u} + C\dot{u} + K u = f(t)$$

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

Earthquake ground motion

The harmonics n=1 and n=0 of Fourier series would exactly represent the horizontal and vertical components of ground motion, respectively. The horizontal component of ground acceleration and harmonic loading is represented as follows:

$$\ddot{a}_h = \{ \ddot{a}_{gh} \text{ Cos } \theta, - \ddot{a}_{gh} \text{ Sin } \theta, 0 \}$$

$$f(t) = - M \ddot{a}_h$$

PARAMETRIC STUDY OF CONTAINMENT SHELL

The study of seismic response of containment shell is made to determine the influence of following parameters :

a) Effect of soil type,
b) Effect of depth of embedment,
c) Comparision of responses of the structure obtained from finite element and beam models, and
d) Effect of type of ground motion.

Problem:

For the purpose of study, outer containment shell of a typical nuclear reactor building (Fig. 1) has been taken. The structure is symmetrical with respect to its vertical axis. It consists of a reinforced concrete cylindrical shell capped with a spherical dome and resting on a raft. The structure is embedded in surrounding soil. Following are the material properties of containment shell and soil considered in this study :

Concrete :

Modulus of elasticity = $2.5x10\ kN/m^2$
Poisson's ratio = 0.25
Unit weight = $2.5\ kN/m^3$
Damping = 5% of critical

Soil :

Shear wave velocity of soil = 300,600,900,1200 m/s
Poisson's ratio = 0.30
Unit weight = $2.00\ kN/m^3$
Translational damping = 20%
Rocking damping = 5%

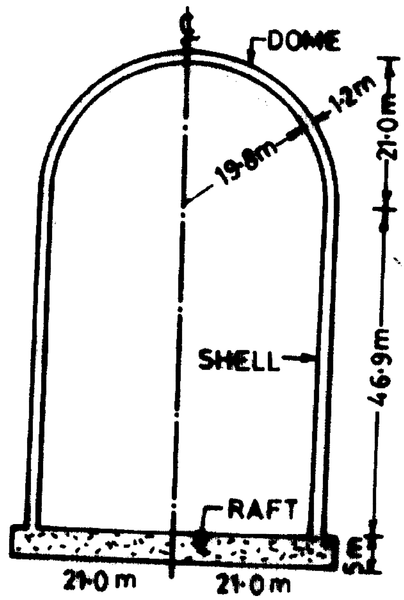

FIG.1: NUCLEAR REACTOR SHELL

To meet the above objectives, following cases have been studied:

CASE I : Fixed base without raft and no soil-structure interaction

The undamped free vibration analysis of outer containment shell (Fig. 1) has been performed to calculate the first three natural frequencies by finite element method and beam method. Frequencies obtained by the above two methods are compared with those of shell model given in Wolf (1985) and shown in Table 1. Maximum difference between Wolf and finite element model is 3.7% while between beam and Wolf models is 8%.

Table 1. Comparison of Time periods (sec)

MATHEMATICAL MODELS	MODE-1	MODE-2	MODE-3
WOLF (1985)	0.228	0.075	0.046
FINITE ELEMENT MODEL	0.237	0.077	0.046
BEAM MODEL	0.210	0.070	0.062

CASE II Influence of shear wave velocity of founding soil

The soil-structure system as shown in Fig. 2 has been taken and study has been made for horizontal excitation of Koyna earthquake time history and different shear wave velocities. This system is analyzed by finite element method and beam method as shown in Figs. 2a and 2b.

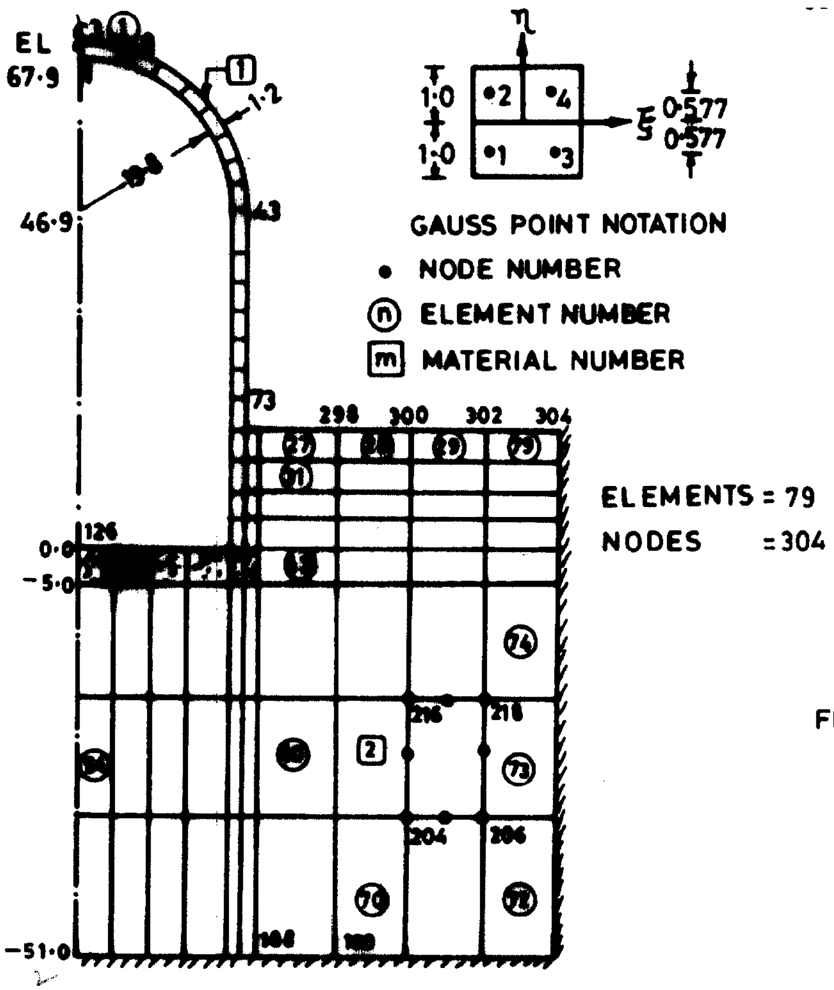

FIG.2(a): FINITE ELEMENT MESH OF SHELL

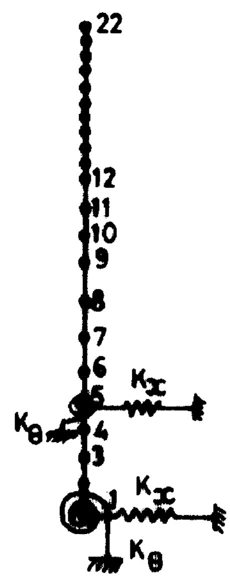

FIG.2 (b): BEAM MODEL OF A SHELL

Table 2 shows time period , weighted modal damping and tip displacement for different shear velocities.

TABLE 2. Time period variation with shear wave velocities

Shear wave velocity (m/s)	Mode	Time periods by Beam (sec)	FEM	Weighted damping %	Tip displ.(mm).
300	1	0.475	0.471	16.3	55.7
	2	0.083	0.367	20.0	
	3	0.070	0.274	17.7	
600	1	0.289	0.318	11.0	28.3
	2	0.070	0.184	20.0	
	3	0.056	0.154	18.0	
900	1	0.235	0.281	8.5	16.1
	2	0.070	0.123	18.1	
	3	0.051	0.108	18.7	
1200	1	0.210	0.266	7.6	12.9
	2	0.070	0.093	19.3	
	3	0.050	0.083	18.9	

Time period values by beam analysis are lesser than those obtained by finite element analysis. As shear wave velocity increases time period decreases considerably for first mode and almost insignificant variation occurs for higher modes.

Weighted modal damping decreases with increase of shear velocity for first mode and very small variation occurs in higher modes.

Tip displacement decreases with increase of shear velocity.

<u>CASE III : Influence of depth of embedment</u>

The seismic response of soil-structure system (Fig. 2) has been studied by varying depth of embedment for horizontal earthquake ground motion and shear wave velocity of 600 m/s, using finite element method.

Table 3 shows values of time period, weighted modal damping and tip displacement for different depths of embedment.

Table 3 Time periods for different embedment depths

Depth of embedment (m)	Mode	Time periods by FEM (sec)	Weighted damping %	Tip displ.. (mm)
0.0	1	0.423	10.9	35.3
	2	0.184	19.8	
	3	0.144	18.5	
4.0	1	0.401	11.2	28.8
	2	0.184	19.4	
	3	0.146	18.2	
8.0	1	0.390	10.5	23.3
	2	0.184	20.0	
	3	0.147	18.4	
12.0	1	0.381	11.1	22.1
	2	0.184	19.1	
	3	0.140	18.3	
16.0	1	0.318	11.0	20.3
	2	0.184	20.0	
	3	0.134	18.0	

It is observed that time period decreases with increase of embedment depth.

There is no significant change in the weighted damping values with increase of embedment depth.

Tip displacement decreases with increase of depth of embedment.

CASE-IV : Influence of type of earthquakes

To compare the deformations, three time histories have been normalized to 0.49g on the basis of peak accelerations. Salient data of these time histories is given in Table 4.

Table 4. Comparison of peak accelerations of three earthquakes

Location	Date of occurrence	Component & Peak Ground acceleration in terms of g		Magnitude (Richter Scale)	Approx.duration (Sec.)
Koyna (India)	Dec.11, 1967	Transverse	0.49g	6.5	10.3
El-Centro (California)	May 18, 1940	N-S	0.33g	7.1	30.0
Uttarkashi (India)	Oct.20, 1991	Longitudinal	0.53g	6.1	37.1

Fig. 3 shows the variation of horizontal deformations along the height of structure for above mentioned three earthquakes.

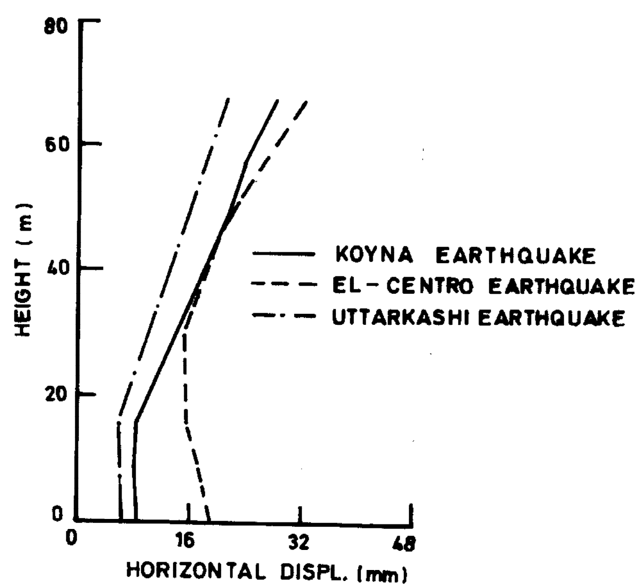

FIG. 3 _ VARIATION OF HORIZONTAL DISPL. ALONG THE HEIGHT

It is observed that deformations due to El-Centro earthquake are lesser as compared to those due to other two earthquakes while magnitude of El-Centro earthquake is higher than that of Koyna and Uttarkashi. This is because of the frequency characteristics of the ground motions being different.

CONCLUSIONS

The seismic response of containment shell on different soil conditions has been studied by axisymmetric finite element and beam models and the following conclusions are derived from the study:

The dynamic response of building is sensitive to the method of modelling of soil-structure system. Axisymmetric finite element method is undoubtedly superior to beam method because stress distribution particularly at the junctions of shell with the raft and dome can be evaluated quite accurately by finite element method.

The structure behave like rigid base for shear wave velocity of 1200 m/s.

Horizontal deformation of structure decreases by 40% with the provision of depth of embedment equal to 1/4 th height of structure.

The ground motions of identical spectral intensity do not result in identical response because of their frequency characteristics being different.

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