Seismic analysis of Maple-X reactor building structure

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ABSTRACT: The paper presents the seismic analysis of the Maple-X Reactor Building Structure. The structure is represented by a 3-D finite element model. From a structural analysis of this 3-D finite element model, a condensed stick model is developed. This stick model is used for the dynamic analysis of the structure. Subsequently, the 3-D finite element model with static inertial loading is analysed. Such an approach is an economical and practical way of analysing complex structures.

1. INTRODUCTION

The Maple-X nuclear reactor is proposed to be built at Chalk River Nuclear Laboratories. This reactor is a prototype of the new multi-purpose research reactor for the future to be marketed by Atomic Energy of Canada Limited. The building, which houses the reactor and other equipment, is required to be designed for a potentially severe earthquake. For that purpose a seismic analysis of the building structure has been undertaken. The methodology, modelling considerations and brief results of this analysis are described.

2. DESCRIPTION OF THE STRUCTURE

The Maple-X reactor building is rectangular in shape 23 m wide and 32 m long. The structural plan is shown in Figure 1. The total building height of 30 m consists of 7 m high peripheral concrete walls supporting a 23 m high cross braced steel structure. A cross sectional elevation of the structure is shown in Figure 2. The structure serves as an enclosure for the heavy concrete pool structure which houses the Maple-X reactor. The lateral load bearing elements are shear walls at the lower part and the cross braced steel frame above the 146 m elevation. The concrete walls also act as retaining structures for the surrounding earth. The lowest floor is located at elevation, 141 m.

The reactor pool structure is founded on the rock below and is structurally separate from the outside building. At elevation 146 m, there is a partial floor slab supported on steel beams. The main operating floor is at elevation 153 m. At that elevation, in parts of the area, concrete flooring is used. In other parts, there is a fixed steel platform. The control room is located at one side of the building. A number of staircases provide the vertical access. A bridge crane supported on the external columns is used for material handling. Above the 149 m elevation, the building has an offset with a reduced width of 17.5 m. The roof is supported on steel trusses spanning 16.5 m across. A system of horizontal bracing is used at the roof level for transferring horizontal loads to the vertical bracing system.

3. 3-D ANALYSIS MODEL

The structural steel frame is represented by a three dimensional (3-D) finite element model. The computer program STARDYNE is used for this purpose. The model is made of 177 nodes and 455 beam elements to represent the structural interactions. The geometry of the model is verified using computer plots. A plot of the 3-D model is shown in Figure 3. The columns are modelled as members pinned at the base. The beams and bracing members are modelled to be pinned at both ends. The roof trusses are replaced by equivalent

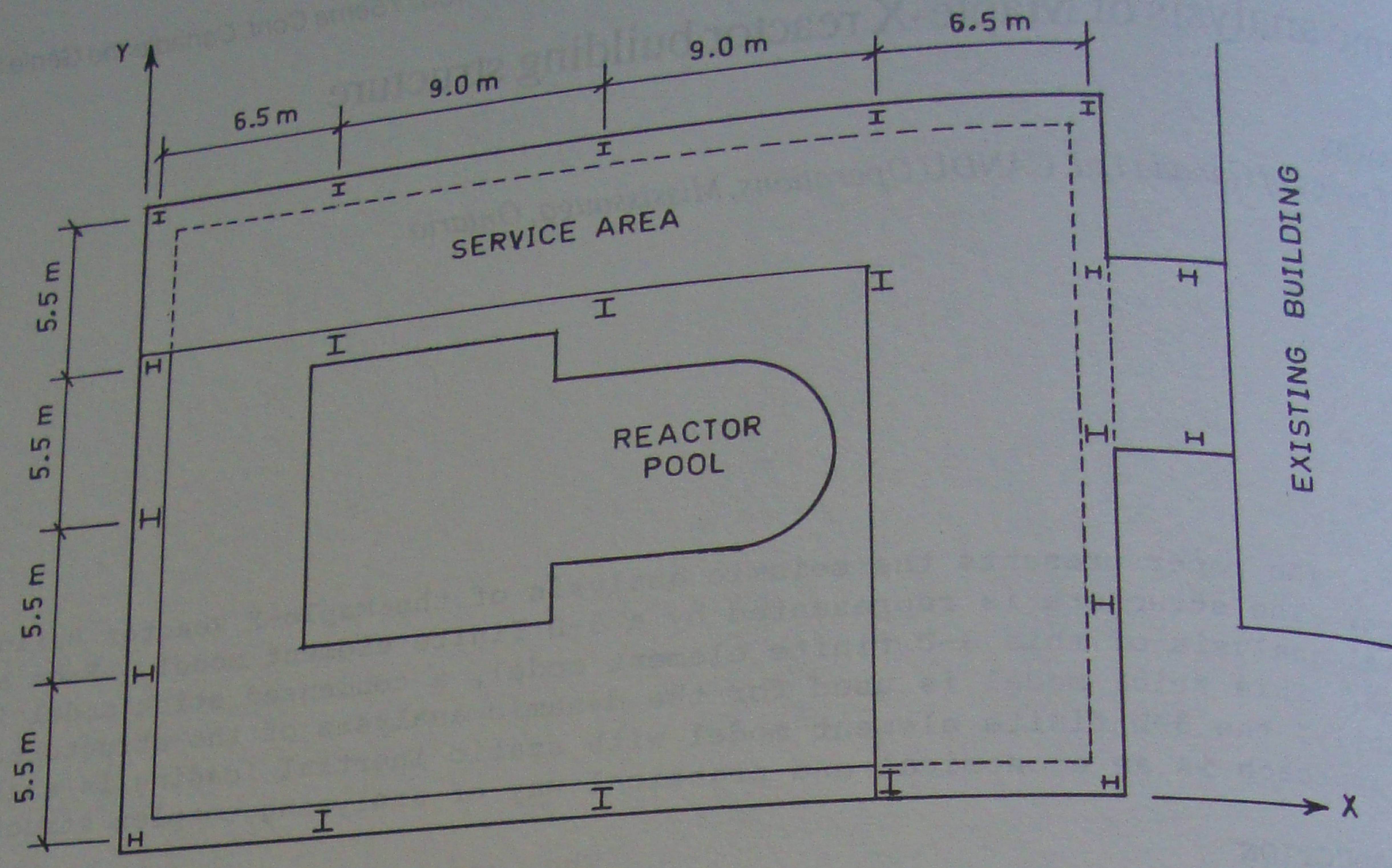

Fig. 1 Maple-X Building Structural Plan

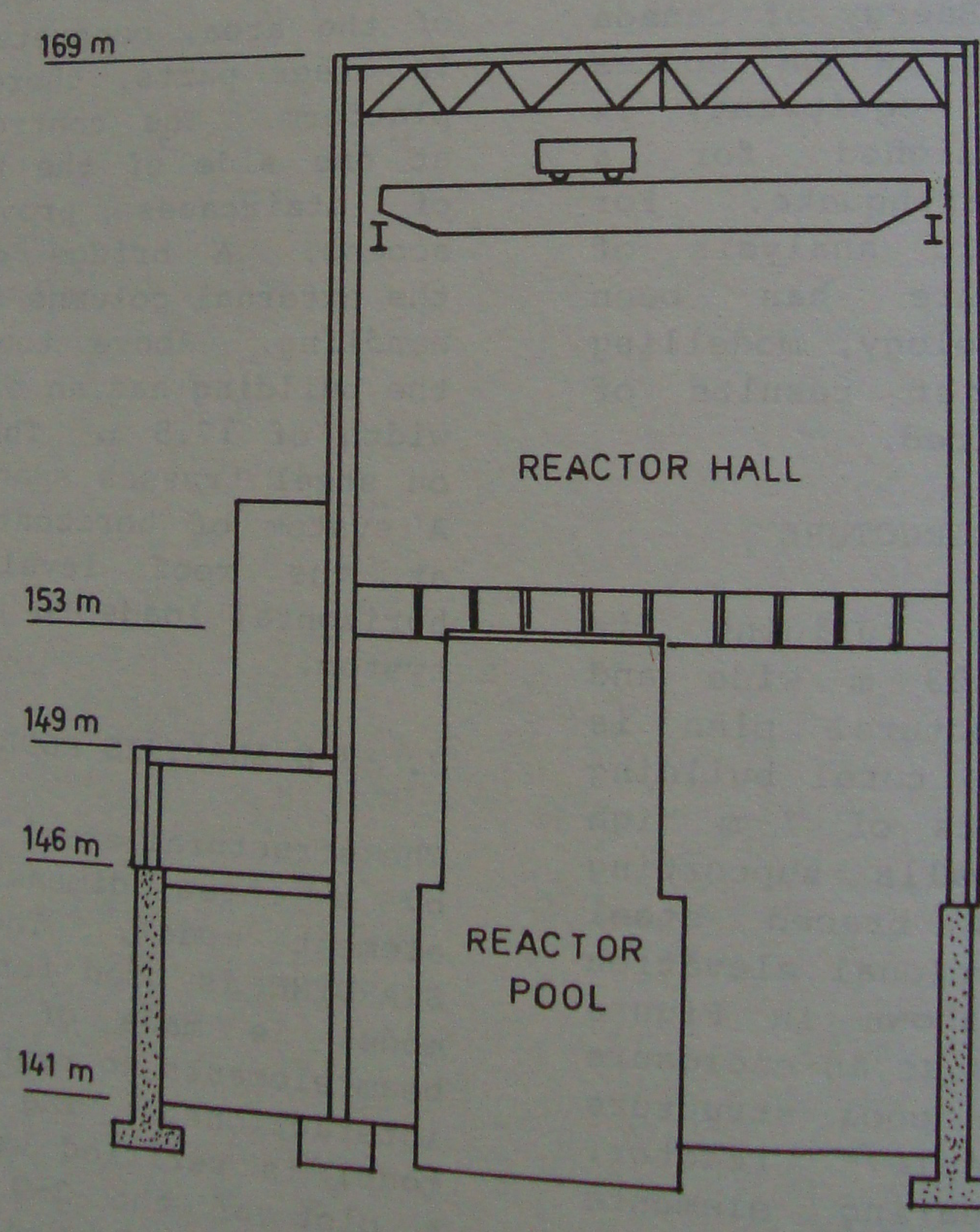

Fig. 2 Maple-X Building Structural Elevation

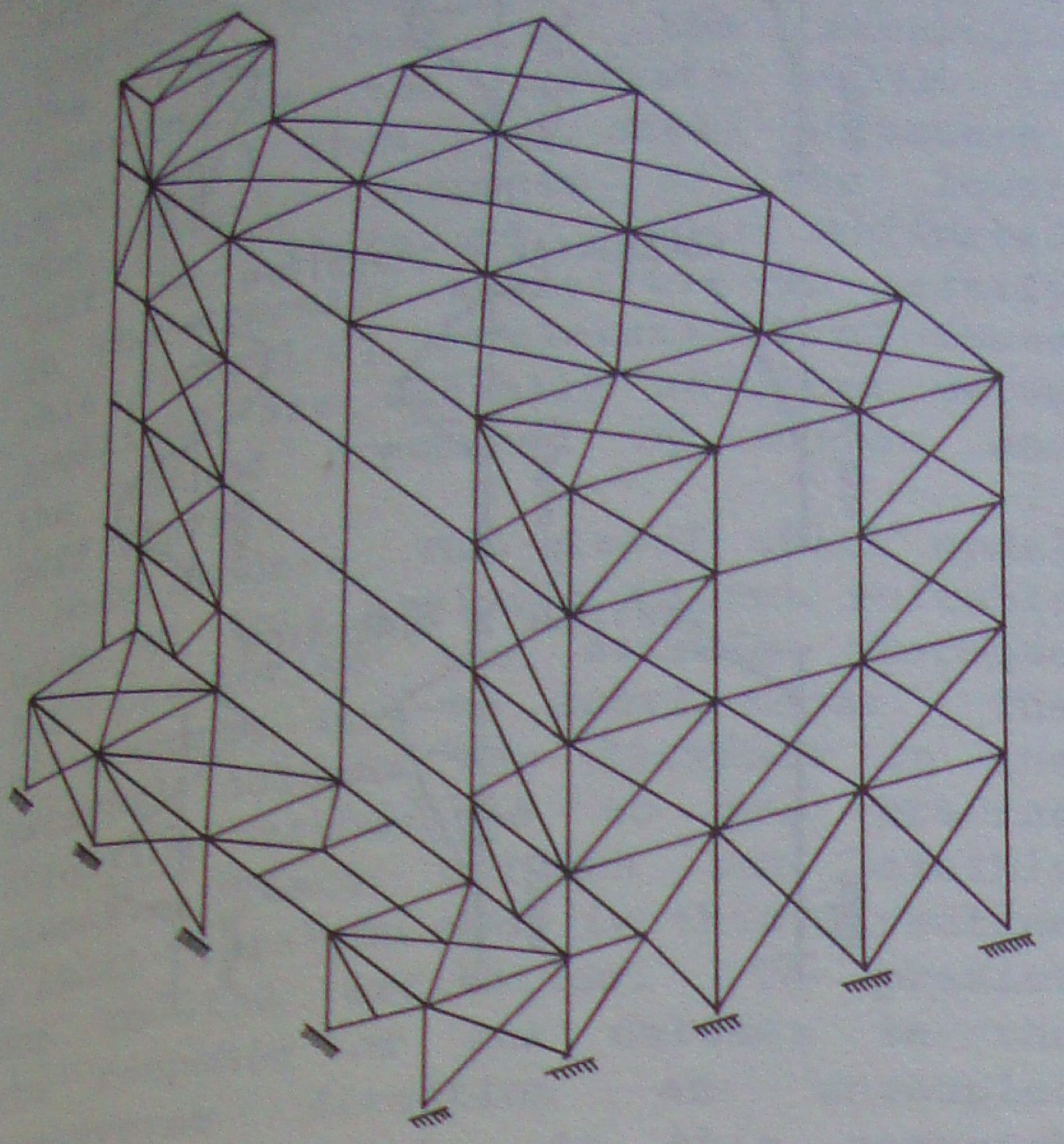

Fig. 3 3-D Analysis Model

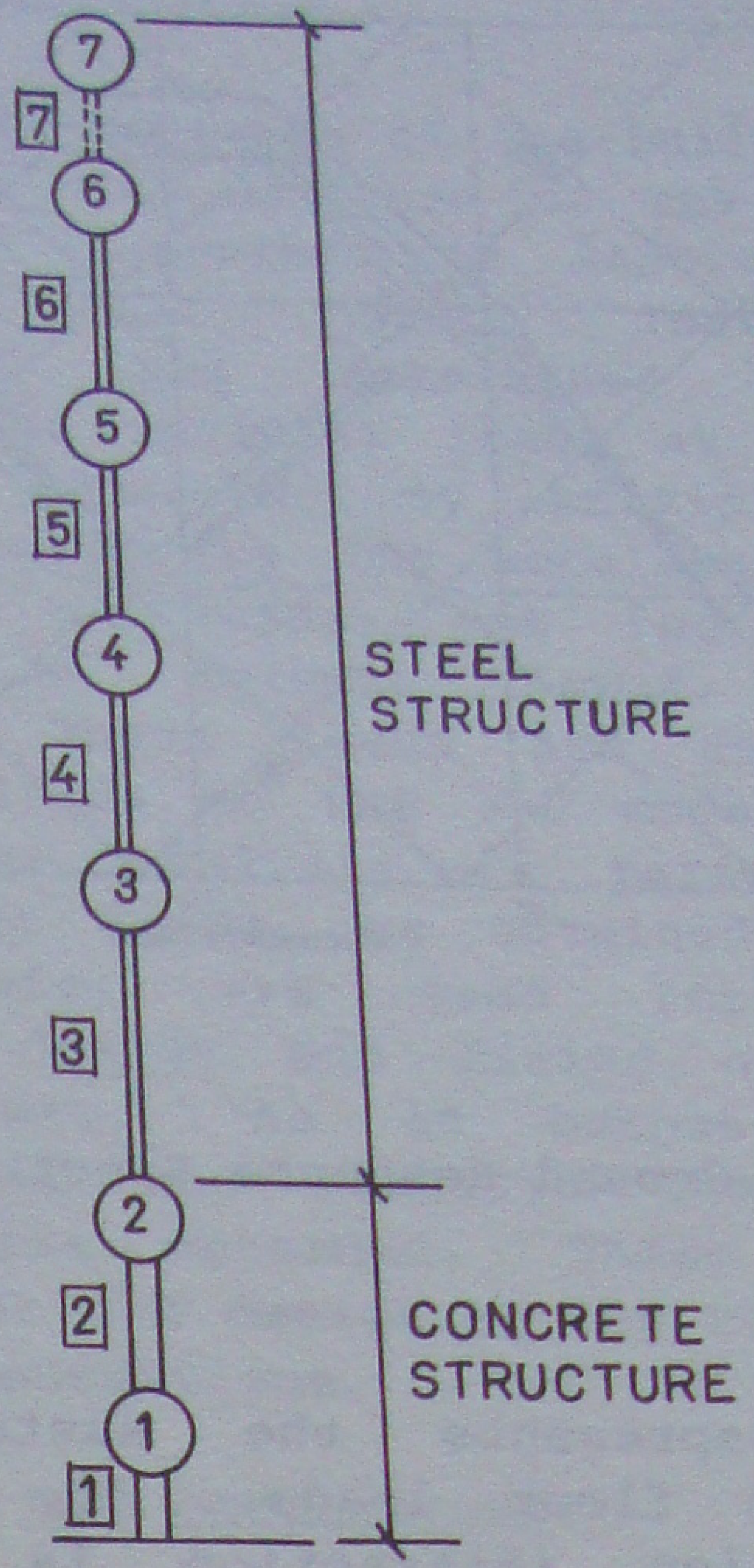

Fig. 4 Dynamic Analysis Stick Model

members with sectional properties having the same deformation characteristics. For other members, the cross sectional properties of the selected sections are used.

A static load analysis of the 3-D model is performed to determine the stiffness characteristic of the structure. For that purpose, a set of fictitious concentrated static loads is applied at the roof level. The deformation of the building due to these loadings is studied. The pattern of displacements is found to be reasonably symmetrical. For an average displacement Δ of the structure due to an applied load P, the spring stiffness is obtained as P/Δ. It is intended to replace the frame structure by a member having an equivalent moment of inertia I, area A and modulus of elasticity E. By equating the lateral stiffness of the flexural member with that of the 3-D frame, the equivalent moment of inertia I of the member is obtained.

This procedure is repeated for both horizontal directions to obtain the values of inertia I in two directions. In the vertical direction, the stiffness is governed by the cross sectional area A. The value of the cross sectional area of the equivalent member is obtained by summing up the area of all the individual columns.

4. DYNAMIC ANALYSIS

The seismic responses of the building structure is determined from a dynamic analysis using the well-known response spectrum method. The theoretical formulation of the response spectrum method can be obtained in Biggs (1964). A simplified stick model, as shown in Figure 4, is used for the dynamic analysis. The stick model, for motions in the horizontal direction, has six masses connected by beam elements. The lower part of the model represents the concrete structure. The sectional properties of the element are calculated on the basis of the geometry of the walls. For the upper part of the structure representing the steel frame the equivalent sectional properties, as explained in Section 3, are used. For motions in the vertical direction an additional mass at node 7 is used. This mass, with the connecting element, represents the effects of the roof trusses. The masses lumped at each node are calculated by adding the dead loads of all components and a fraction of the specified live loading. This fraction is taken to be 25% to 50%

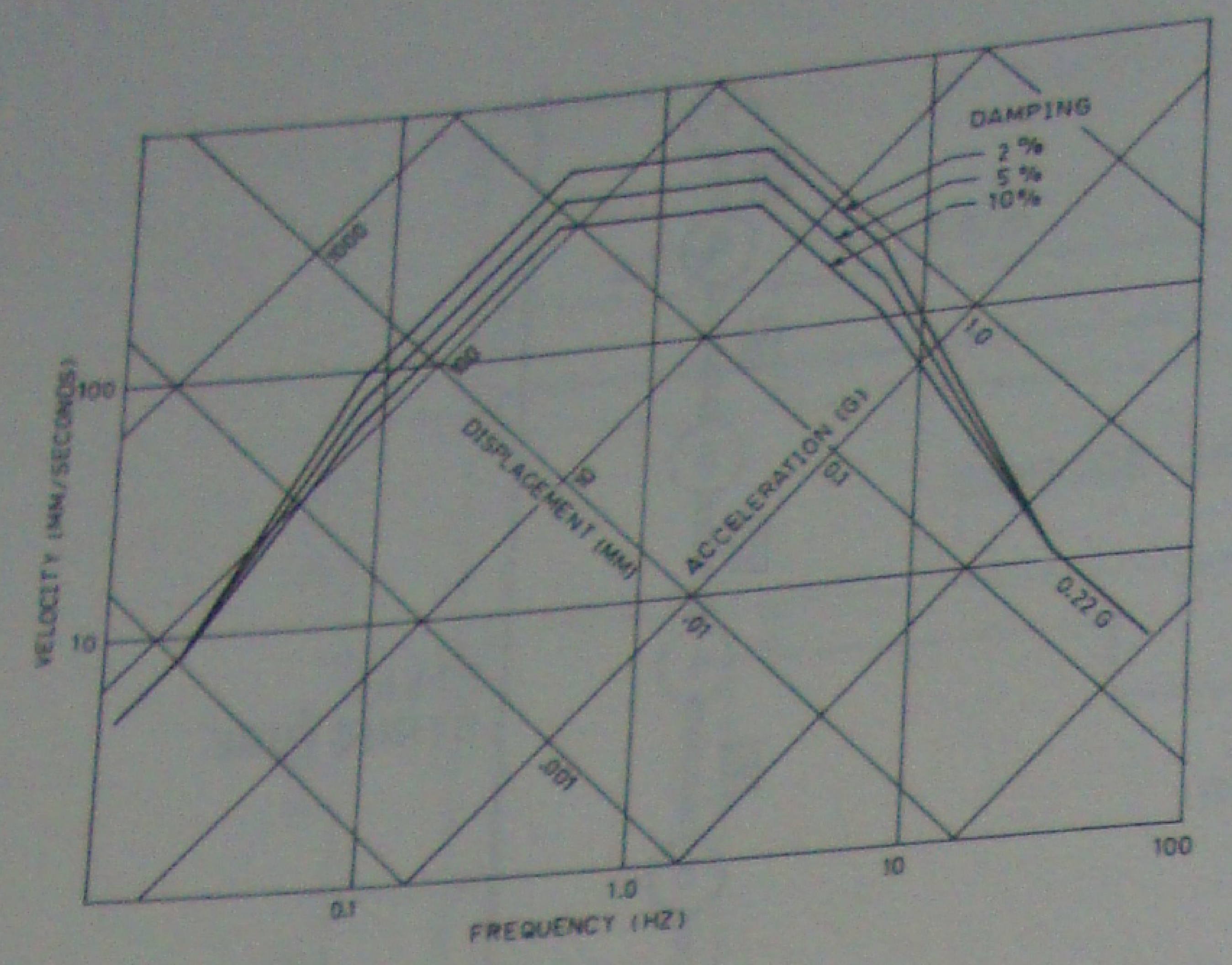

Fig. 5 Ground Response Spectra

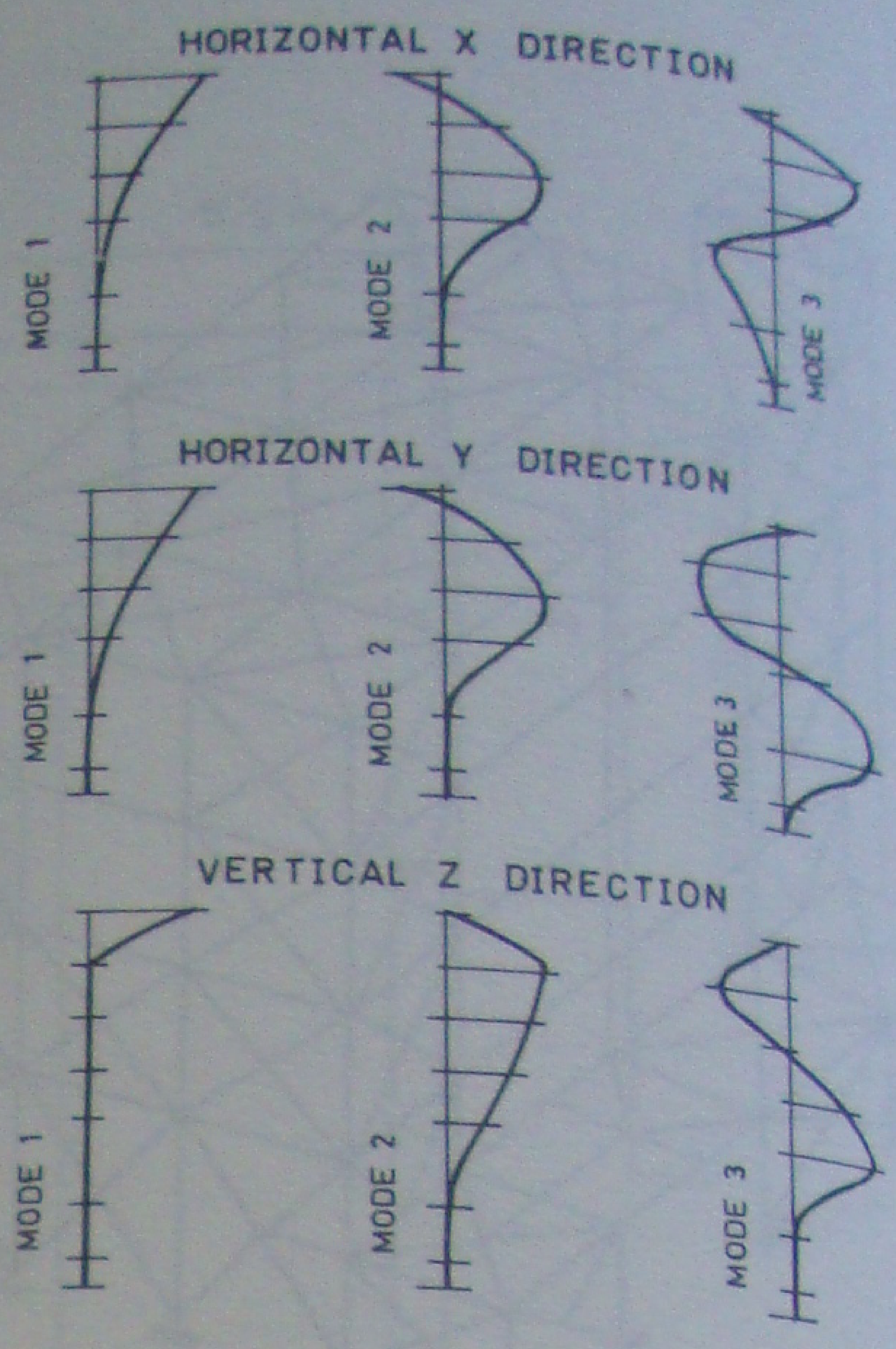

Fig. 6 Mode Shape of Structure

and represents the sustained part of the floor loads. The effect of foundation interaction is found to be small. Consequently the base of the model is assumed fixed for the analysis.

The ground response spectra corresponding to an acceleration of 0.22 g are used for the analysis. These spectra are shown in Figure 5. They represent the effects of a potentially severe design basis earthquake as used for the design of nuclear power plants. The damping values used in the analysis are based on the recommendations in CAN3-289.3 (1981). Accordingly, for the bolted steel structure and the reinforced concrete, a damping value of 5% of critical has been used.

A frequency analysis of the structure is performed using routines of the STARDYNE computer program. Since the stick model is uncoupled, three separate computer runs, one for each direction, are necessary. The frequencies of the structure in three orthogonal directions are given in Table 1. The frequency analysis provides the mode shapes and participation factors. Mode shapes for the first three modes are plotted in Figure 6. Subsequently to the frequency analysis, the response spectrum analysis of the dynamic stick model is performed, also using routines of the STARDYNE program. The response spectra, as given in Figure 5, is used for input in the horizontal direction. In the vertical direction, the input spectra is scaled by a factor of 0.667 according to CAN3-289.3 (1981).

Table 1: Frequencies of Maple X Reactor Building

Mode Number	Frequency (Hz) Horiz. X	Horiz. Y	Vert. Z
1	1.7	2.2	3.2
2	11.8	14.1	12.0
3	33.0	32.6	31.2

5. SPECIAL CONSIDERATIONS

The dynamic analysis produces accelerations and displacements at the nodal points of the structure. Additionally, the storey shears and bending moments at various levels are obtained. A close review of the results is undertaken to determine their appropriateness. As a result, the following considerations are found to be needed:

Rigid Body Modes: The accelerations at nodes close to the base, as obtained from the response spectrum analysis, are found to be lower than the ground acceleration. For node numbers 1 and 2, the accelerations are found to be lower than 0.22 g. The base shear and the bending moment for element numbers 1 and 2 are also lower than the real value. This is due to the effect of truncation of high frequency rigid-body modes during modal analysis. The lower part of the structure representing the concrete walls is more rigid than the steel structure. The seismic response of the lower part is, therefore, under estimated in the computer analysis. To rectify this situation, accelerations of these locations are manually adjusted using the method presented by Biswas and Duff (1978).

Local Modes: The global stick model used for this analysis is not suitable for predicting the seismic response of elements due to local modes. The external columns are flexible in the direction transverse to the bracing planes. These columns can exhibit a local vibration mode in this direction due to the excitation. To predict the response of the columns in the transverse direction an uncoupled approach is used. In this approach the seismic response of the attachment point is established from a global model. The local response is then obtained by applying an amplification factor to the response of the attachment point. The amplification factor depends on the closeness of the natural frequency of the local element and the global structure, as well as the damping characteristics. Amplification factors as used for seismic response of equipment in nuclear power plants, as presented by Duff (1975), are used for that purpose. Using such an approach a local acceleration value of 2 g is obtained. This acceleration is used in the transverse direction for member design.

The adjusted response accelerations at different points of the structure are given in Table 2.

Table 2. Accelerations Due to a Design Earthquake

Node Number	Acceleration (g)		
	Horiz. X	Horiz. Y	Vert. Z
7	----	----	0.49
6	0.58	0.70	0.42
5	0.52	0.55	0.36
4	0.48	0.50	0.28
3	0.37	0.34	0.20
2	0.22	0.22	0.17
1	0.22	0.22	0.15

6. STRUCTURAL ANALYSIS

The structural analysis of the building is performed with the use of the 3-D static model described in Section 3. For each node point, inertial accelerations are determined from Table 2. The inertial loads at each joint are generated by multiplying the nodal weight by the acceleration. Three sets of loads, one for each direction of seismic input, are generated. These loads are applied as static loads to the 3-D model and a structural analysis is performed. These member loads, as obtained from the analysis, are used for the structural design and sizing of the steel members. As an output from the analysis the reaction loads at the base are obtained. These loads are used for the design of the concrete walls and foundations.

7. SUMMARY AND CONCLUSIONS

A seismic analysis of the Maple-X reactor building structure has been presented. The analysis is done in two stages to avoid the use of large dynamic models. Such models are very expensive to run. The use of a condensed stick model for the dynamic analysis is very cost effective. The local responses of members are generated using an uncoupled approach. Subsequently, using the 3-D model, member forces are obtained which can be used for the structural design. Such a two-stage analysis can be an effective tool for the design of complex structures.

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