Dynamic Behavior Structural Response and Capacity Evaluation of the Standardized VVER-1000 Nuclear Power Plants Subjected to Severe Loading Conditions

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Summary

In order to verify the structural capacity of standardized VVER-1000 MW nuclear power plants, comprehensive static and dynamic analyses were performed in cooperation between Siemens and Atomenergoprojekt.

The main goal of these investigations was to perform of a number of seismic analyses of standardized VVER-1000 reactor buildings on the basis of 13 given seismological inputs, taking into account the local soil conditions at 17 different sites defined by in-situ investigations.

The analyses were based on appropriate mathematical models (equivalent beam models as well as detailed spatial surface element models) of the coupled vibrating structures (base structure, outer structure, containment, inner structure) and of the layered soil.

The analyses were mainly performed using the indirect method (substructure method). Based on the results of the seismic analysis as well as the results of static analysis (pressure and temperature due to LOCA, dead weight, prestressing) an assessment was made of the seismic safety of the containment and the reactor building.

Using a complex 3D model of the structure and the soil, the influence of the flexibility of the basement structure on the structural response was also studied.

The structural analyses of the VVER-1000 reactor building led to the conclusion that its design accounts well for the main factors governing the dynamic behavior of the building. The assessment of the forces acting in the structures shows that the bearing capacity of the analyzed building structure corresponds to an earthquake intensity of about 0.2 g to 0.25 g.

1 Introduction

Based on state-of-the art techniques, earthquake analyses and dimensioning of structures of a reactor building are normally performed in several subsequent steps.

In the first step it has to be shown that all designed and pre-dimensioned structures are generally able to support safely the loads resulting from the given earthquake, and that the stability of the building is ensured.
For this there are mostly used adequate simplified mathematical models and calculation procedures.
The structural dynamic analysis of the second step is focused on a detailed analysis of the dynamic behavior of the coupled system soil-structure and on the computation of load functions (time histories, response spectra) on all places where components and systems are installed.

In the case of recalculation of a building (as it was the case in this study) with existing dimensions, usually the inverse sequence is followed. This means that in a first step the expected structural response is analyzed by means of detailed analytic models and site specific input data, as well as questions related to stability and functionality of components. In the second step, the forces and stresses acting in the building structures are checked. In this case the information for dimensioning of the structures and for evaluation of the stability of the building can be taken from the analysis with the detailed mathematical models actually used.

The main goal of the study was the preparation of a number of analyses of the dynamic behavior of a standardized VVER-1000 reactor buildings on the basis of 12 given (plus 1) seismological input (additionally developed) taking into account the local conditions at 17 sites defined by soil investigations.

The analyses are based on appropriate mathematical models (equivalent beam model as well as detailed spatial model) of the coupled vibrating structures (base structure, outer structure, containment, inner structure) and of the layered soil. The soil conditions were taken into account by means of soil impedances (equivalent stiffness and damping).

The analyses were mainly performed using the indirect method (substructure method). Based on the results of the analysis an assessment of the earthquake safety of the building and the containment was performed in the following steps.

Prior to performance of the dynamic analysis, the seismological input data based on information provided by special institutes were evaluated. Furthermore, the soil dynamic data of 17 given sites were evaluated and concentrated in characteristic soil types. Five (5) different soil types were defined eventually.

Within the study, the following results finally were obtained:

- Structural responses (site-specific design spectra) for all 13 seismological inputs and 5(soft, soft/layered, medium, medium/layered, hard) characteristic soil types.

- Superimposed and smoothed response spectra for each of the above-mentioned groups of soil and seismological sets of data.

- Superimposed and smoothed design spectra over all soil types and seismological inputs.

- Assessment of the safety margins of the structural design as well as of the forces acting in the VVER-1000 reactor building structures.

2 Structural Design of the VVER 1000 Reactor Building

The VVER-1000 reactor building consists mainly of a concrete containment with inner structures and of an outer structure, both supported by a square base structure.

The dimensions of the base structure are 67.8 m x 67.8 m, the total height from top of the foundation slab to top of the base structure is ca. 75 m. The base structure is well stiffened by means of a number of walls and ceilings (see Figs. 1 and 2).

The total height of the outer structure is about 45.6 m, the highest point of the containment is at ca. 65.7 m above plant grade.

The foundation slab also measures 67.8 m x 67.8 m and is 2.40 m thick. The building is directly founded on the naturally layered soil.

The reactor containment consists of prestressed concrete and is lined with 8-mm-thick steel plates. The walls of the base structure are made in normal concrete. Some of them strengthened by 8-cm-thick prefabricated reinforced panels.

Measures for soil conditioning below the foundation slab have not been taken into account. The base structure is founded about 7.0 m below plant grade. The lateral space between base structure and soil is refilled and well compacted.

3 Input Data

3.1 Seismological Data

The earthquake loads were defined by 12 sets of recorded time histories and the corresponding free-field spectra.

These are:

1. 10 seismological time histories given by the Academy of Science of CIS (TH1 to TH30). In Figs. 3 and 4 one example of the recorded input data is shown.
2. 1 set of time histories given by Institute Atomenergoprojekt (TH41 to TH43, Figs. 5 and 6).
3. 1 site-specific set of time histories for the Crimean site (THSS1 to THSS3, Figs. 7 and 8).

Based on information and on earthquake time histories provided (especially the 10 time histories TH1 to TH30), an additional evaluation was performed within this study. The above-mentioned response spectra (1) were first enveloped (Fig. 9). Taking into account the natural range of uncertainties of the seismological records, smoothed free-field spectra with 84% fractile were derived (Fig. 10). These spectra form the basis for generating artificial time histories [1] compatible with the above-mentioned spectra (Fig. 11).

3.2 Soil-Dynamic Data

The information on soil layering and soil dynamic data is based on soil profiles and tables containing soil-mechanic and partly soil-dynamic data for 17 nuclear power plant sites.

The shear moduli at smallest strains (G_O) were calculated on the basis of cross-hole test data, if available. For the other sites the shear moduli were estimated on the basis of soil mechanic data with reference to scientific publications as well as to experience gained from nuclear power plant sites treated in Germany and abroad (Table 1).

For the definition of soil types covering all dynamic soil conditions, the 17 sites were combined in 3 (5) groups named "soft" soil, "medium" soil, "hard" soil (Fig. 12).

The "soft" soil profile includes the softest soils found at all 17 sites, thus leading to very low equivalent spring stiffnesses, and a layered profile (soft soil over bedrock), thus leading to a very low radiation damping ("soft/layered").

The "hard" soil profile describes the hardest soil found at all 17 sites showing competent rock at the foundation level.

The "medium" soil profile was chosen in order to result in a horizontal equivalent spring stiffness situated in the middle between that of the soft and the hard soil. To account for the lower damping of a layered profile, it is accompanied by the "medium/layered" soil type.

Using the shear moduli versus depth as per soil profile in Fig. 12, the earthquake-adapted shear moduli and damping were computed (Fig. 13 and 14).

Finally, equivalent frequency-independent spring and damping values (Tab. 2 to 4) representing the foundation stiffness at dominant frequencies of the soil-structure system were obtained using the program SASSI /2/.

4 Mathematical Model

The type of mathematical model depends not only on the final objective and the type of information needed but also on the design and mass distribution of the structure and on the characteristics of load functions. The mathematical model and the degree of discretization were chosen that way, that the mode shapes of the structure in the relevant frequency range could be computed reliably. Furthermore, the number of nodes, where information is needed, influenced the model.

In view of the geometric configuration, stiffening and mass distribution of the reactor building in question, as well as the frequency content of the dynamic excitation, an equivalent beam model (Fig. 15) was used. In order to study more in detail the flexibility of the some construction elements and stage of stresses in characteristic regions a 3-dimensional finite element model was developed (Fig. 16).

The beam model includes the outer structure, the containment, the inner structure and the base structure as an entirely connected total system. The derivation of equivalent stiffnesses and masses was performed by means of computer codes [5] based on engineering inputs and assumptions to be defined for each floor and region.

The spatial plate model (Fig. 16) represents more detailed geometric conditions and local characteristics (Fig. 17). Especially the stiffnesses of walls and ceilings are modeled more adequately by equivalent finite elements [6]. The masses, are also accounted for more realistically by a large number of nodes. Because of the rather rigid design concept of the supportive concrete structure, a mathematical representation by means of an equivalent beam model was used for the derivation of the dynamic responses.

5 Methods of Investigation

The seismological and dynamic soil-conditions at the site are substantial influence on the dynamic behavior and the structural response of stiff buildings and on the damping behavior of the coupled soil-structure system.

In some cases, especially, when the free-field spectra have a steep slope in the significant frequency range (in this case with several seismological inputs), even small variations of soil parameters can result in substantial differences in the structural response.

On the other hand it is known, that the mode shape of the building can influence the seismological free-field response. Here, an energy exchange between soil and structure takes place.

In practice, mainly indirect procedures (substructure methods) are used to investigate the dynamic behavior of structure and soil in the time domain separately in several steps (Fig. 18). The main step of this procedure, i.e. derivation of equivalent stiffnesses and coupling matrices, is based on the assumption of a rigid foundation. To demonstrate that this assumption is appropriate for this type of building design, additional analysis was performed using specific site conditions (Crimean site).

Using the 3D-structural model of the building (Fig. 19) coupled to the soil model (Fig. 20) the influence of the flexibility of the base structure on the structural response was investigated by a frequency-domain analysis [7].

The analysis procedure using a beam model, or a spatial 3D-plate model is shown in Fig. 21. Fig. 22 shows the analysis procedure using the coupled model.

6 Parameter Variation

To demonstrate the influence of the different soil types and 13 seismological excitations analyses were performed for the input combinations shown in Table 5.

The variation of the soil properties as a function of depth were demonstrated using the soft soil example (Fig. 13 and 14).

In the case of soft and medium soil conditions, the free-field motions are modified when deconvoluted (Fig. 18) to the foundation level $(\ddot{X}_E \neq \ddot{X}_F)$. In order to include a conservatism and due to the relatively shallow embedment of the VVER-1000 reactor building at the foundation level, the free-field excitation $(\ddot{X}_F)$ were used.

The modal damping of the coupled system is also of high relevance. However, it was calculated indirectly during the analysis, and in line with the relevant codes and standards (KTA, IAEA, USNRC) which limit the damping and as follows:

- horizontal mode	15 %
- vertical mode	30 %

When using the direct method such a limitation is not relevant, because energy dissipation is explicitly taken into account, on the basis of the material data of the structure and the subsoil.

7 Characteristic Results

7.1 Structural Response

The analyses of structural response for the characteristic regions of the building (location of components) were performed using beam models for 5 soil types (soft, soft/layered, medium, medium/layered, hard) and 13 seismological input definitions.

In order to stress the influence of the different seismological inputs the resulting spectra for each soil type were compared for certain nodes. As example, the results obtained for medium soil conditions are shown in Figs. 23 to. 28. Additionally, Figs. 29 to 34 show spectra enveloping all seismic input definitions for the different soil types in order to demonstrate the influence of the soil stiffness.

To cover the results, enveloped smoothed design spectra for each soil type and for all excitations were obtained. Due to the similarity of the results, the structural responses of soft and soft/layered as well as medium and medium/layered were combined in one group (soft, medium, respectively).

In order to provide one overall information including all sites and all seismological inputs, the above-mentioned smoothed spectra for soft, medium and hard soil were finally combined in one general set of design response spectra.

For some characteristic regions of the building, the general design response spectra are shown in Figs. 35 to 40. The procedure of superposition of information and the identification of relevant reports is shown in Fig. 41.

Similarly the analyses and evaluations were performed using the 3D model. The influence of the soil-dynamic data and of the seismological input was investigated in the same way.

7.2 Internal Forces

Global forces (normal and shear forces, bending and torsional moments) were analyzed for the building structure under the load case safety earthquake. The maxima for each floor are pointed out, separately for the containment, the outer structure, the inner structure and the base structure. For an assessment of the stability, these forces were superposed with the static forces. For analysis of load components acting in different directions, the maximum earthquake loads were superposed using statistic formula (SRSS-formula).

8 Comparison of Beam Model / 3D-Model

The structural dynamics analyses were performed using 2 different mathematical models taking into account the interaction effects between soil and structure as well as the damping behavior of the coupled vibrating system. At the same time, the structure itself was idealized by means of appropriate and qualified models.

The mathematical models were excited by given or artificial time histories derived from the given free-field spectra. In both types of analysis, the modification of the shear moduli due to the building load and the earthquake deformation were taken into account (Fig. 13).

The general design spectra resulting from the use of a 3D model for comparison with the beam model results are shown for some characteristic regions (Figs. 42 to 47).

When evaluating the response spectra for characteristic regions of the building it can be seen that the increase of the zero period acceleration versus building level is moderate (Fig. 48 and 49). The resonance peaks of all spectra are rather low compared to other reactor structures. This shows that the building is well designed to withstand earthquake loads.
The results of both types of analysis using beam or spatial model are in good agreement. However it can be observed that in some regions of the building the representation by means of an beam model results in remarkable differences.

9 Evaluation of Results

The "General Design Spectra" (Fig. 35 to 40) are general, soil-independent structural response spectra for dimensioning of components and systems, valid for sites with ground accelerations up to 0.25 g. They may be called "Design spectra VVER-1000" for all sites in the former USSR. The derivation of the general response spectra for the VVER-1000 plants is done in compliance with the procedure used for the Siemens-KWU BWR 1300 plants of the Konvoi type. For the Konvoi plants, enveloping spectra for sites with different soil conditions and ground accelerations (up to about 0.3 g) were also developed.

In order to evaluate the results obtained, the general response spectra of the VVER-1000 plants were compared with the enveloping KWU-Konvoi spectra for comparable building regions (Fig. 50 to 53).

Although there are substantial differences in the design and dimensioning of both reactor building types, the derived response spectra are well comparable for both plant types. In the region of the base structure and the containment support, the response spectra are well comparable. Only in the outer region of the PWR 1300, higher vertical accelerations are to be expected than with the VVER-1000 due to larger rocking effects (see Fig. 50 and 52).

Somewhat higher acceleration values in horizontal direction are to be expected from the VVER-1000 in the region where the primary system components (reactor section) are anchored (see Fig. 52). This is due to resonance effects between the base structure and the reactor sections in connection with hard soil conditions. For vertical directions in this region, the VVER-1000 building shows lower values. The horizontal spectra for the crane support level (Fig. 53) are mainly governed by stiffnesses and masses of both cylinder types. Due to the bigger masses in the upper part (prestressed concrete) the acceleration peak at the VVER containment is found in a lower frequency range than with the PWR 1300. Above the frequency range of 5 Hz, the spectral accelerations of the VVER-1000 are lower by a factor of 0.5.

It can be generally stated that the components located in the Russian VVER-1000 and the German PWR 1300 buildings are exposed to similar loads, if soil conditions and seismic excitation are comparable.

10 Conclusions

An analysis of the structure of the VVER-1000 reactor building leads to the statement that its design accounts well for the main factors governing the dynamic behavior of the building. The high stiffness of the structure as well as the low position of the center of gravity are of a very positive effect. The assessment of the forces acting in the structure shows that the bearing capacity of the analyzed building structure corresponds to an earthquake intensity of about 0.2 g to 0.25 g (the higher range is related to soft soil conditions).

Three sets of design spectra were derived for soft, medium and hard soil conditions. They govern the results obtained for seismic input data typical for all regions of the Russia. The design spectra mentioned may be used on sites where the site specific conditions are known. For the general situation when the soil conditions at the site are not specified, the General Design Spectra may be used.

When comparing the dynamic response of the building structures with the design spectra of the standardized SIEMENS/KWU PWR 1300 (KONVOI) reactor building, the conclusion can be drawn that the loading conditions for components and systems in both cases are comparable. Therefore, there are no doubts regarding the seismic stability and appropriate design of components and systems.

Depending on the seismic intensity of the site, it may become necessary to strengthen the building structures by more reinforcement of higher concrete quality. These measures will not change substantially the validity of the design spectra.

The horizontal response obtained by means of 3D model is generally lower (excluding the roof of the condensing tower) due to more adequate representation of the frequencies, mode shapes and modal masses.

The vertical response leads generally to higher values because of realistic representation of the behavior of the floor.

11 References

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(M. Tabatabaie-Raissi, J. Lysmer, University of California, Berkeley)

[3] SHAKE
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[4] STRUDYN
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[5] VVER-1000 - Reactor Building
Mathematical (Beam) Model for Seismic Analysis
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[6] VVER-1000 - Reactor Building
Mathematical (3D) Model for Detailed Seismic Investigations
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[7] Influence of Base Mat Flexibility on Dynamic Response of Embedded Building Structures
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Paper K05/1

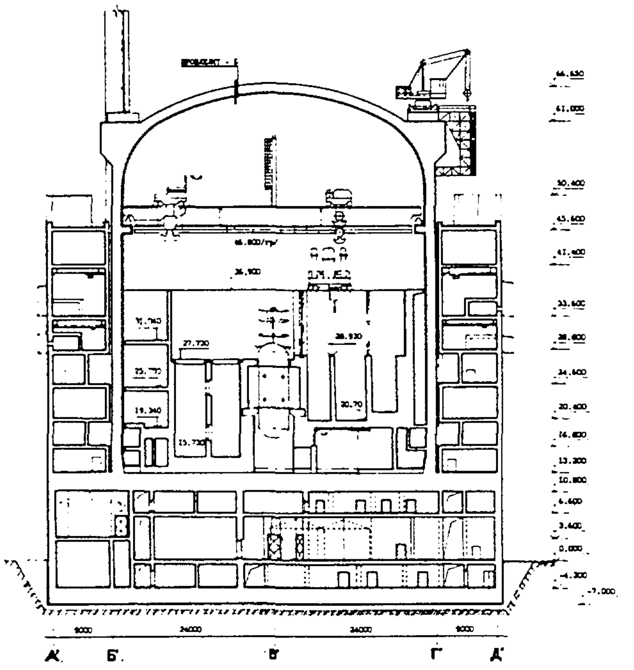


Fig. 1 VVER 1000 USSR
Reactor Building - Cross Section

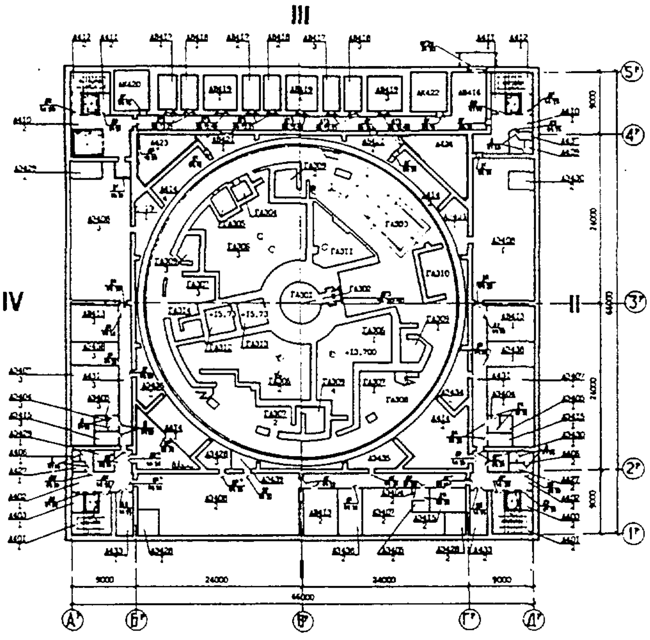
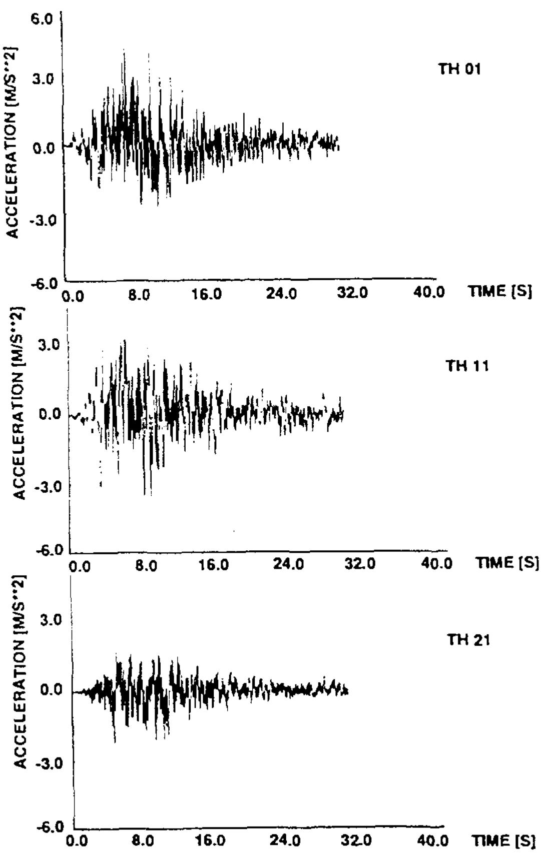


Fig. 2 VVER 1000 USSR
Reactor Building - Plan View



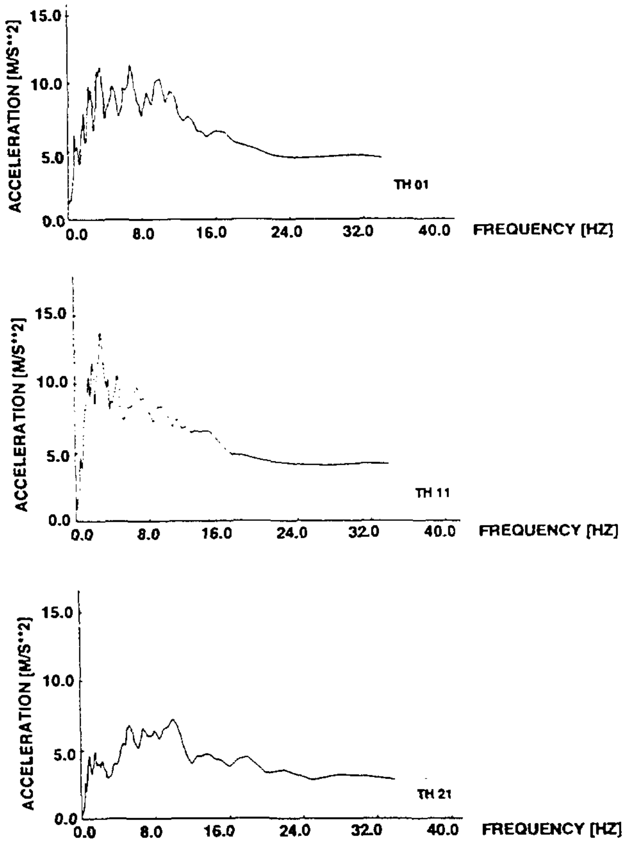


Fig. 3 Input Definition of the USSR Academy of Science Fig. 4 Input Definition of the USSR Academy of Science

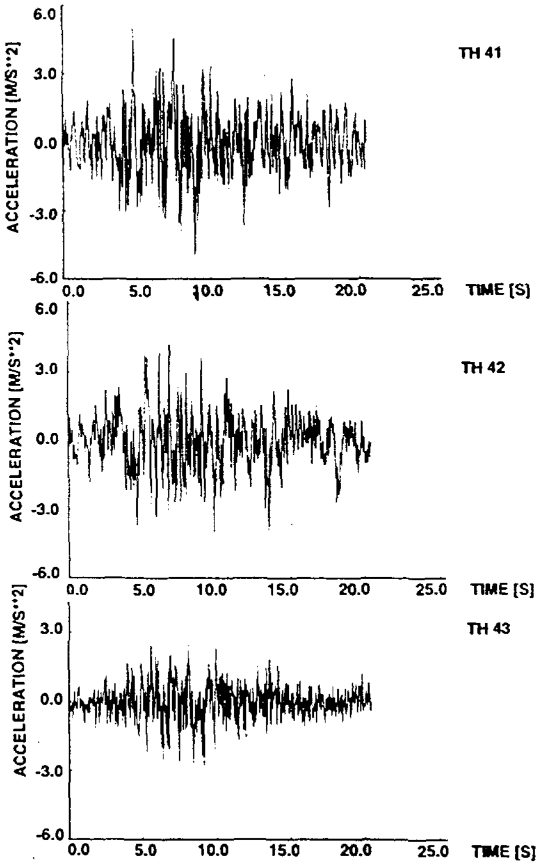


Fig. 5 Input Definition AEP

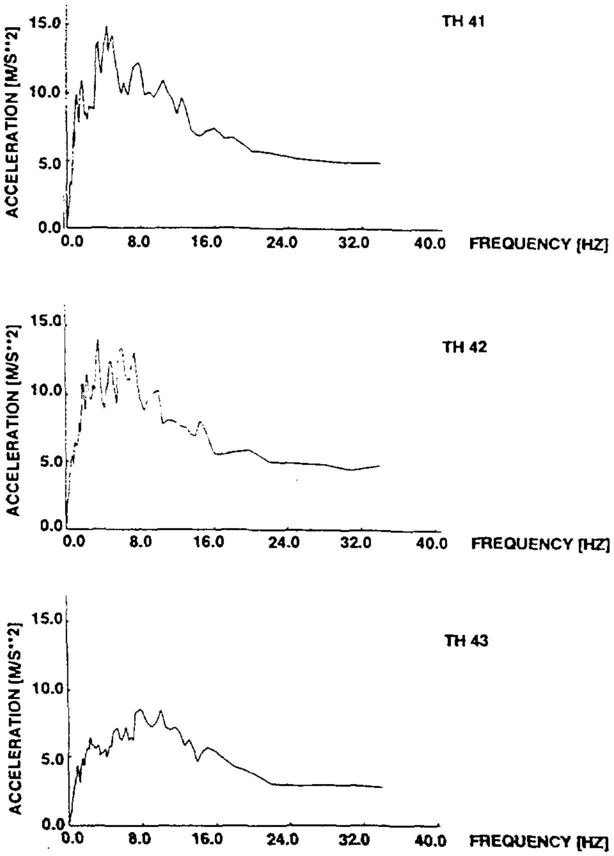


Fig. 6 AEP Input Definition

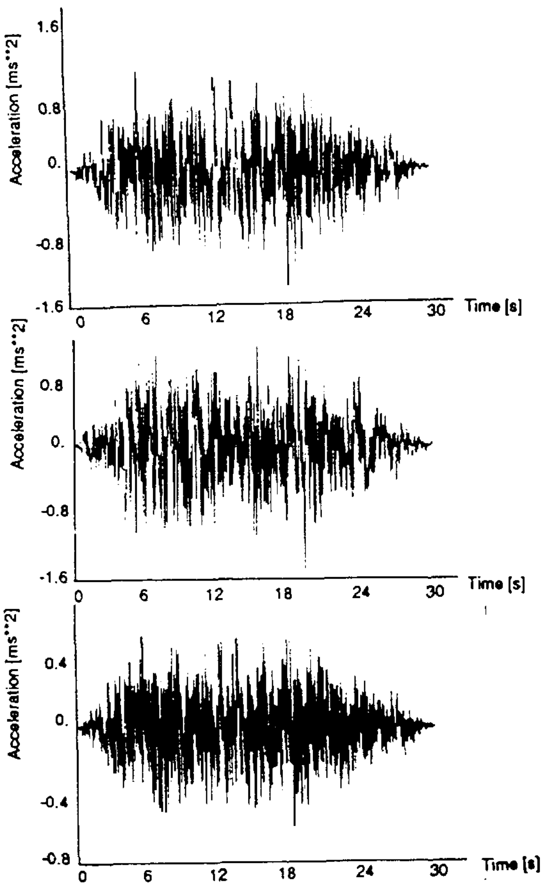


Fig. 7 Seismic Excitation Crimea

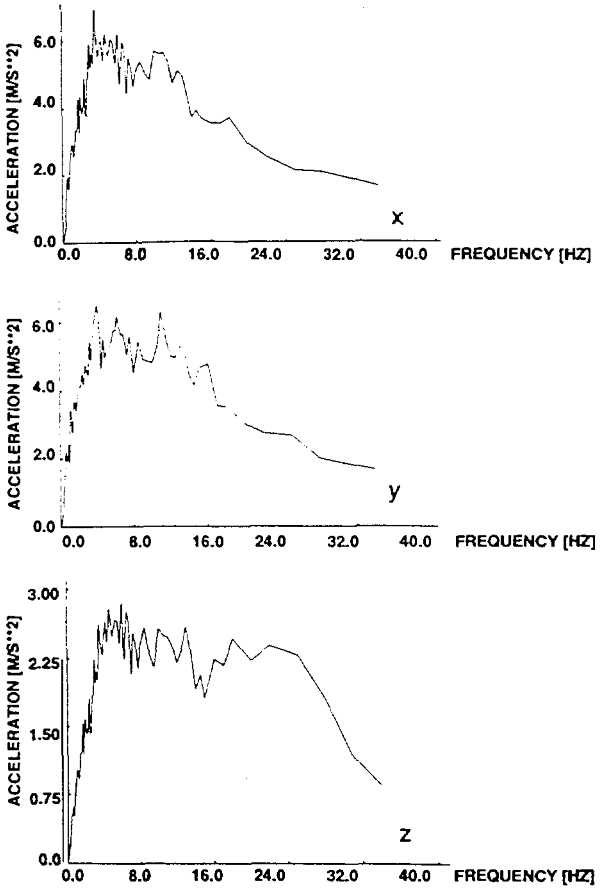


Fig. 8 Site Specific (Crimskaja) Input Definition

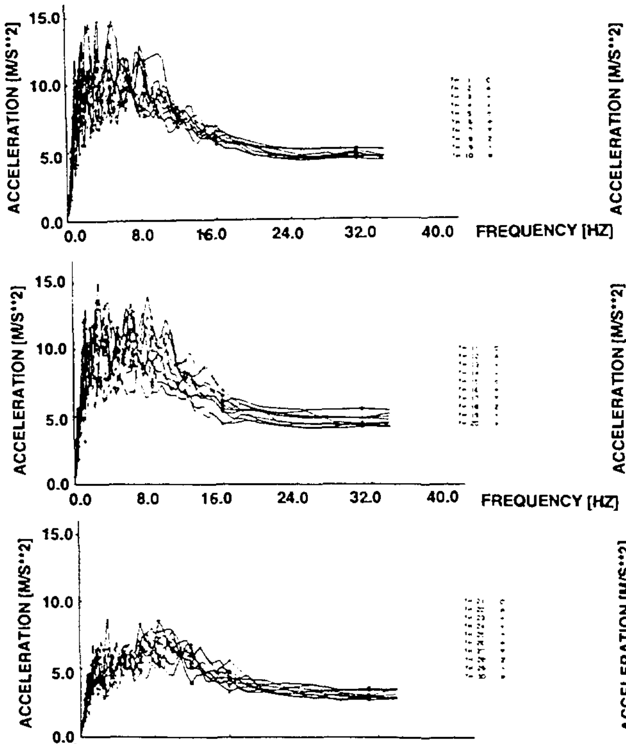


Fig. 9 Input Spectra of the Academy of Science Comparison

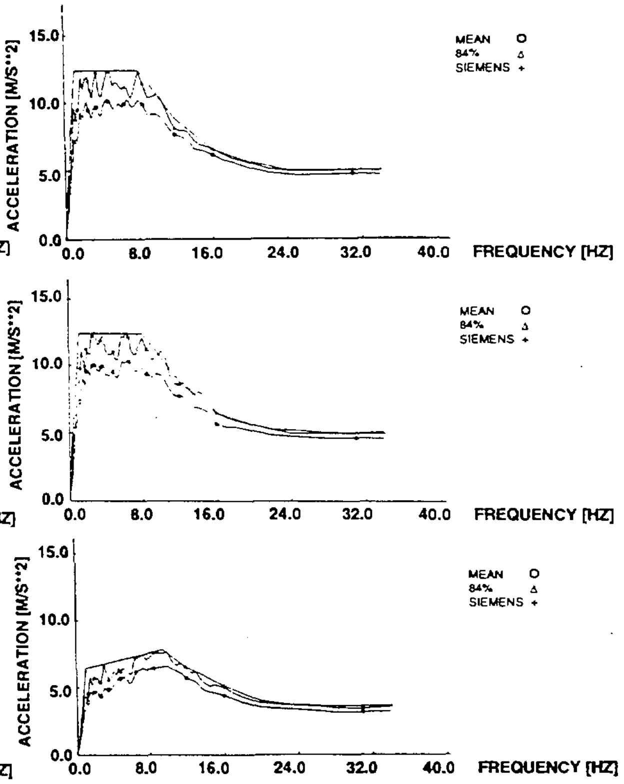


Fig. 10 Enveloped and Smoothed 84% Fractile Free Field Spectra

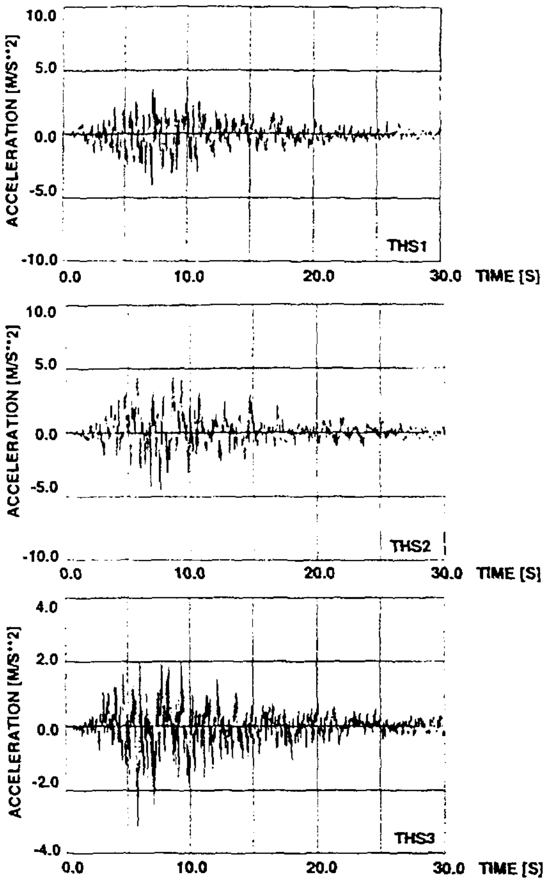
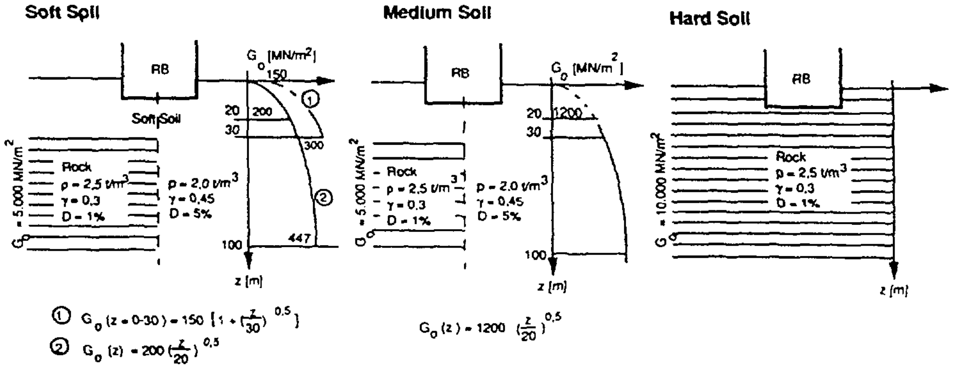


Fig. 11 Artificial Time Histories generated on the Basis of the 84% Fractile Spectra



LEGEND G_0 = shear modulus at smallest strains [$\gamma \leq 10^{-4}$]

ρ = density [t/m³]

ν = Poisson 's ratio [-]

D = hysteretic material damping [% of critical damping]

z = depth [m]

RB = reactor building

Fig. 12 Selection of Soil Types for Earthquake Analyses of VVER 1000 Nuclear Power Plants in USSR

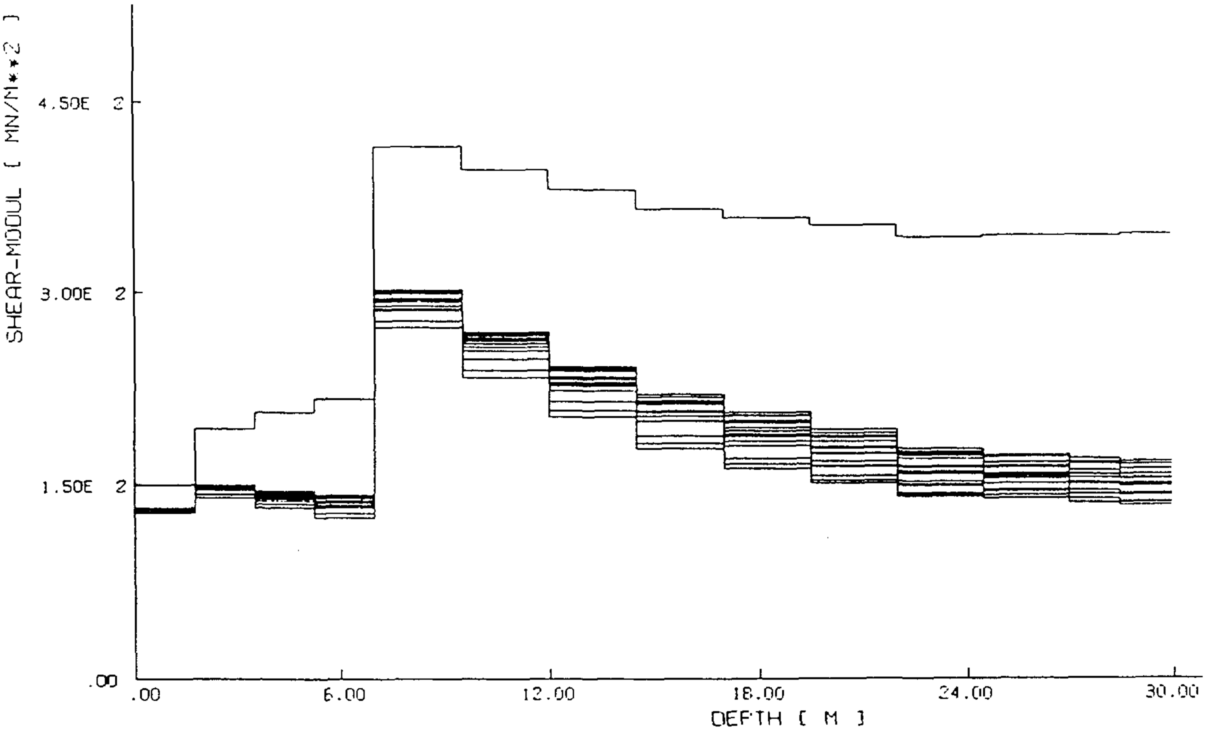


Fig. 13 Earthquake Adapted Shear Moduli Soft/Layered Soil Condition

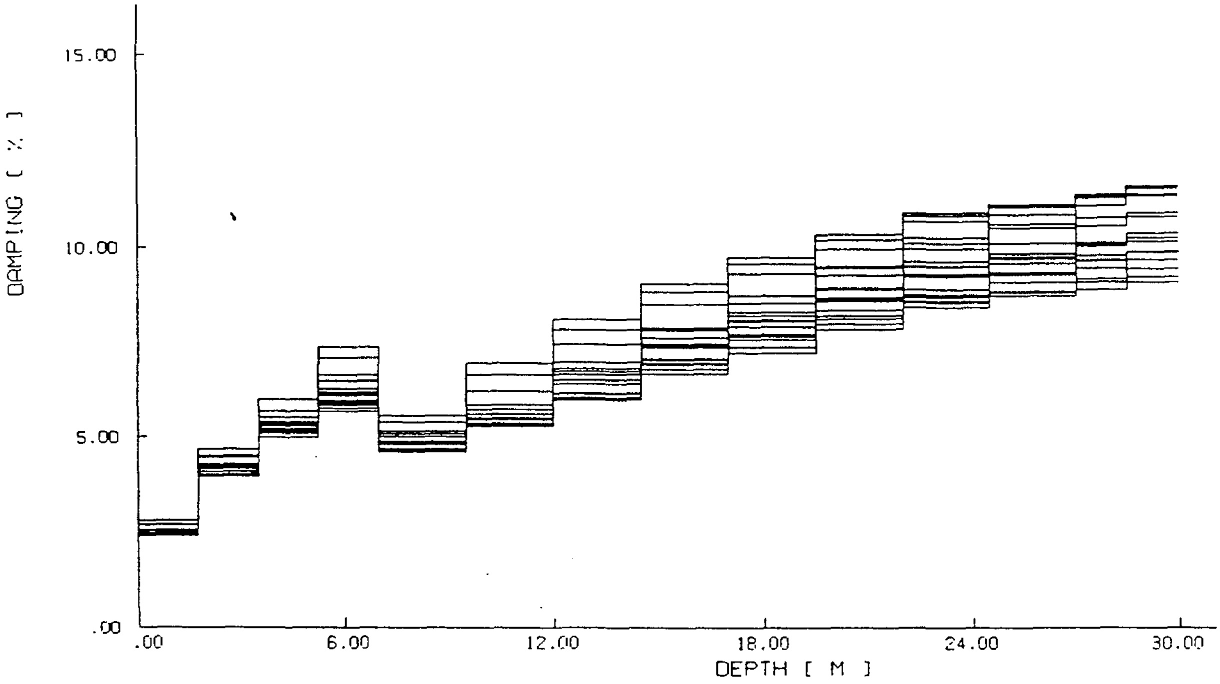


Fig. 14 Earthquake Adapted Material Damping Soft/Layered Soil Condition

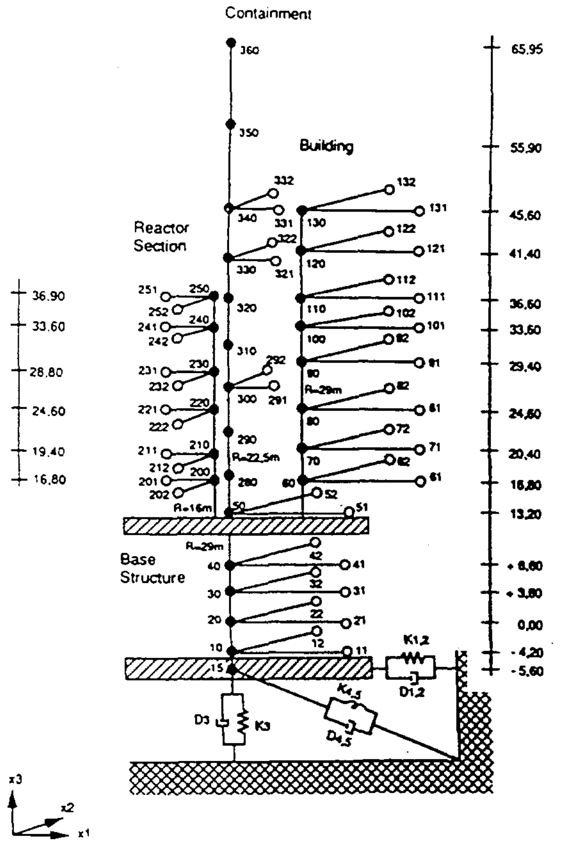


Fig. 15 VVER 1000 USSR
Beam Model of the Reactor Building

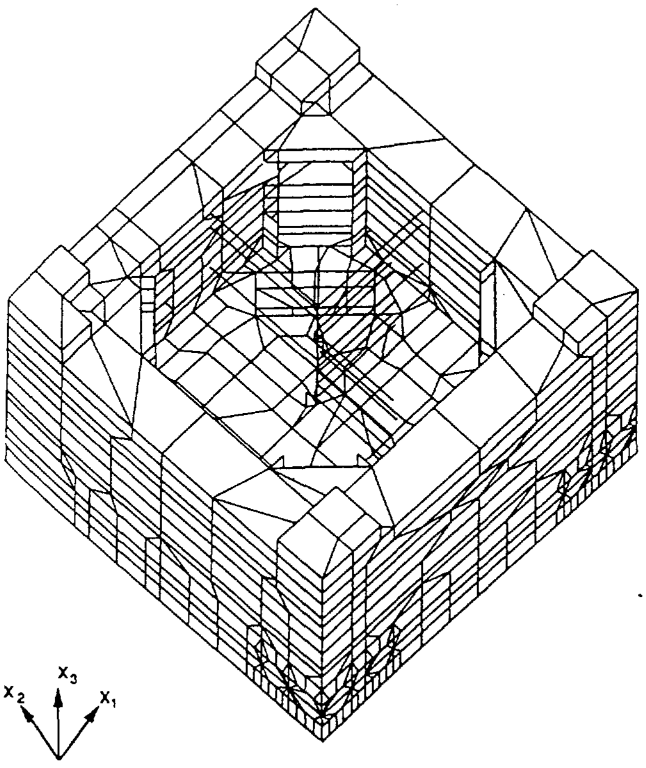


Fig. 16 Spatial Model of the Basement Structure
and Sorounding Building

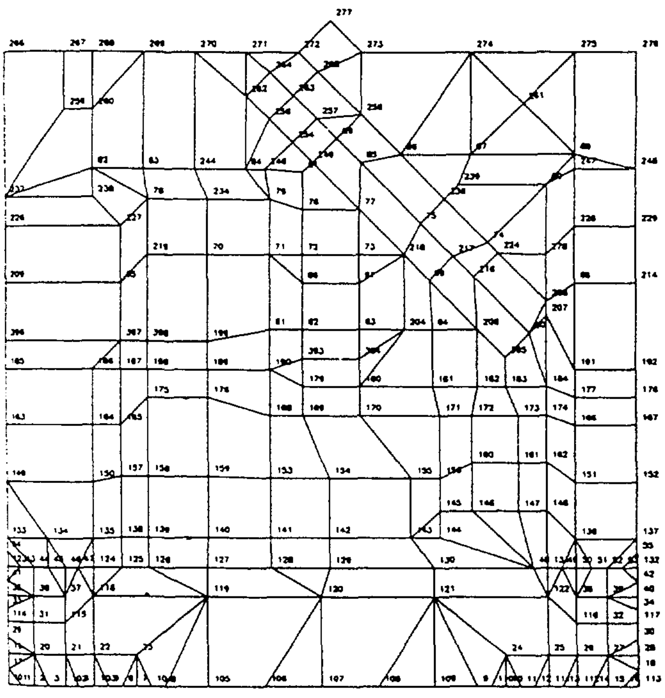


Fig. 17 Ratio of Discretization of the Base Mat

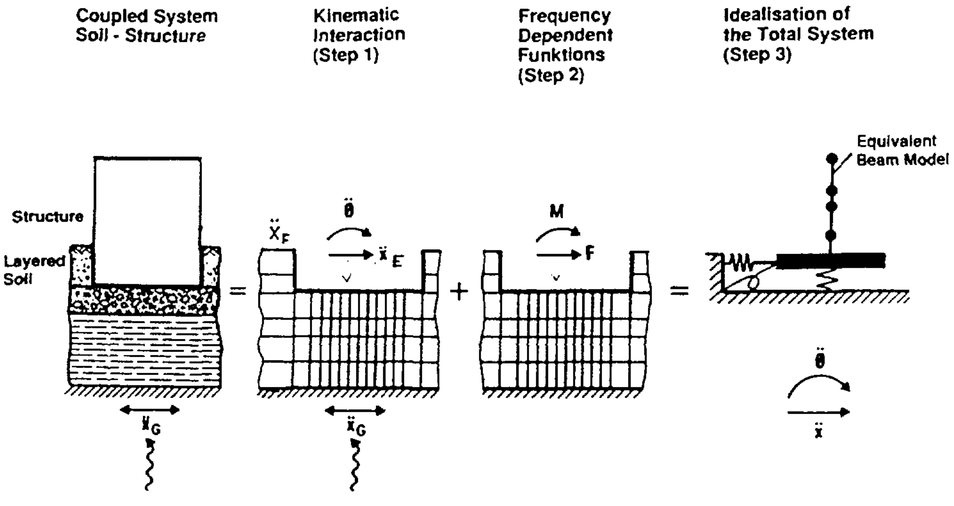


Fig. 18 Indirect Method of Calculation of the Soil-Structure Interaction Effects (Decoupled Models)

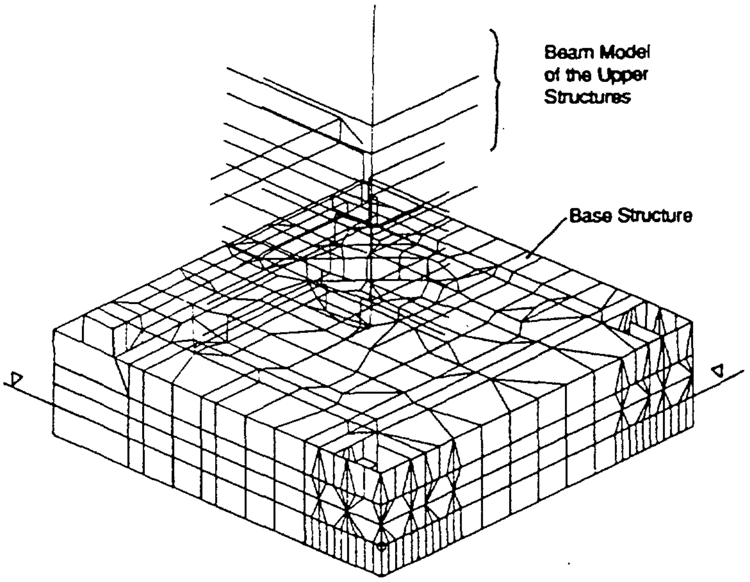


Fig. 19 Combined (Spatial/Beam) Model of the Reactor Building

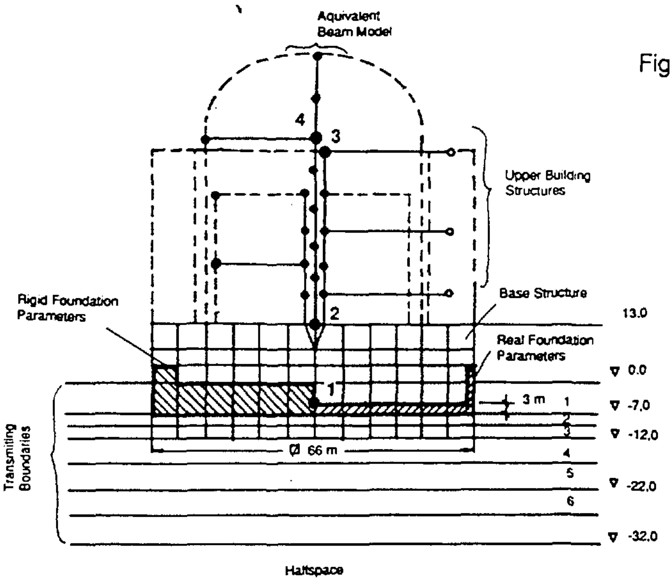


Fig. 20 Soil Profile, Scheme of the Coupled Soil-Structure Model

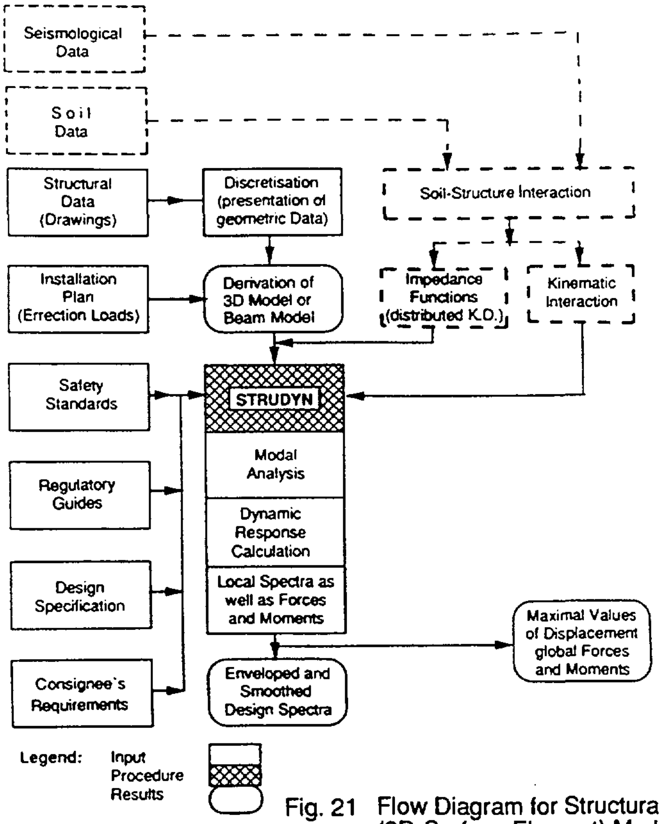


Fig. 21 Flow Diagram for Structural Analysis using decoupled (3D-Surface Element) Model (Indirect Calculation Method in Time Domaine)

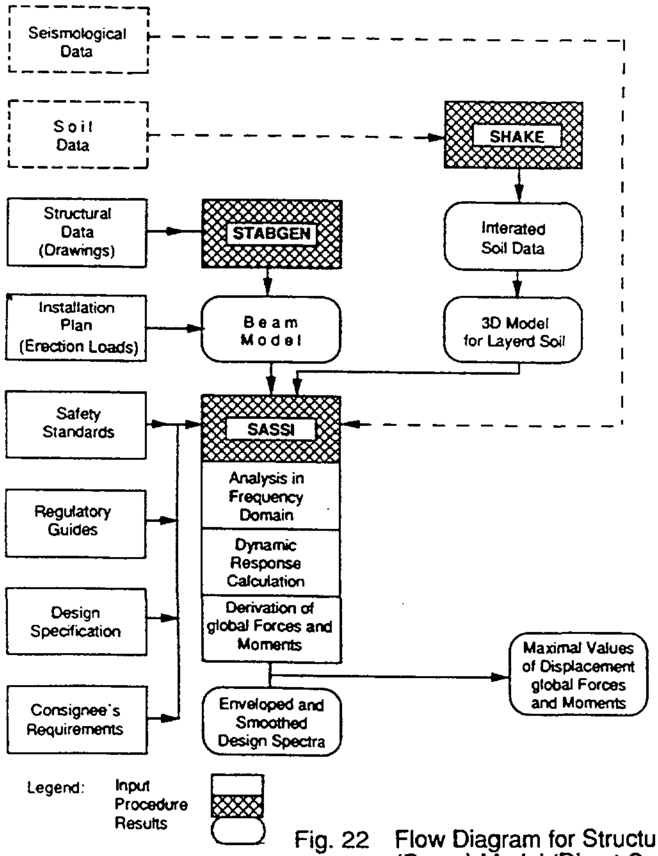


Fig. 22 Flow Diagram for Structural Analysis using coupled (Beam) Model (Direct Calculation Method in Frequency Domaine)

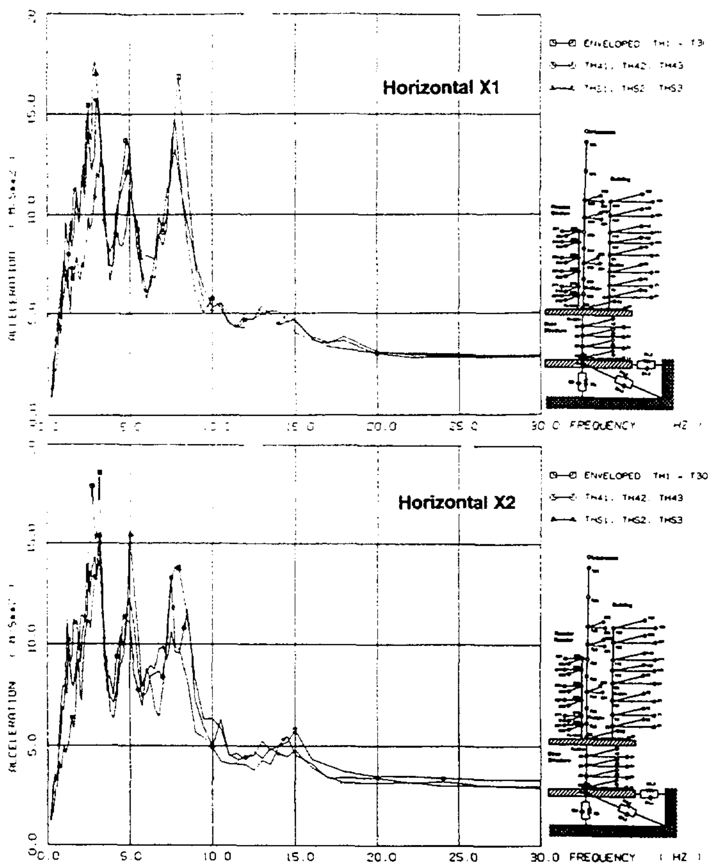


Fig. 23 Dynamic Response (Beam Model) on the Foundation Level, for Different Seismic Input Definitions (Medium Soil) Horizontal Direction (Base Structure)

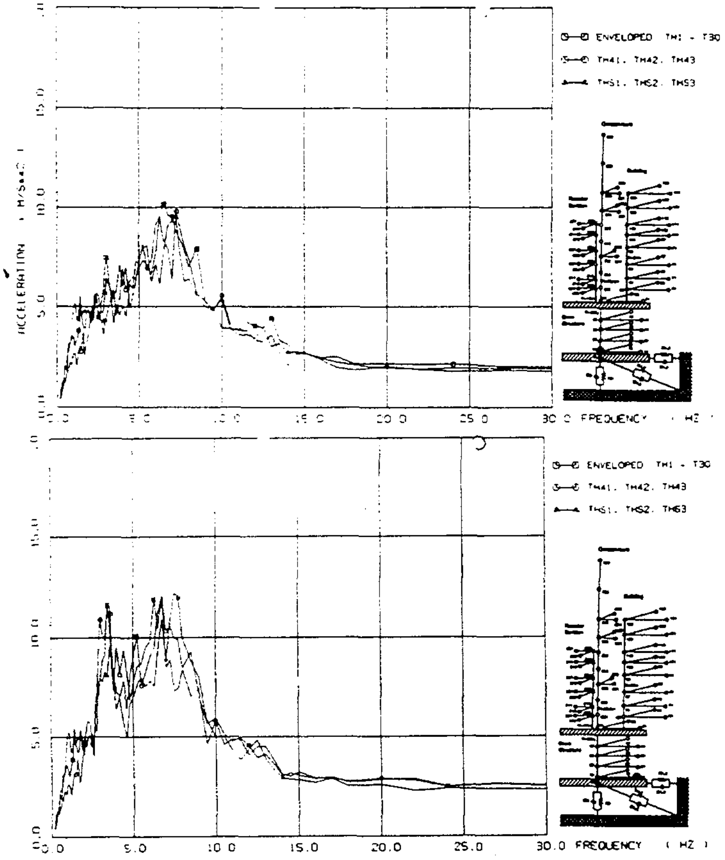


Fig. 24 Dynamic Response (Beam Model) on the Foundation Level, for Different Seismic Input Definitions (Medium Soil) Vertical Direction (Base Structure)

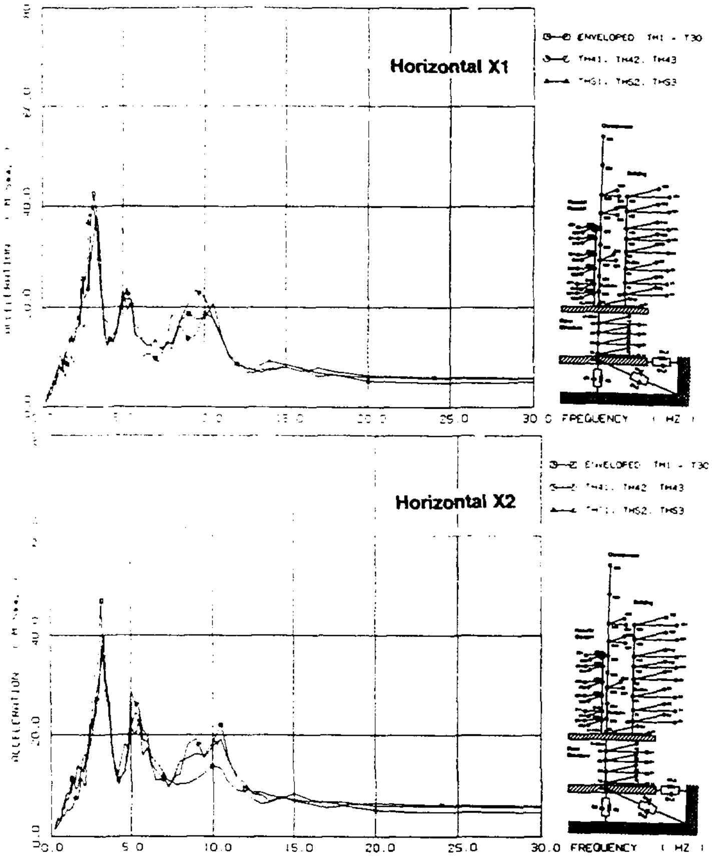


Fig. 25 Dynamic Response (Beam Model) on Floor at 36.9 m for Different Seismic Input Definitions (Medium Soil) Horizontal Direction (Reactor Section)

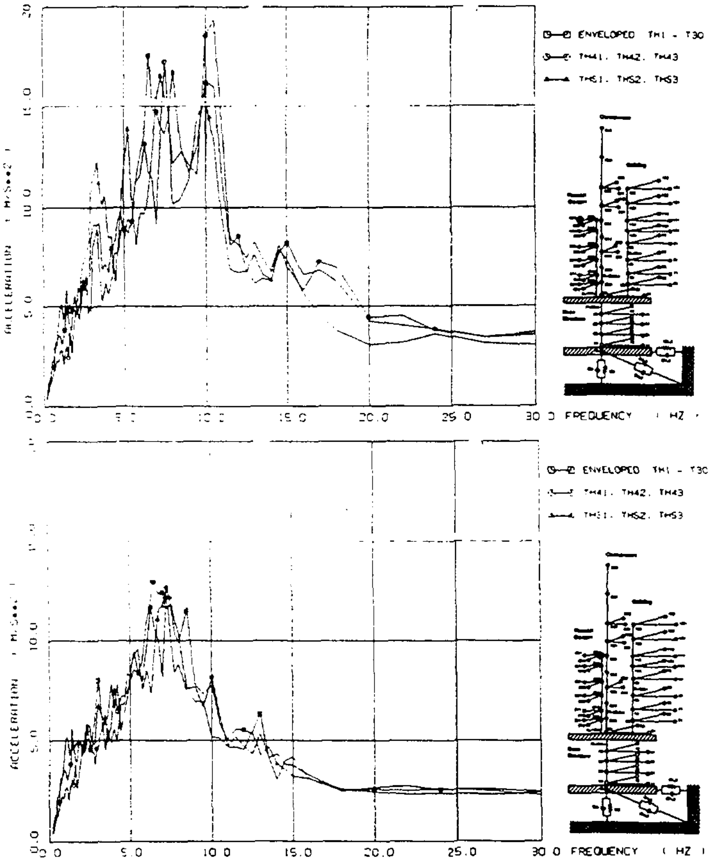


Fig. 26 Dynamic Response (Beam Model) on Floor at 36.9 m for Different Seismic Input Definitions (Medium Soil) Vertical Direction (Reactor Section)

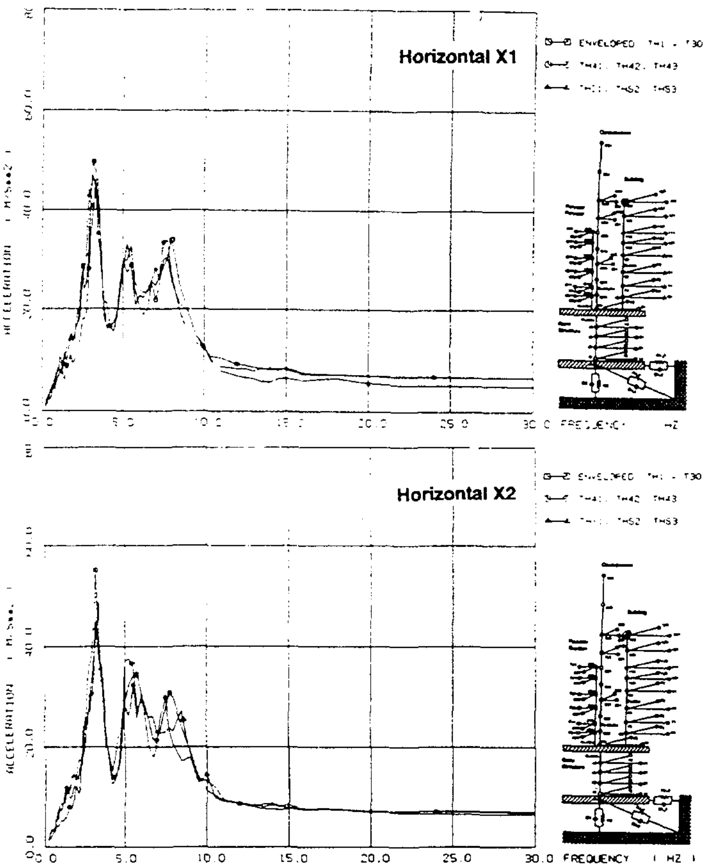


Fig. 27 Dynamic Response (Beam Model) on Floor at 45.3 m for Different Seismic Input Definitions (Medium Soil) Horizontal Direction (Building Structure)

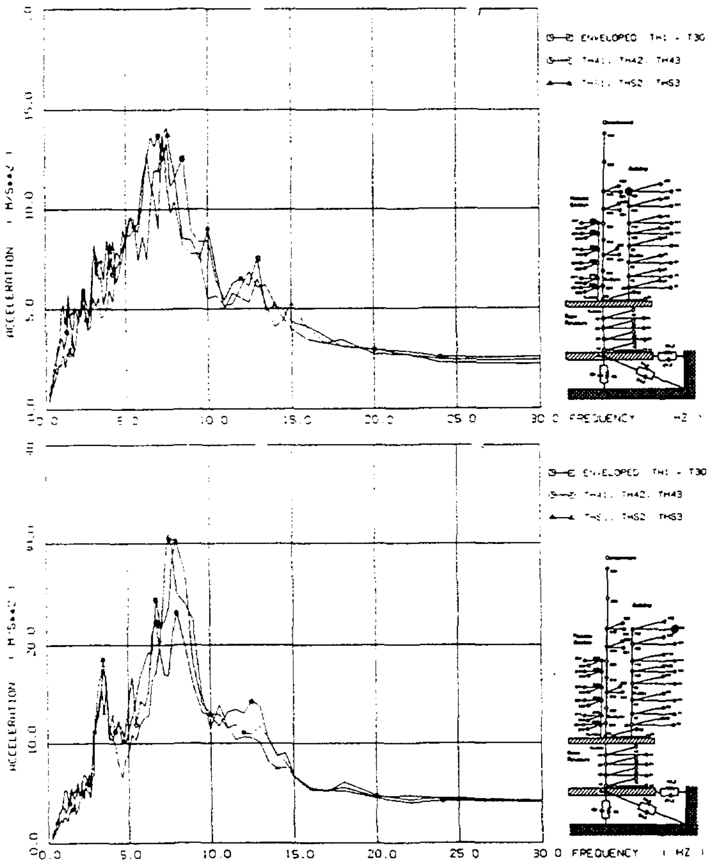


Fig. 28 Dynamic Response (Beam Model) on Floor at 45.3 m for Different Seismic Input Definitions (Medium Soil) Vertical Direction (Building Structure)

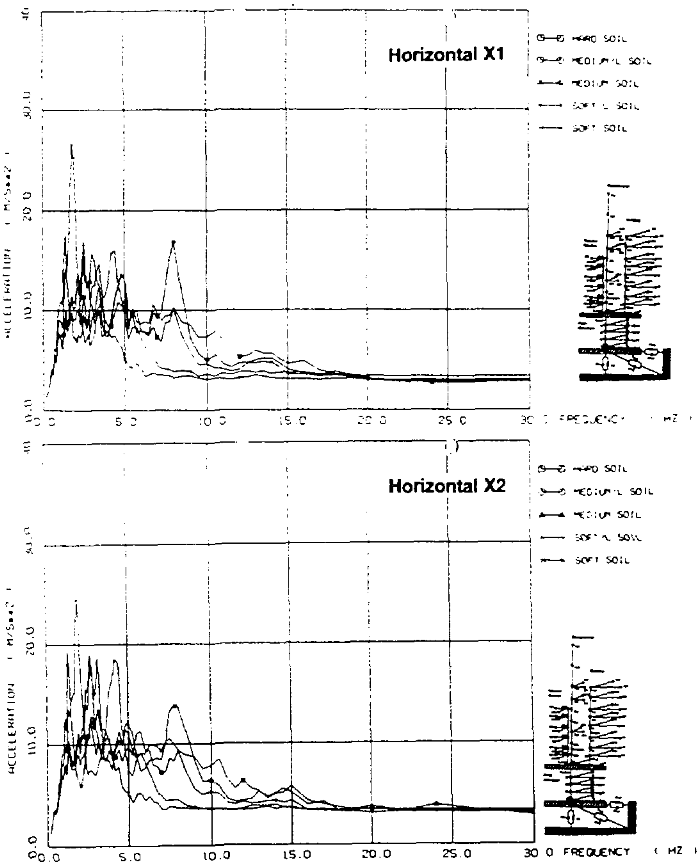


Fig. 29 Dynamic Response (Beam Model) on the Foundation Level.
Different Soil Conditions (all Seismic Input Definitions) Horizontal Direction (Base Structure)

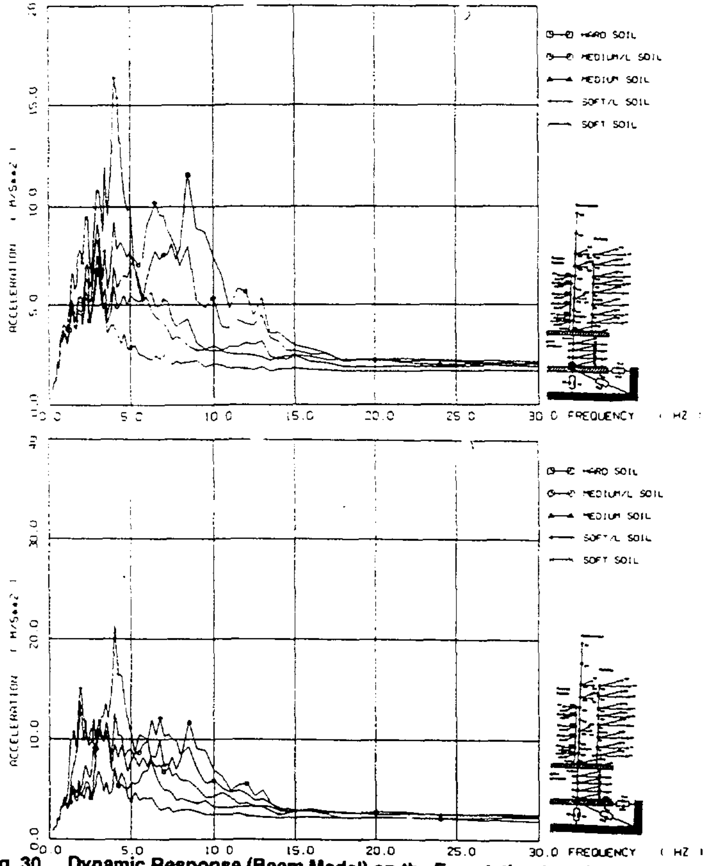


Fig. 30 Dynamic Response (Beam Model) on the Foundation Level,
Different Soil Conditions (all Seismic Input Definitions) Vertical Direction (Base Structure)

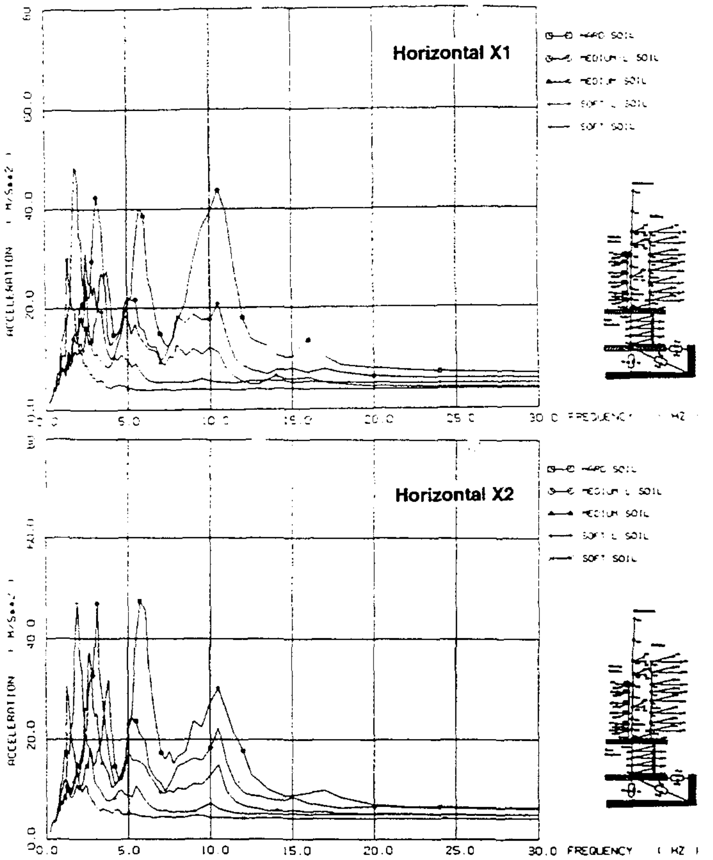


Fig. 31 Dynamic Response (Beam Model) on Floor at 36.9 m Different Soil Conditions (all Seismic Input Definitions) Horizontal Direction (Reactor Section)

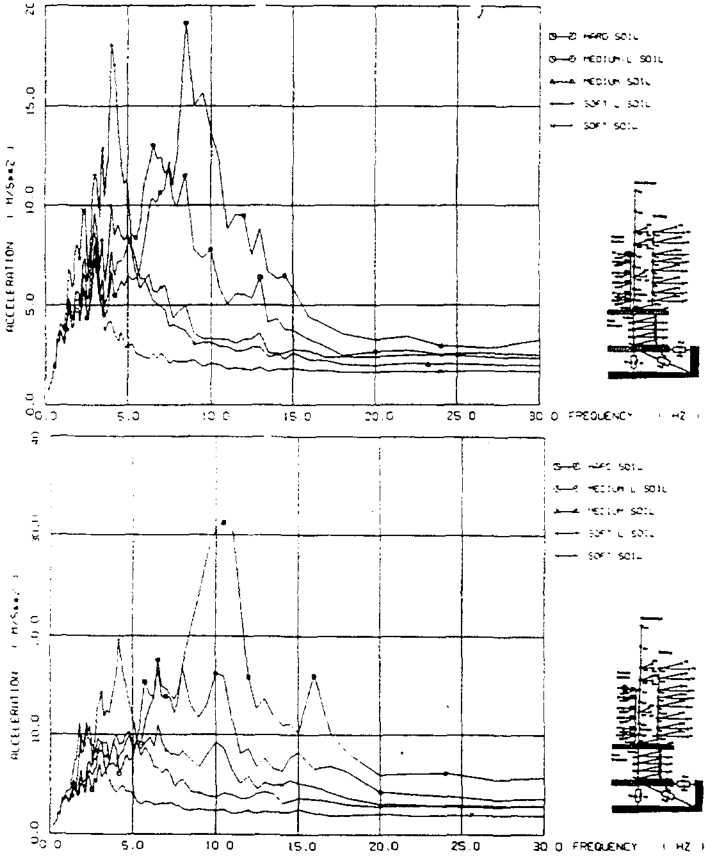


Fig. 32 Dynamic Response (Beam Model) on Floor at 36.9 m Different Soil Conditions (all Seismic Input Definitions) Vertical Direction (Reactor Section)

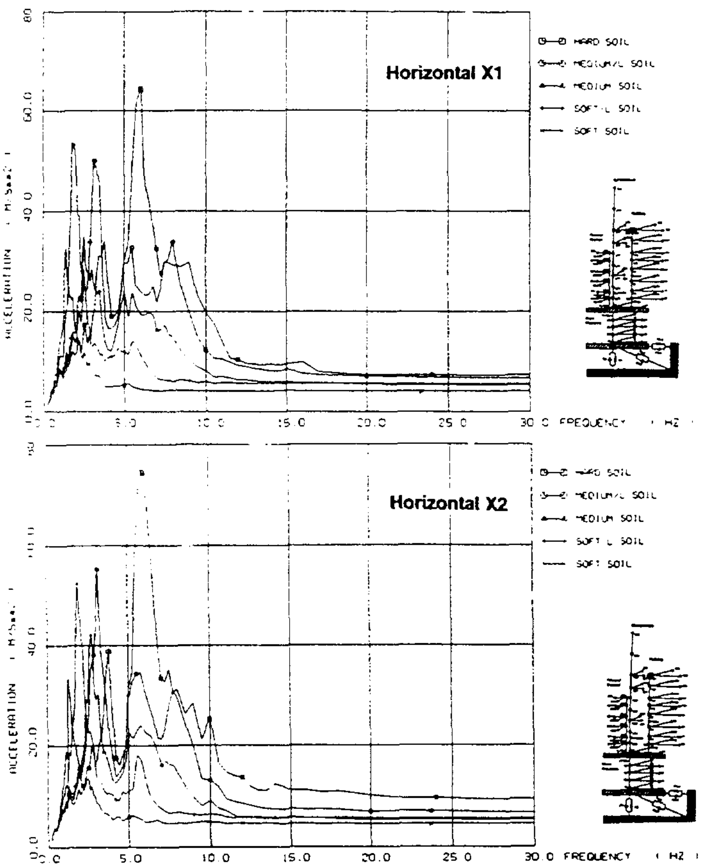


Fig. 33 Dynamic Response (Beam Model) on Floor at 45.3 m
Different Soil Conditions (all Seismic Input Definitions) Horizontal Direction (Building Structure)

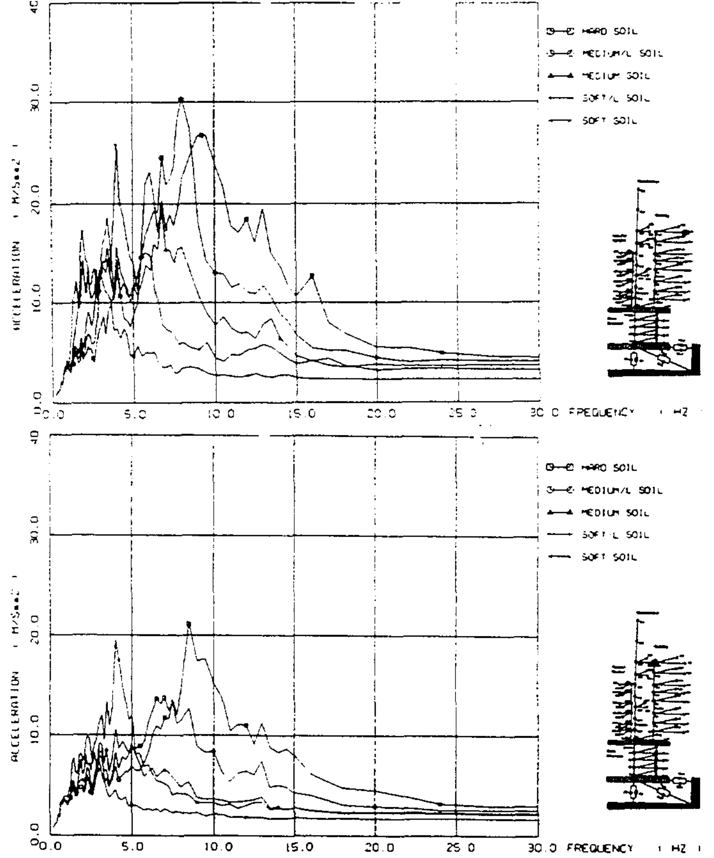


Fig. 34 Dynamic Response (Beam Model) on Floor at 45.3 m
Different Soil Conditions (all Seismic Input Definitions) Vertical Direction (Building Structure)

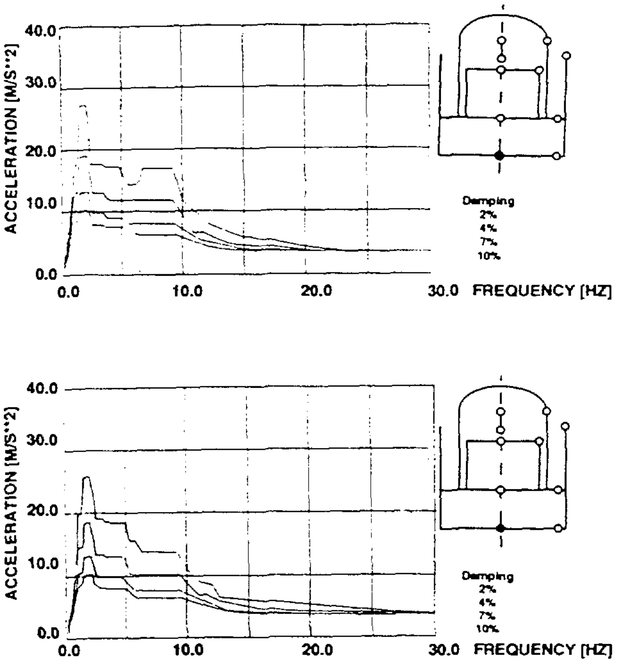


Fig. 35 Dynamic Response (Beam Model) on the Foundation Level, All Soil and Seismological Conditions Horizontal Direction (Base Structure)

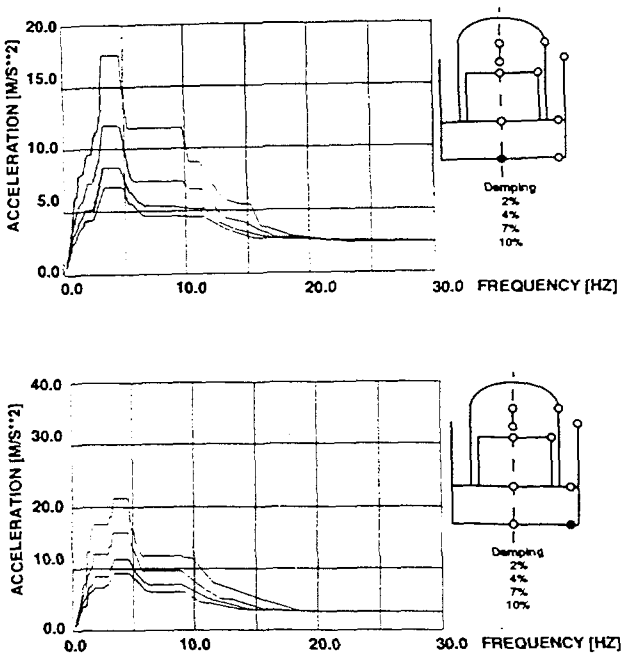


Fig. 36 Dynamic Response (Beam Model) on the Foundation Level, All Soil and Seismological Conditions Vertical Direction (Base Structure)

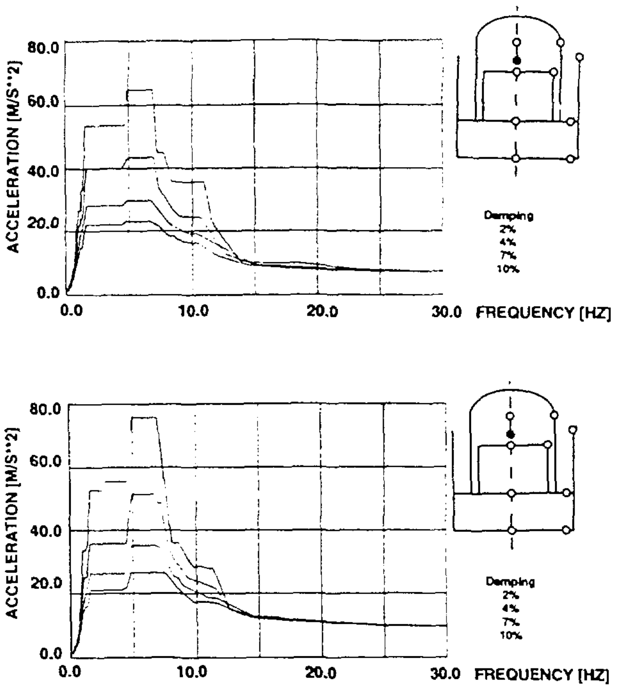


Fig. 37 Dynamic Response (Beam Model) on Floor at 45.3 m
All Soil and Seismological Conditions
Horizontal Direction (Building Structure)

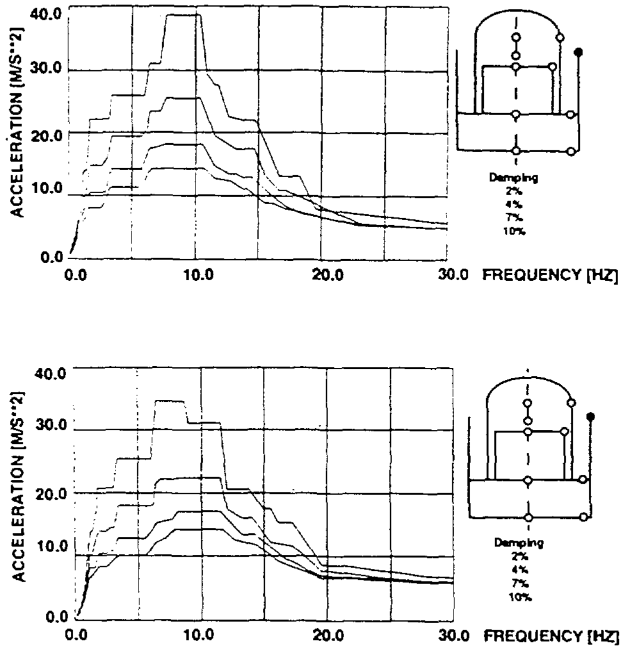


Fig. 38 Dynamic Response (Beam Model) on Floor at 45.3 m
All Soil and Seismological Conditions
Vertical Direction (Building Structure)

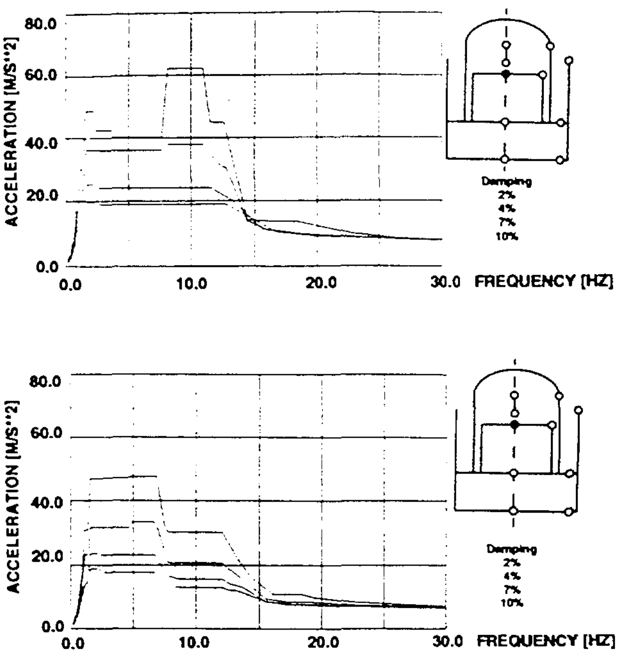


Fig. 39 Dynamic Response (Beam Model) on Floor at 36.9 m
All Soil and Seismological Conditions
Horizontal Direction (Reactor Section)

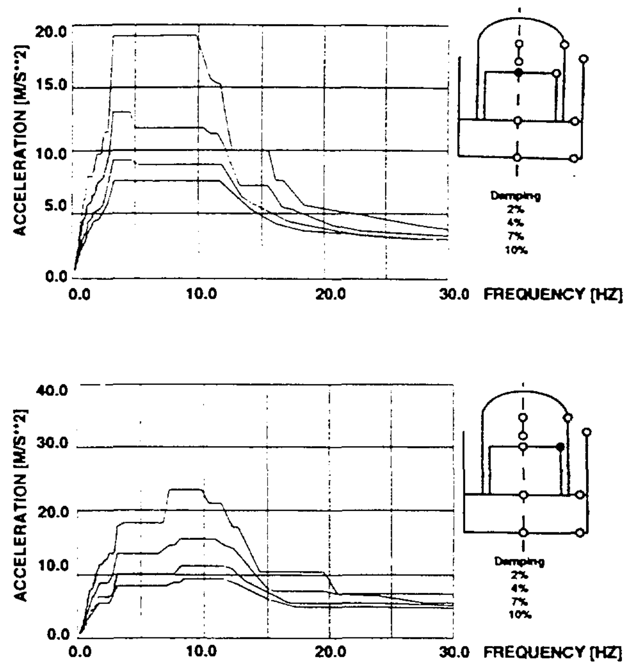


Fig. 40 Dynamic Response (Beam Model) on Floor at 36.9 m
All Soil and Seismological Conditions
Vertical Direction (Reactor Section)

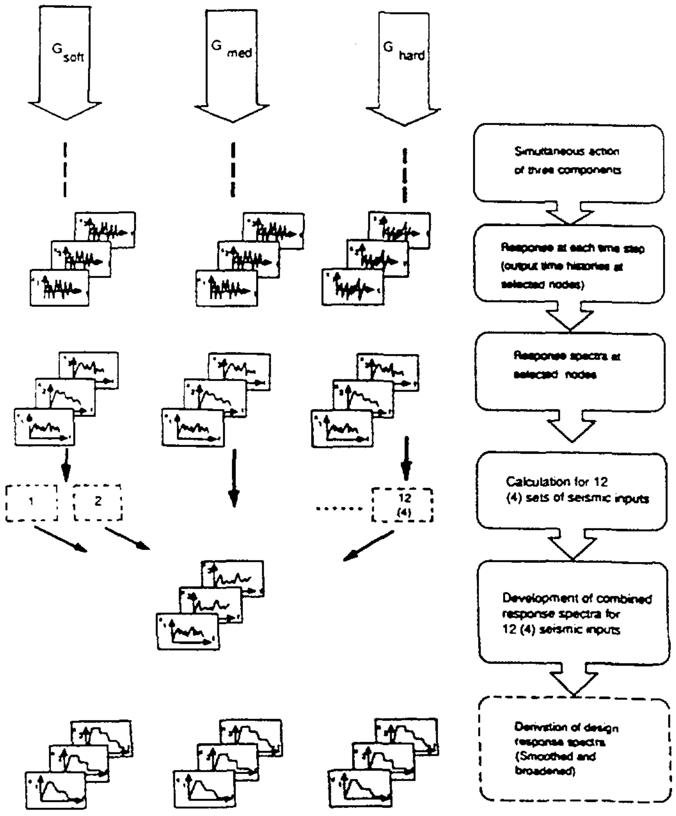


Fig. 41 Combination of Spectra
(Derivation of Design Response Spectra)

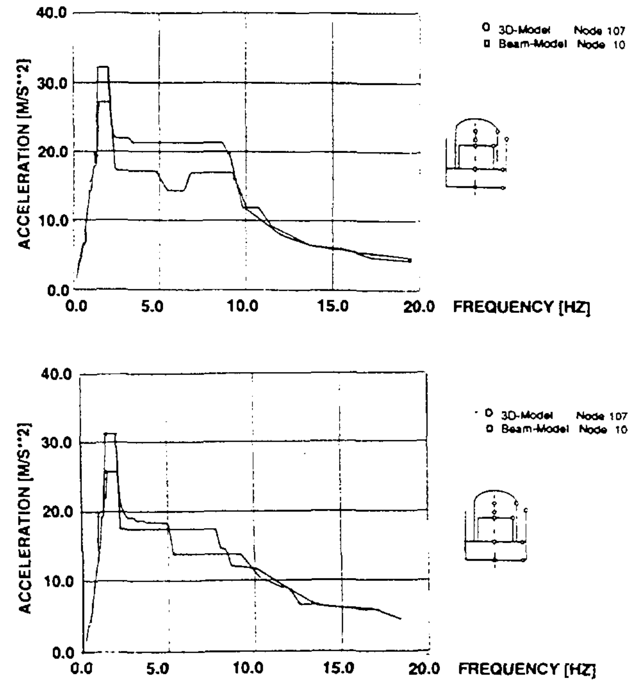


Fig. 42 Comparison of General Response Spectra obtained by Means of Beam Type and 3D-Type Model

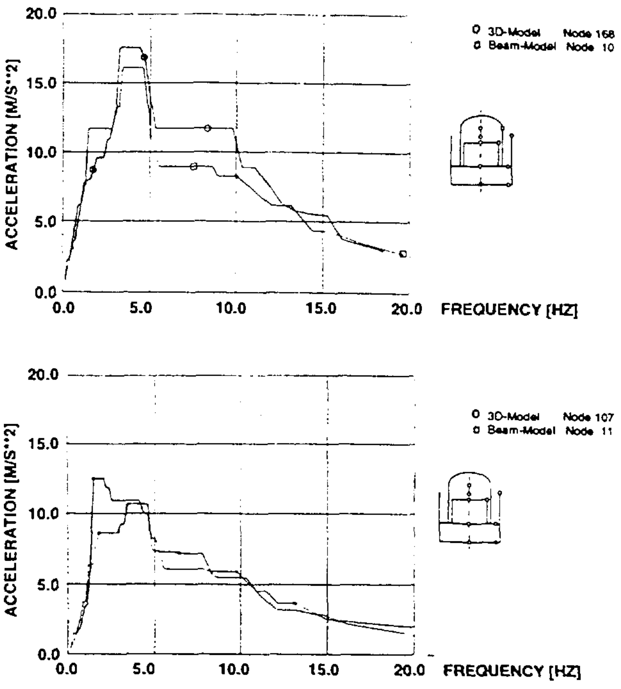


Fig. 43 Comparison of General Response Spectra obtained by Means of Beam Type and 3D-Type Model

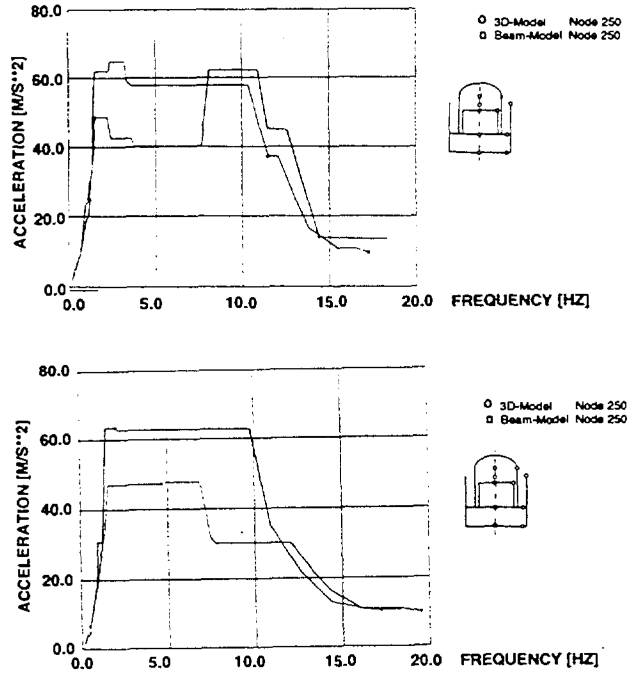


Fig. 44 Comparison of General Response Spectra obtained by Means of Beam Type and 3D-Type Model

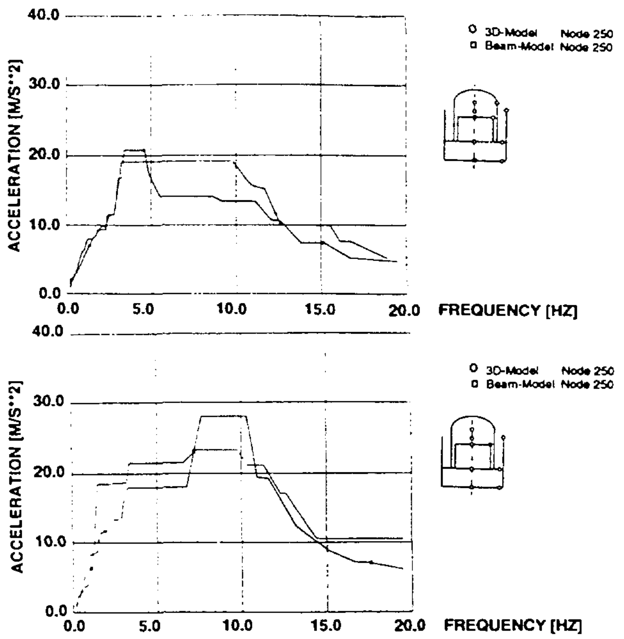


Fig. 45 Comparison of General Response Spectra obtained by Means of Beam Type and 3D-Type Model

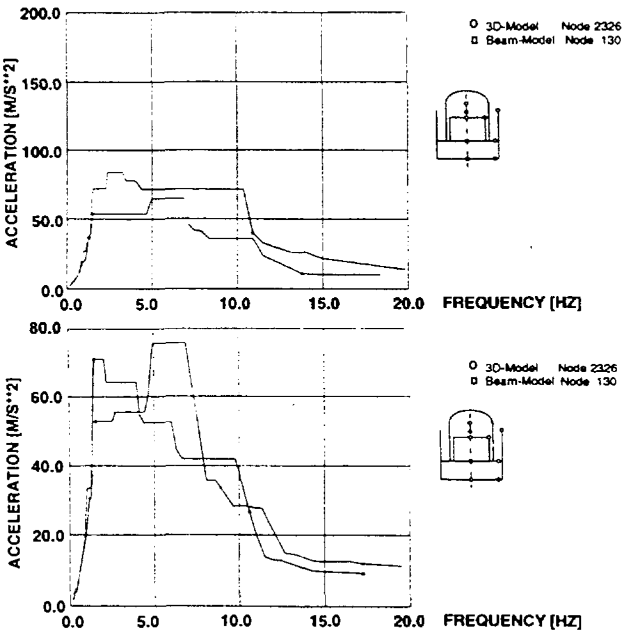


Fig. 46 Comparison of General Response Spectra obtained by Means of Beam Type and 3D-Type Model

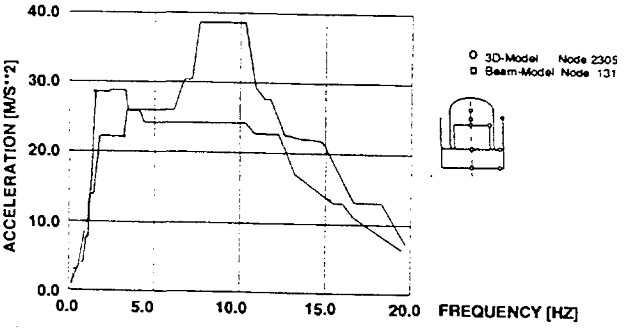


Fig. 47 Comparison of General Response Spectra obtained by Means of Beam Type and 3D-Type Model

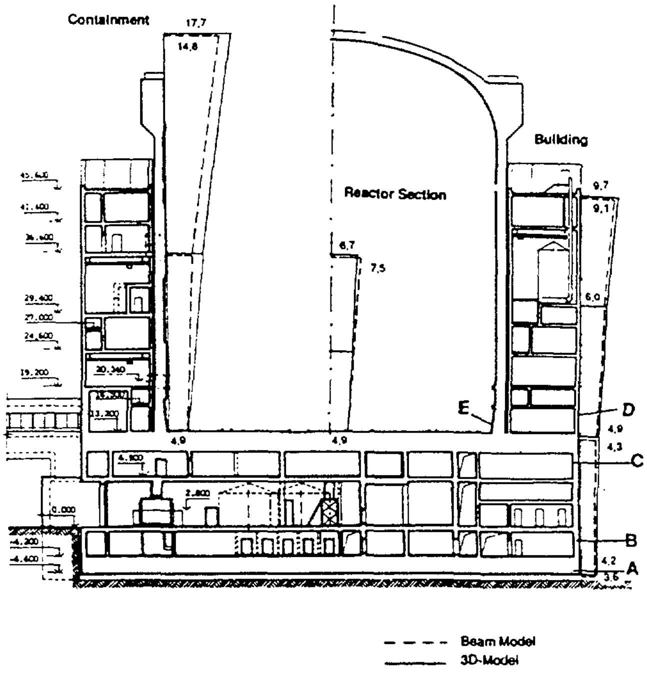


Fig. 48 Rigid Body Accelerations Versus Building Level (Horizontal)

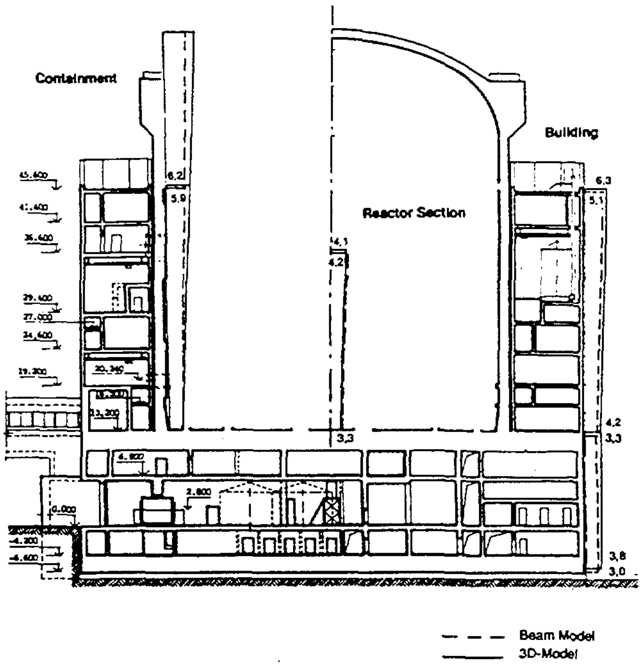


Fig. 49 Rigid Body Accelerations Versus Building Level (Vertical)

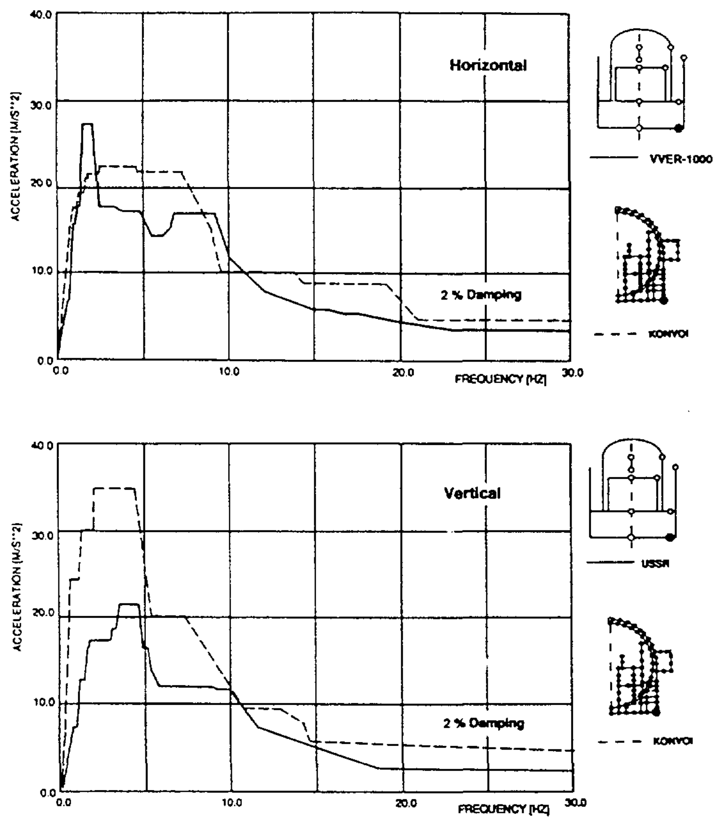


Fig. 50 Comparison of Spectra on Foundation Plate

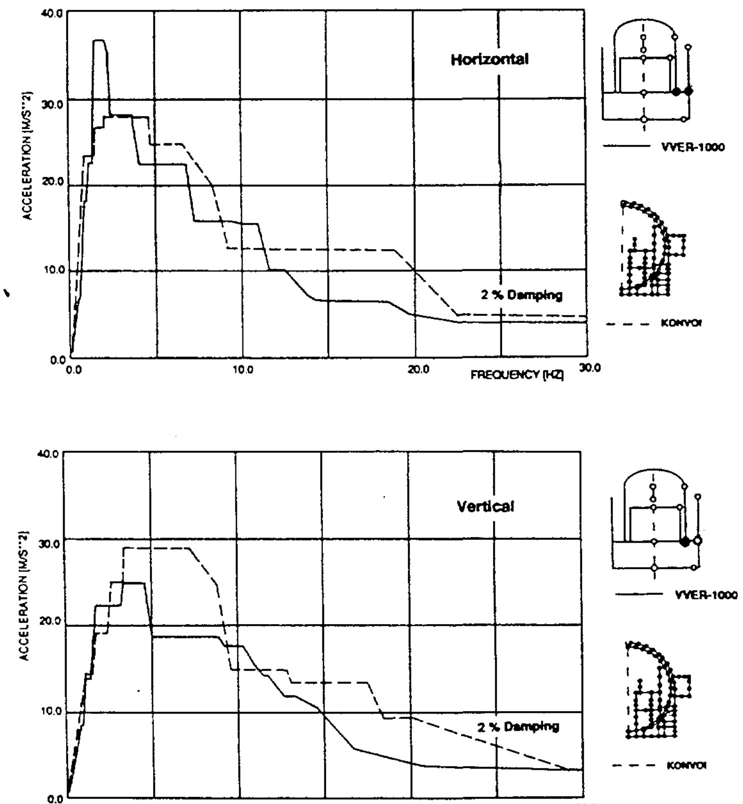


Fig. 51 Comparison of Spectra at Elevation about + 12.0 m (Fixing Point of the Containment)

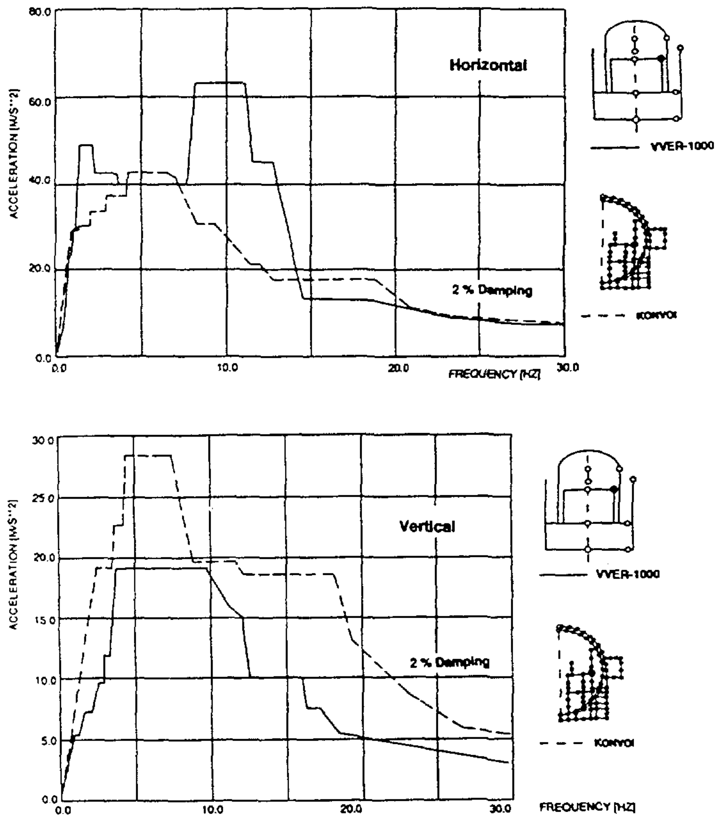


Fig. 52 Comparison of Spectra for the Reactor Section

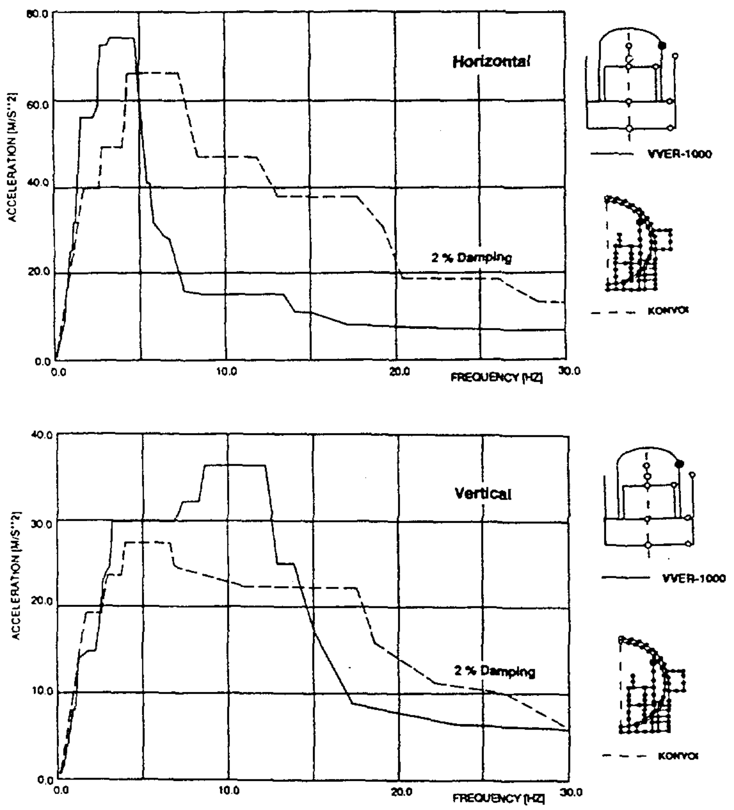
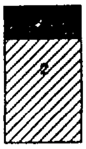


Fig. 53 Comparison of Spectra for the Design on Supporting Level of the Crane

Tab. 1 Definition of typical Soil Properties for Earthquake Analyses of the VVER-1000 Nuclear Power Plant based on the Evaluation of 17 Given Soil Profiles

	SOFT	MEDIUM	HARD
HALFSPACE	$G(z) = 200\,(\frac{z}{20})^{0.5}$ D = 5 % ν = 0,45 ρ = 2,0 t/m 3	G = 1200 MN/m^2 D = 5 % ν = 0,45 ρ = 2,0 t/m^3	G = 10.000 MN/m^2 D = 1 % ν = 0,30 ρ = 2,5 t/m^3
LAYERED  	G_1 = 230 MN/m^2 D_1 = 7 % ν_1 = 0,45 ρ_1 = 2,0 t/m^3 G_2 = 5.000 MN/m^2 D_2 = 1 % ν_2 = 0,30 ρ_2 = 2,5 t/m^3	G_1 = 1.200 MN/m^2 D_1 = 5 % ν_1 = 0,45 ρ_1 = 2,0 t/m^3 G_2 = 5.000 MN/m^2 D_2 = 1 % ν_2 = 0,30 ρ_2 = 2,5 t/m^3	

Tab. 2 Frequency Adapted Soil Springs and Damping Ratio Soft Soil Condition

Soft Soil / Halfspace				
DIR	x,y	z	xx, yy	zz
K_0 [kN,m]	41 E6	83 E6	61 E9	53 E9
F [Hz]	1,4	1,9	1,4	1,4
K [kN,m]	**35 E6**	**61 E6**	**53 E9**	**46 E9**
D [%]	**26**	**46**	**8**	**8**

Soft Soil / Layered				
DIR	x,y	z	xx, yy	zz
K_0 [kN,m]	86 E6	277 E6	120 E9	88 E9
F [Hz]	2,0	4,0	2,0	2,0
K [kN,m]	**67 E6**	**193 E6**	**112 E9**	**77 E9**
D [%]	**10**	**17**	**7**	8

K_0 = static stiffness

F = eigenfrequency

k = frequency independent stiffness

D = frequency independent damping ratio

Tab. 3 Frequency Adapted Soil Springs and Damping Ration
Medium Soil Condition

Medium Soil / Halfspace				
DIR	x,y	z	xx, yy	zz
K_0 [kN,m]	239 E6	336 E6	340 E9	390 E9
F [Hz]	2,6	4,1	2,6	2,6
K [kN,m]	**231 E6**	**247 E6**	**297 E9**	**352 E9**
D [%]	**29**	**79**	**10**	**8**

Medium Soil / Layered				
DIR	x,y	z	xx, yy	zz
K_0 [kN,m]	353 E6	792 E6	513 E9	436 E9
F [Hz]	3,2	6,5	3,2	3,2
K [kN,m]	**313 E6**	**676 E6**	**482 E9**	**400 E9**
D [%]	**14**	**32**	**5**	**5**

K_0 = static stiffness   k = frequency independent stiffness

F = eigenfrequency   D = frequency independent damping ratio

Tab. 4 Frequency Adapted Soil Springs and Damping Ration
Hard Soil Condition

Hard Soil				
DIR	x,y	z	xx, yy	zz
K_0 [kN,m]	1836 E6	2261 E6	2320 E9	3200 E9
F [Hz]	3,6	9,2	3,6	3,6
K [kN,m]	**1830 E6**	**2010 E6**	**2230 E9**	**3100 E9**
D [%]	**13**	**56**	**1,7**	**1,5**

K_0 = static stiffness   k = frequency independent stiffness

F = eigenfrequency   D = frequency independent damping ratio

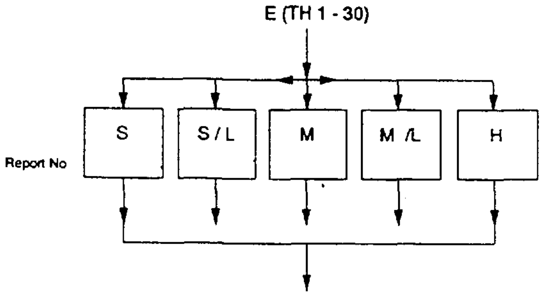
Tab. 5 Parameter/Variation and Total Sets of Results

Seismic Input Definition	1) TH1 to TH30 **(10 Sets)** 2) TH41 to TH43 **(1Set)** 3) THS1 to THS3 **(1Set)** 4) THSS1 to THSS3 ***(1Set)**					1) THE1 to THE3 2) TH41 to TH43 3) THS1 to THS3 4) THSS1 to THSS3 *		
Type of Model	Beam Model Calculation					3D Model Calculation		
Type of Soil	Soil Type					Soil Type		
	soft	soft/L	med	med/L	hard	soft	med	hard
Indirect Method	12	12	12+1*	12	12	3	3+1*	3
	Total Sets of results = 61					Total Sets = 10		
Direct Method							1*	

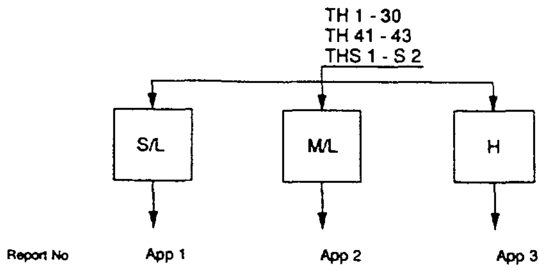
* SS = Special Site (Crimea)

Tab. 6 VVER-1000
Comparison of Response Spectra

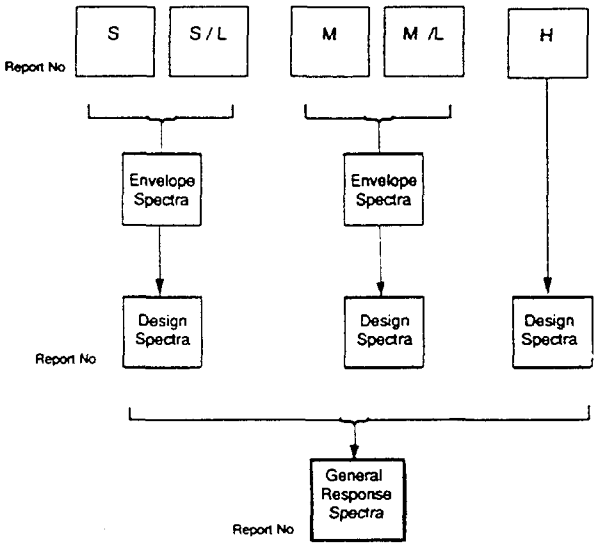
A) Comparison of results obtained for different soil groups



B) Comparison of Results for different Seismic Inputs



Tab. 7 VVER-1000 - Documentation of Results, Design Response Spectra, General Response Spectra



Tab. 8 VVER-1000 - Documentation of Results Individuel Response Spectra