Title: **Blind Pre-Analysis of the Main Building Complex - WWER-1000 Kozloduy**

Contributor: **N.J. Krutzik**

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Blind Preanalysis of the Main Building Complex VVER-1000 KOZLODUY

Comparison of Analytical
and Experimental Results Obtained by Explosive Testing
(Task 8a of Workplan 96/97)

Prepared by:
Siemens AG, Offenbach/Germany
Power Generation Group (KWU) NDA2
N.J. Krutzik

1 Introduction

In accordance with the 96/97 workplan of the Research Programme on "Benchmark Studies for Seismic Analysis and Testing of VVER-Type Nuclear Power Plants", blind preanalyses were prepared for the main building complex of the VVER-1000 (Figures 2-1 and 2-2) based on given excitations derived from explosive tests. The investigations were performed by several institutions based on various mathematical models and procedures for consideration of soil-structure interaction effects, but on the same explosive test input data recently obtained /3/. The methods of calculation and software tools used will also be different.

The aim of this investigation is to validate different idealization concepts (mathematical models for the idealization of the structures and the soil) as well as investigation procedures (time domain and frequency domain analysis) and finally the software tools by comparing structural response results (time histories and response spectra).

This report contains the results of the blind preanalysis performed by Siemens using an equivalent beam model of the main building of the VVER 1000. The calculations were performed by means of a frequency domain calculation.

2 Description of Analyzed Structure

The reactor building (Figure 2-1) is designed as a square, reinforced-concrete structure, each side measuring approximately 67.8 m in length. It is supported on a 2.3-m-thick foundation slab.

The bottom of the building foundation is located approximately 6.5 m below plant grade. Taking of the embedment ratio into consideration, this results in a total height of approximately 73 m, of which 66 m are above plant grade. The load-bearing and stiffening members mostly comprise walls and floors. Up to approximately the 13.2 m elevation, the walls and floors (which for reasons of radiation shielding as well as structural requirements are of massive design) form a composite system of rigid cells.

Above the 13.2 m elevation, the reactor building is subdivided into three structures separated by construction joints: the surrounding building, the prestressed concrete containment and the reactor section.

All three structures are supported on a 2.4-m-thick floor. The surrounding building encompasses the containment. Apart from the outer and inner walls, only the horizontal floors make any significant contribution to its structural rigidity.

The containment is a prestressed concrete structure of cylindrical shape with a spherical dome at the top which is designed with a cylindrical transition section. The containment has a diameter of 45.0 m, a wall thickness of 1.2 m and a height of approximately 53 m. It is lined over its entire inner surface with 8 mm thick steel plate to guarantee leaktightness. The polar crane, which has a rated loading capacity of 400 t, is installed at a height of approximately 46.8 m.

The reactor section, which is located inside the containment between the top of the base structure at elevation 13.2 m and the service floor at elevation 36.9 m, contains the reactor pressure vessel, the steam piping, the steam generators, the reactor coolant pumps, the refuelling machine and the fuel pool.

The surrounding building, the containment and the structures of the reactor section are coupled via the base structure and represent an interactive vibrating system.

3 Mathematical Model

3.1 Idealization of the Structures

It is well known that the accuracy of results obtained by finite element analysis is dependent on the degree of idealization employed. However, the greater the degree of idealization, the more complex the problem (i.e. the greater number of nodal points of the mathematical model).

The type idealization used for the structure in question is largely dependent on its mass distribution and geometrical design, as well as on the purpose of the analysis and the results desired.

On the basis of the objective to be achieved in the present case, this means that the building must be represented using a discretization such as to enable the time histories of local responses in all structural areas were the measuring instrumentation are located.

As far as the tests of the VVER 1000 reactor building KOZLODUY is concerned, these areas shown in Figures 2-1 and 2-2.

Considering the geometric shape, stiffening and mass distribution of the reactor building under consideration as well as the base excitation to be introduced, the use of an equivalent beam model was assessed to be admissible and appropriate (Figure 3-1). The beam model includes the outer structure, the containment, the inner structure and the basemat structure as a fully connected total system.

The masses are considered as weight, and comprise the deadweight of the walls, the floors and the supported equipment. These are combined for each level of the structure (in most cases, floors) and lumped as translational masses at the center of gravity of this level.

On account of the eccentricity existing in all three directions, three mass moments of inertia are computed for each mass point. The mass center of gravity is connected to the shear center by means of a rigid beam element. The relative locations of additional points of interest in the building are likewise represented using mass less rigid beam elements.

3.2 Properties and Soil Models

The soil condition of the Kozloduy site may be characterized as a soft to medium soil type. Shear wave velocities and density measurements represent the basis for the definition of shear moduli of the corresponding layers.

The soil dynamic input data were evaluated for the Kozloduy site and defined within the framework previous of research activities /1/.

In addition to the information mentioned above, the results of laboratory tests of the individual soil layers have been compiled /2/.

The soil profile in the vicinity of Unit 5 of KOZLODUY, showing the respective thickness of layers, is illustrated in Figure 3-2.

In order to demonstrate the differences in assumptions made in benchmark studies in the past regarding the properties, the shear wave velocities of the upper layers have been compared in Figure 3-3 is evident that below a depth of 30 m all assumptions were nearly equal.

Finally in this investigation the capabilities and the layering shown in Figures 3-4 were used. Due to the low level of the explosive excitation no adoptation of the shear moduli and material damping to the strains were considered.

4 Explosive Loading

The explosive excitation was represented by means of measured acceleration time histories (one for each translational direction) acting simultaneously (Figure 4-2). They have a duration of 30 s /3/.

The time histories were measured (Location FF) at a distance of about 139 m from Unit 5 (Figure 4-1). The maximum acceleration amplitudes were at about 0.10 m/s² and 0.20 m/s² for the horizontal and vertical directions, respectively. The corresponding acceleration response spectra are shown in Figure 4-3.

5 Structural Response

The dynamic response of the main building complex was calculated (using the frequency domain approach) for locations defined by ISMES letter dated Feb. 21, 1990 /3/. The response spectra were therefore calculated for the foundation mat, the elevation of 13.2 m as well as at the upper regions of the crane reactor building (Figures 2-1 to 2-2). Based on the secondary time histories obtained for these locations, response spectra were derived as requested for 2%, 4% and 7% damping (Figures 5.1 to 5.32).
The calculated spectra correspond to the soil conditions G_{ave} only.

6 Comparison of Results

A quick look comparison of the analytical results of the blind preanalysis with the experimental (measured) results /6/ were shown first time during the RCM EQE, Oct. 13 to 17, 1997 in San Francisco.

As soon as the experimental results derived for all characteristic regions are available they will be compared with the analytical results shown in Figures 5-10 to 5-33.

The comparison and evaluation of the results performed for the 2 % response spectra will be used.

Some results of the quick look comparison lifted during the RCM above mentioned and depicted from the preliminary report /6/ are shown in Figures 6.1 to 6.10.

7 References

/1/ Initial Data of Kozloduy NPP site, Part I NPP Kozloduy
October 1993

/2/ Initial Data of Seismic Input and Soil Condition of Kozloduy NPP Site,
Extension to Part II Soil Conditions Kozloduy June 1994

/3/ Benchmark Studies for the Seismic Analysis and Testing of VVER Type NPPs
Seismic Benchmark of Kozloduy NPP
ISMES Letter dated Feb. 21, 1997

/4/ SASSI, A Computer System for Dynamic Soil-Structure Interaction Analysis,
Siemens KWU Version 1/1991
(Original source M. Tabatabaie-Raissi, J. Lysmer, University of California, Berkeley)

/5/ STABGEN, Generation of Equivalent Beam Models
Siemens KWU Software Version 9/84

/6/ Kozloduy Nuclear Power Plant
Dynamic Structural Testing Buried Explosions Excitation June/July 1996
Benchmark Report ISMES

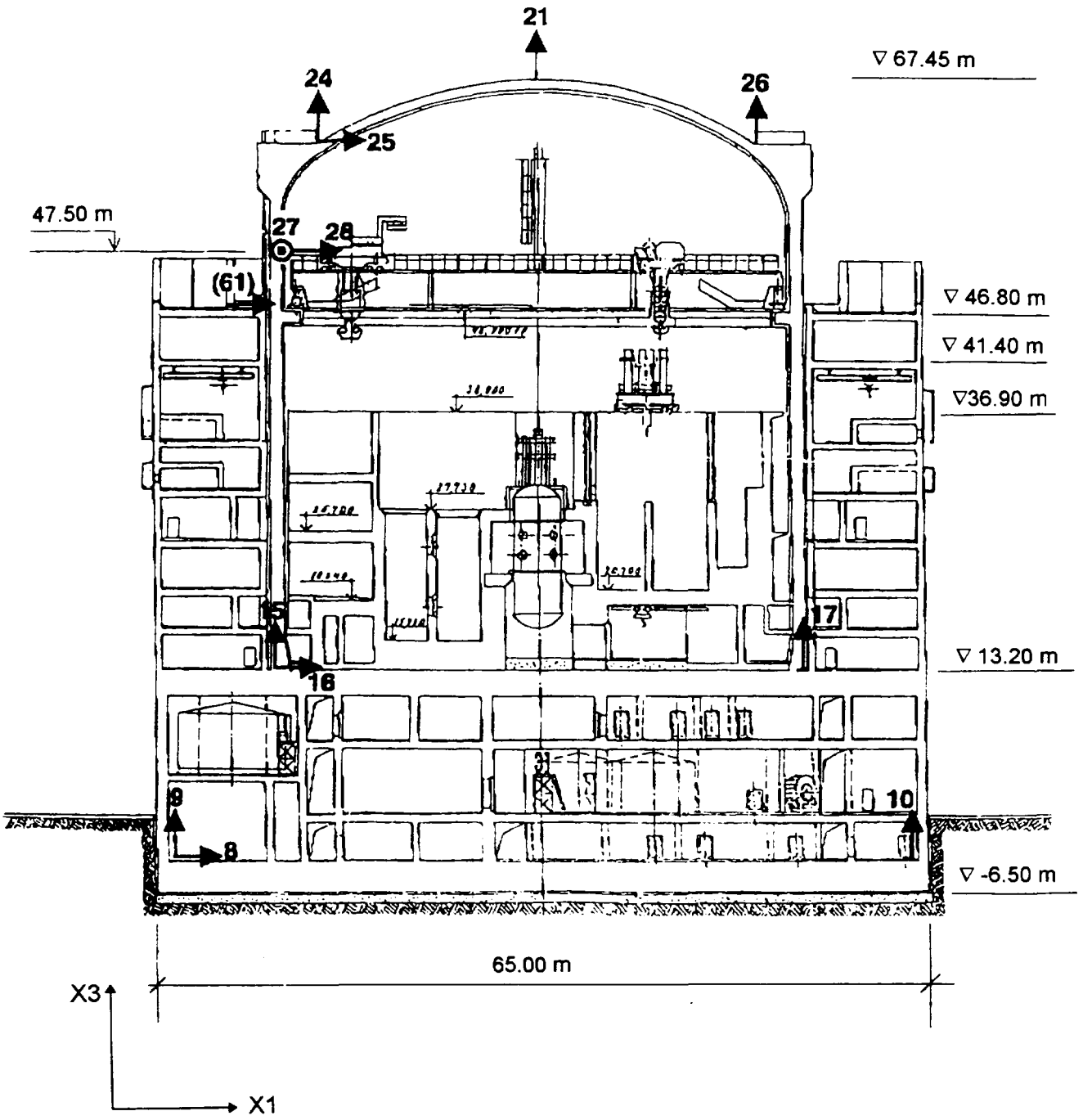


Fig. 2-1 VVER-1000 MW Reactor Building KOZLODUY Transversal Section and Characteristic Output Regions

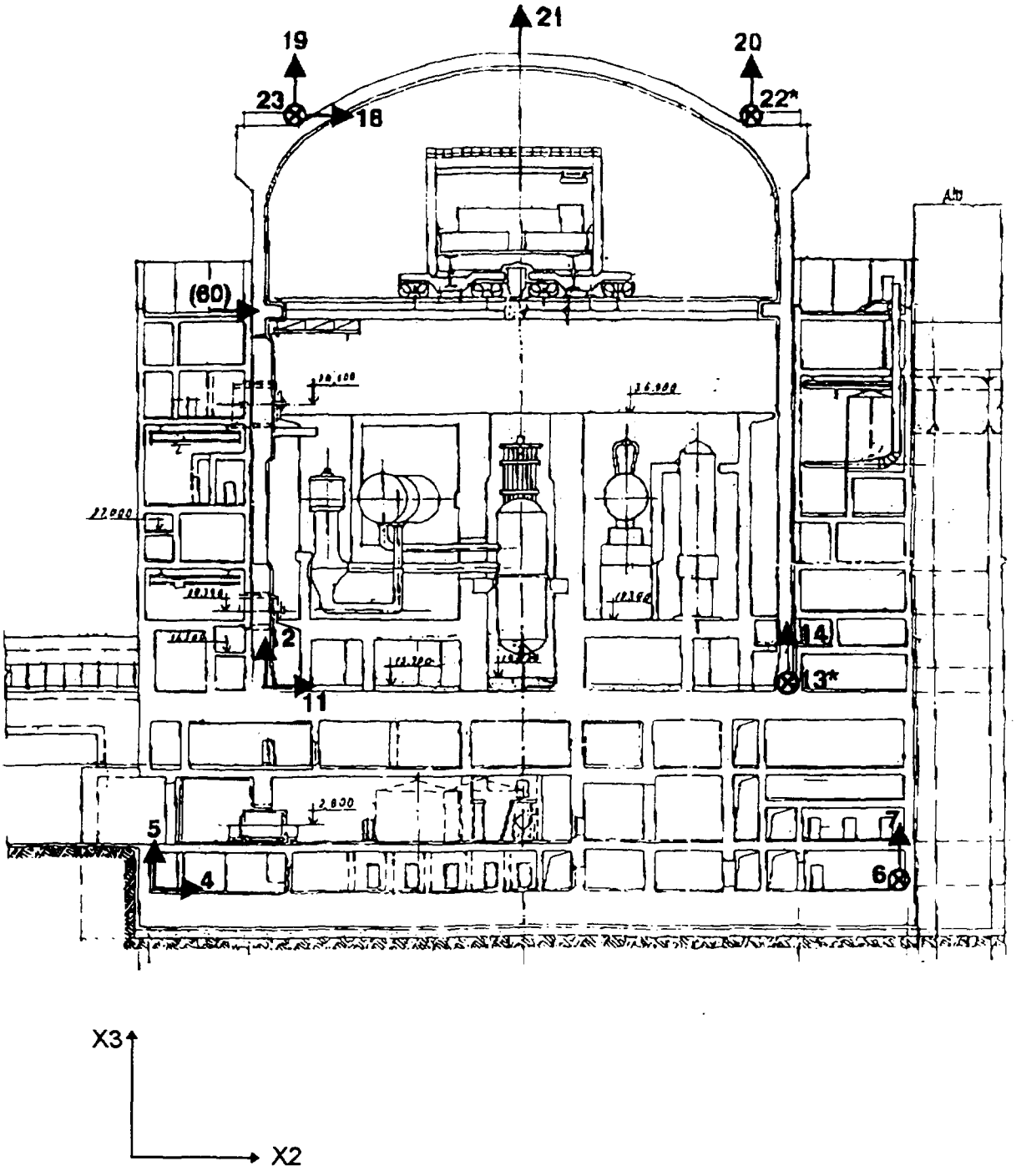


Fig. 2-2 VVER-1000 MW Reactor Building KOZLODUY Longitudinal Section and Characteristic Output Regions

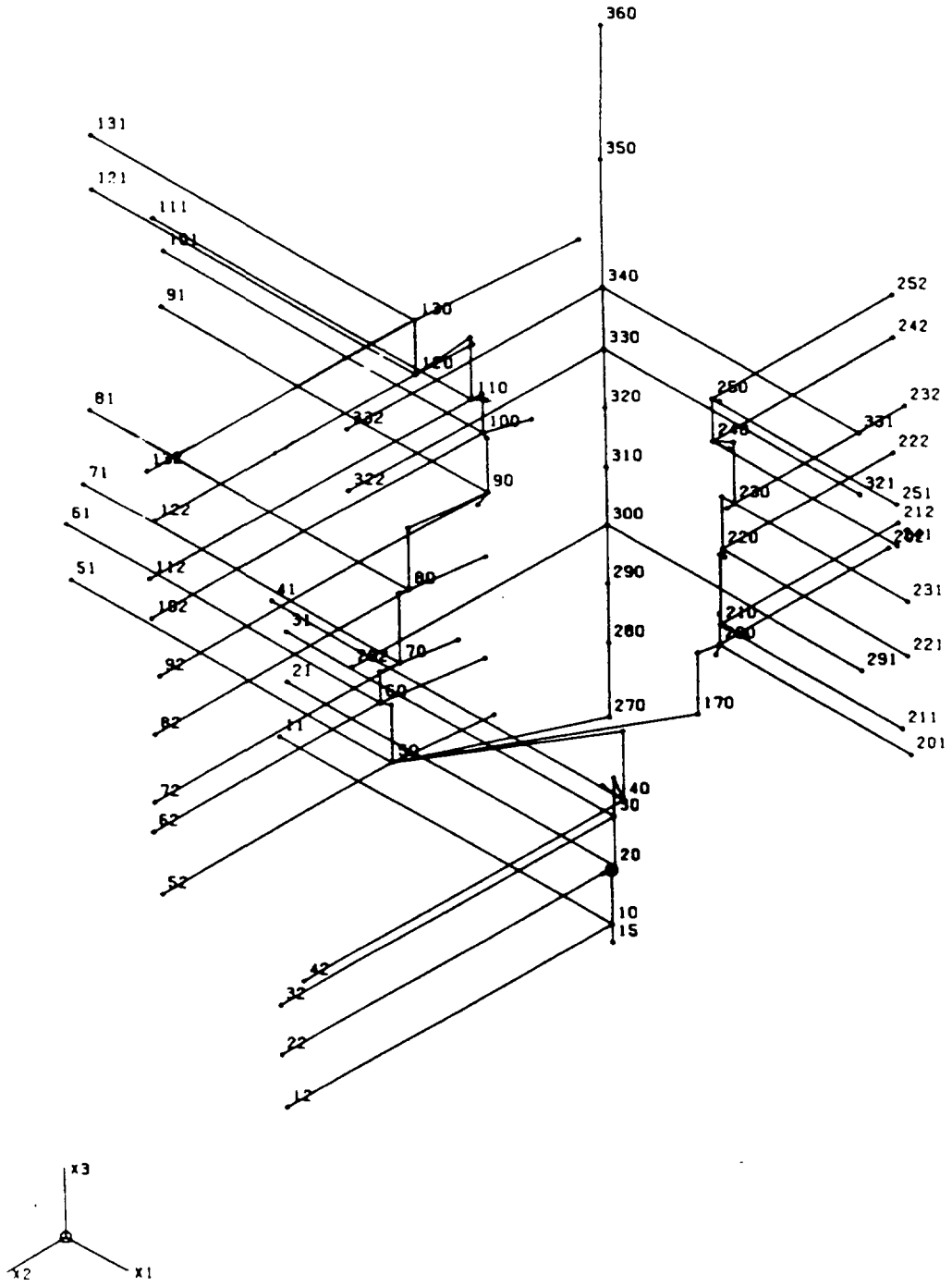


Fig. 3-1 VVER-1000 MW Reactor Building KOZLODUY Beam Model

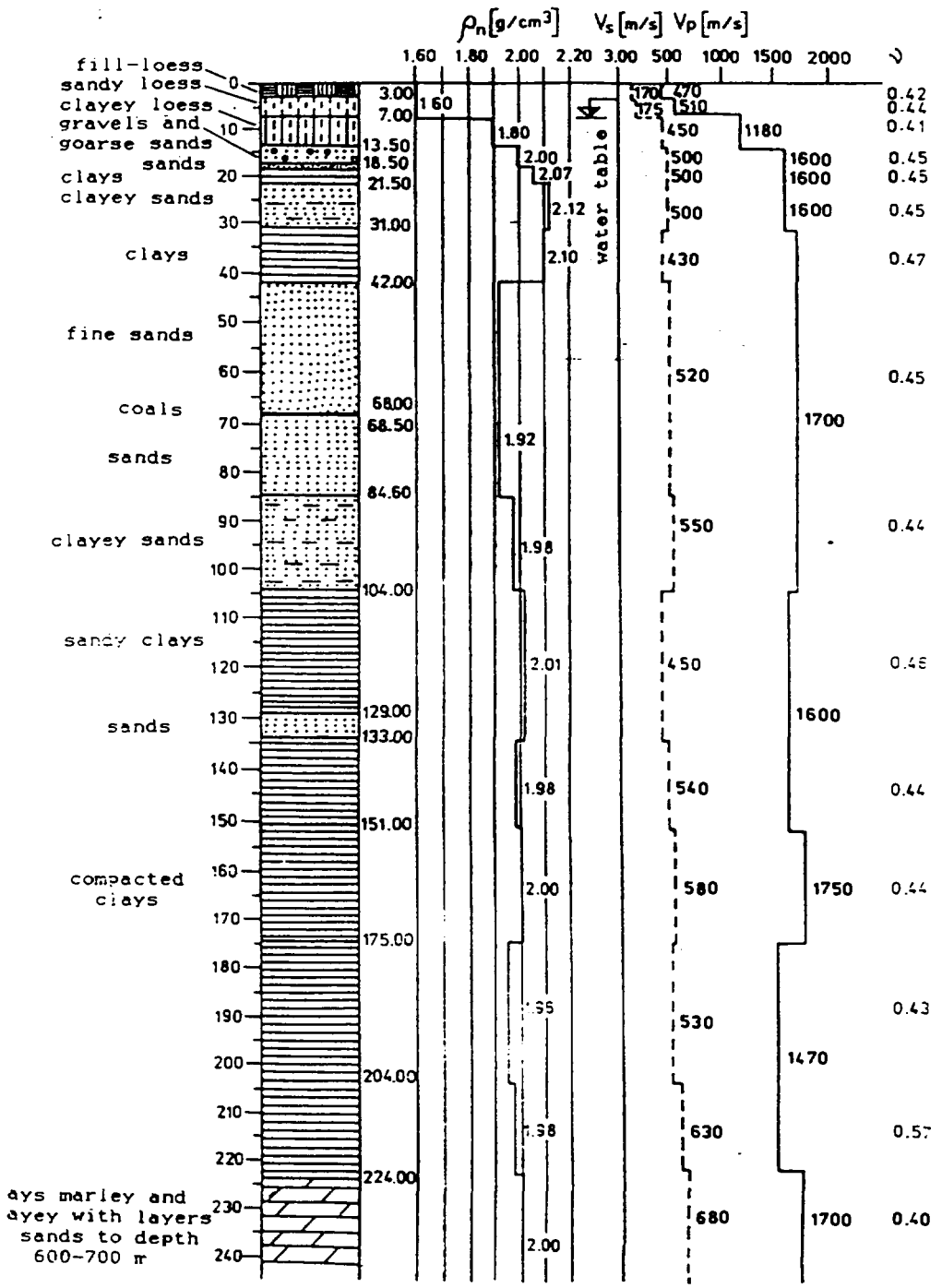


Fig. 3-2 Reactor Building KOZLODUY, Unit 5
Soil Profile Assumed in Benchmark 1

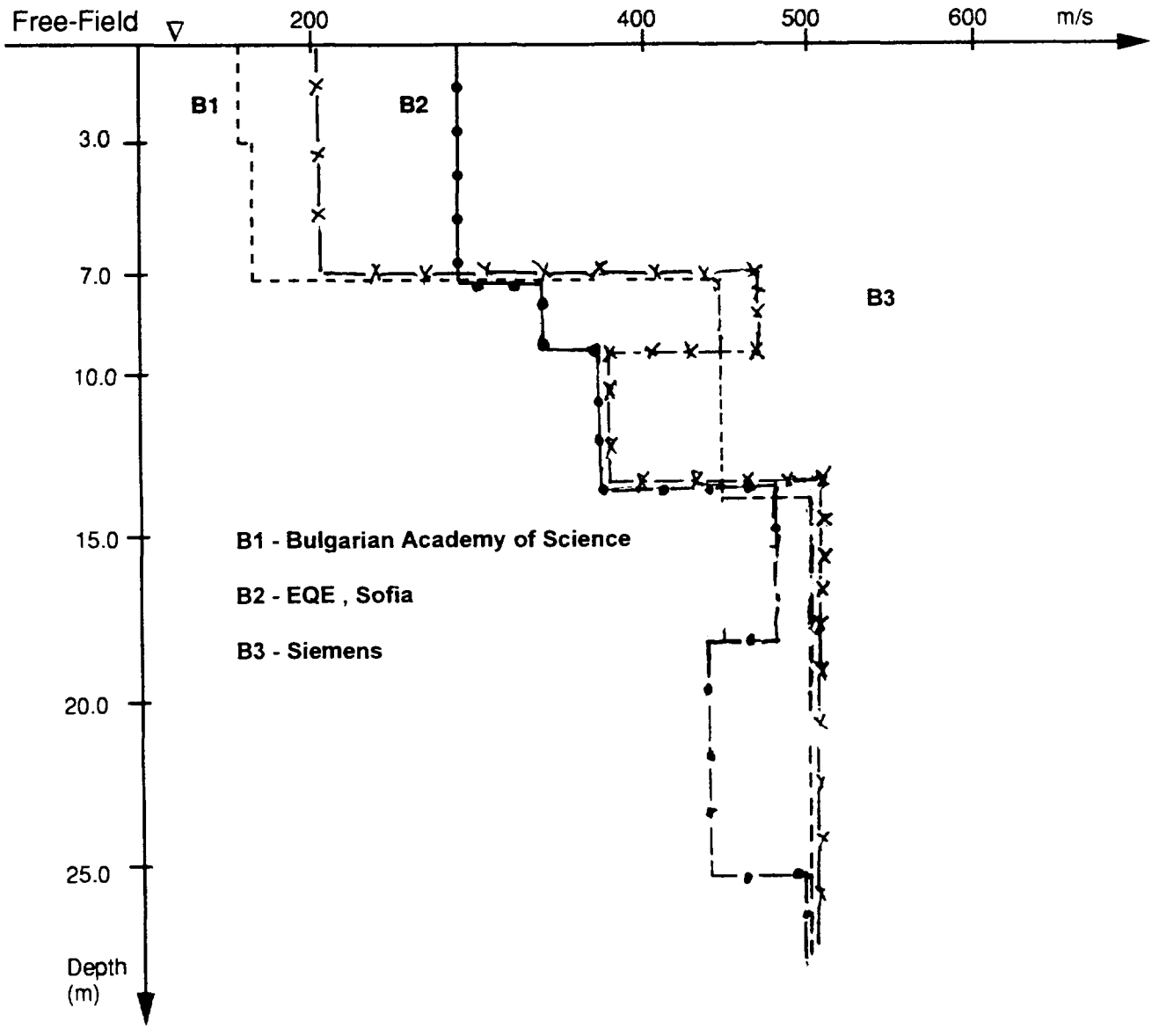


Fig. 3-3 Reactor Building KOZLODUY, Unit 5
Comparison of Soil Profile

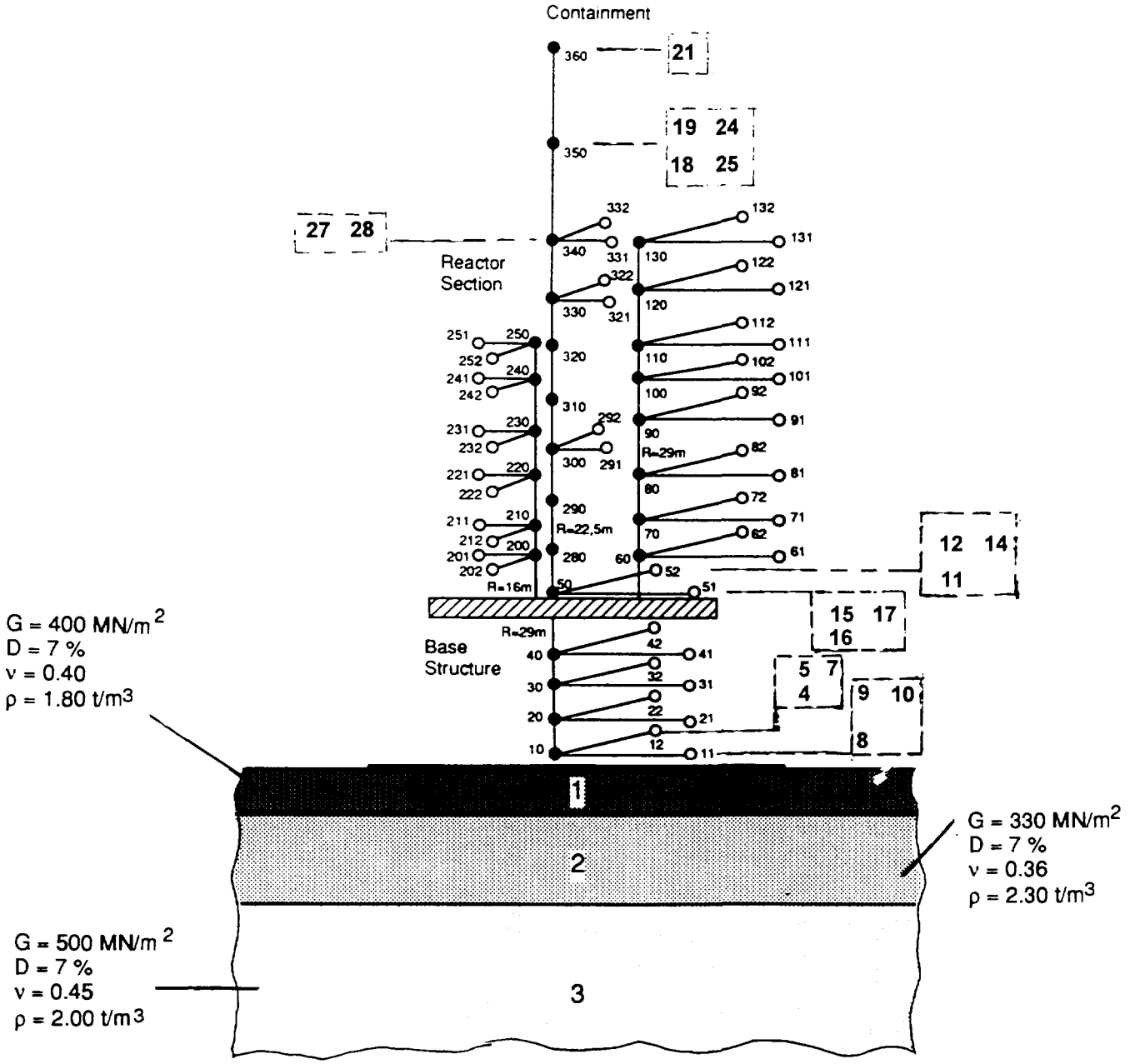


**Fig. 3-4 Reactor Building KOZLODUY, Unit 5
Foundation Model (Embedded Case)**

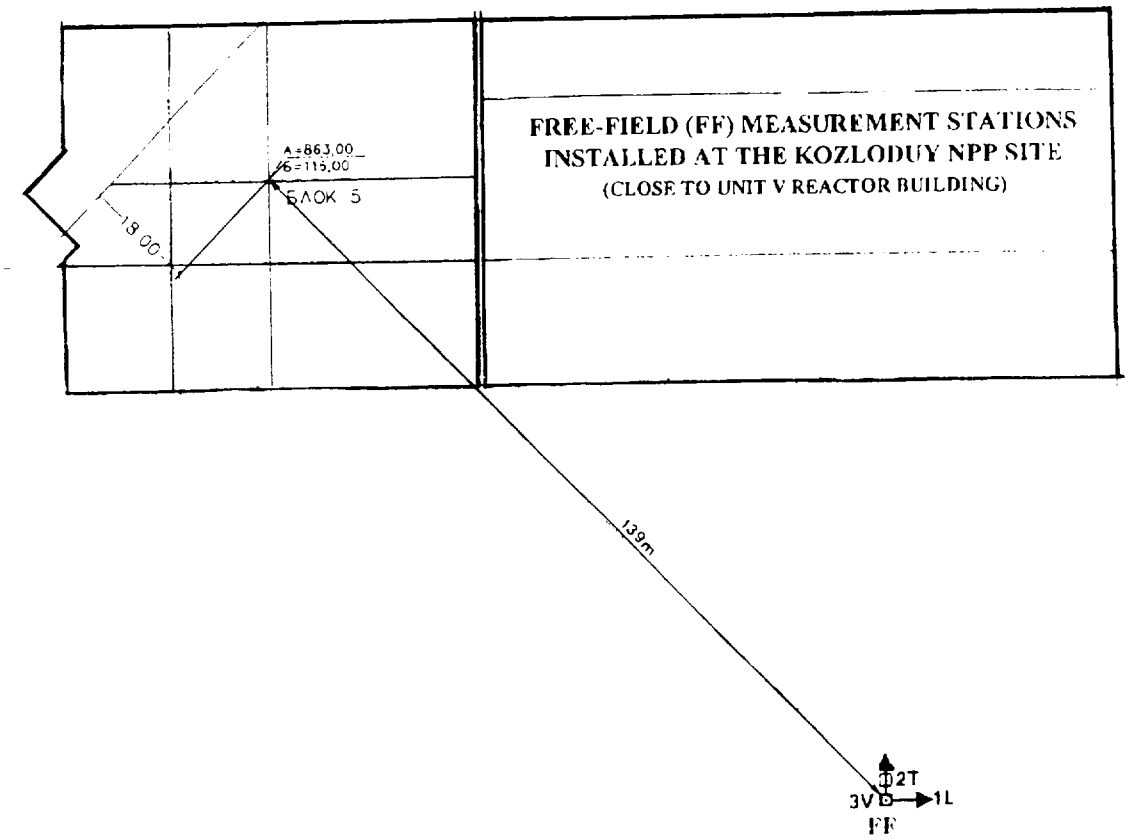


Fig. 4-1 Free-Field Measurements at KOZLODUY Site, Unit 5 During Blast

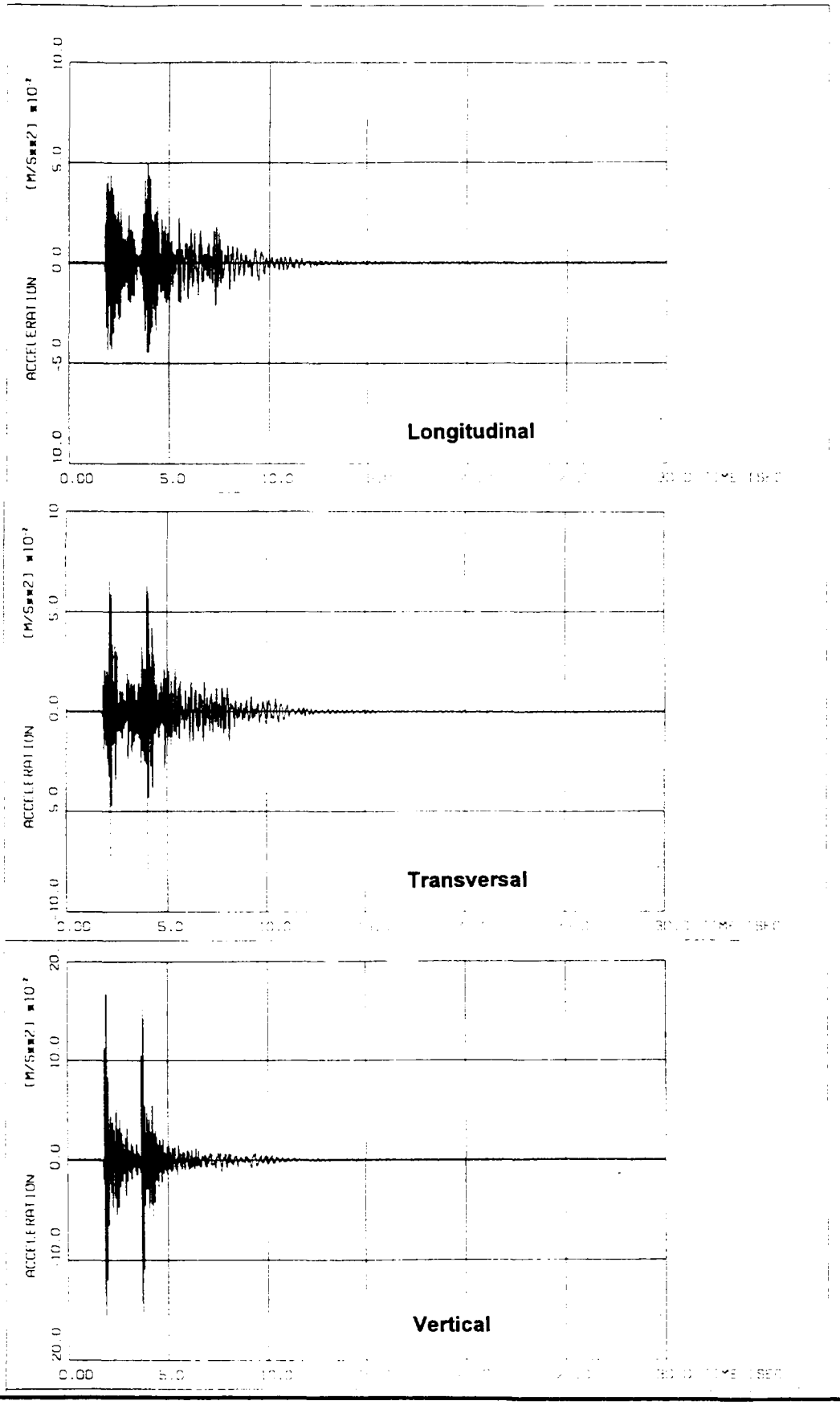


Fig. 4-2 Acceleration Time Histories Measured in Distance of about 139 m (FF) from Centre of KOZLODUY Unit 5

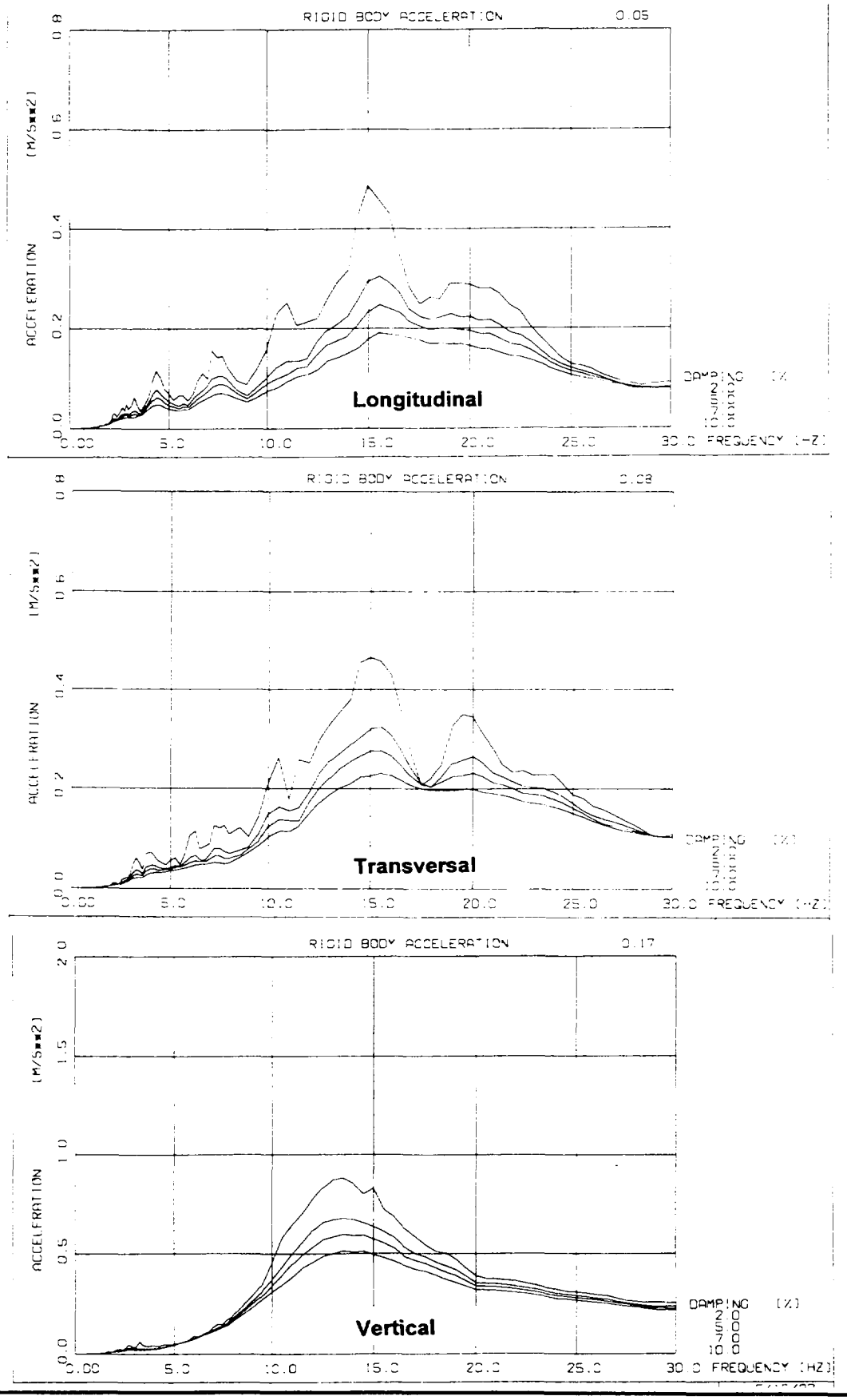
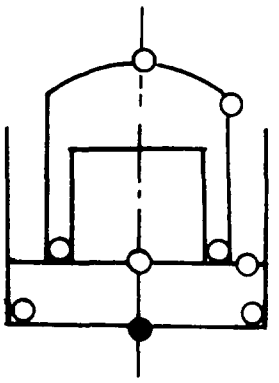


Fig. 4-3 Acceleration Response Spectra of the Excitations Measured in Location (FF)



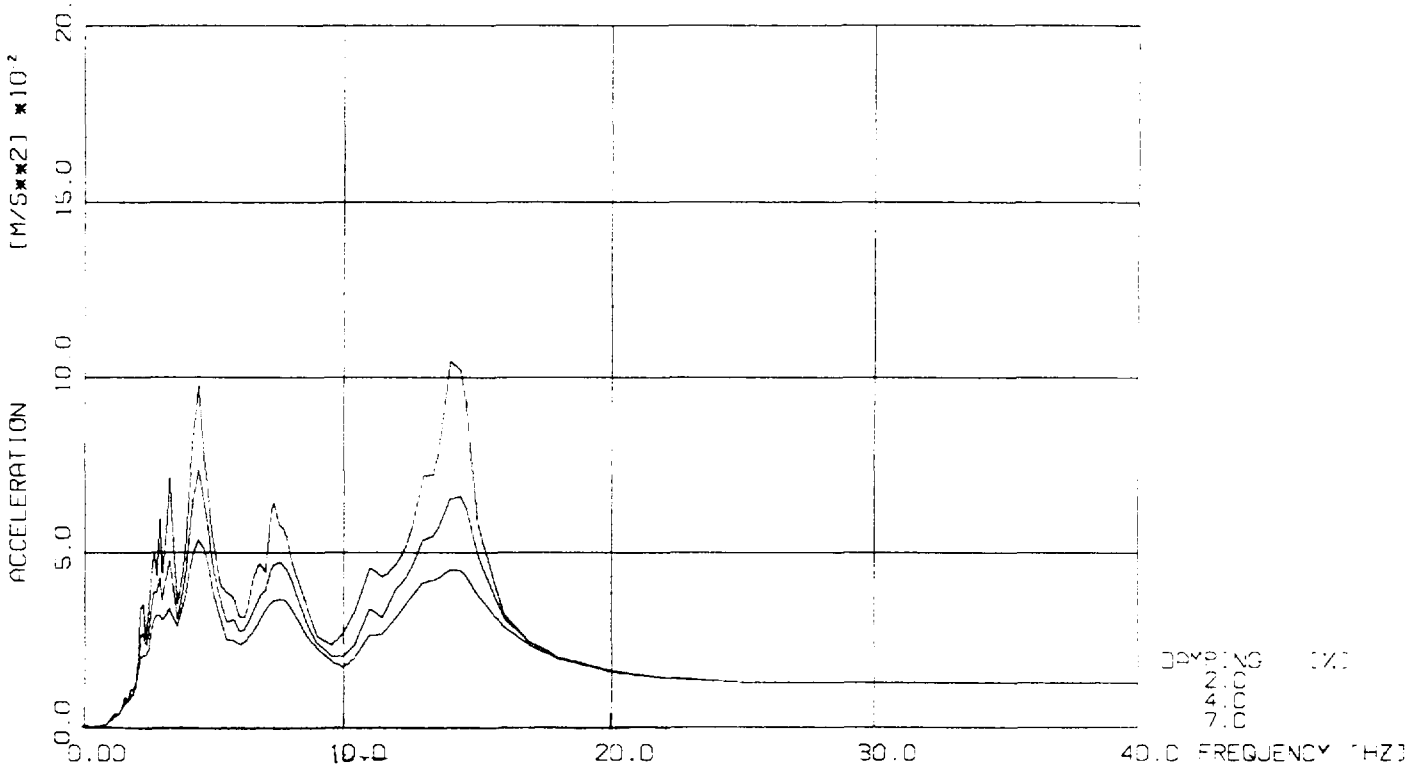
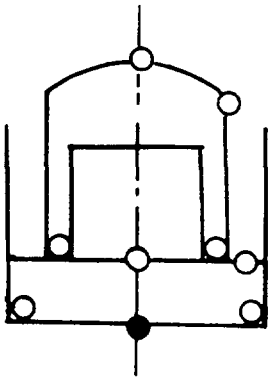


Fig. 5-1 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Found. Level - 6,5 m, Node 10, Direction 1
Instr. Points -



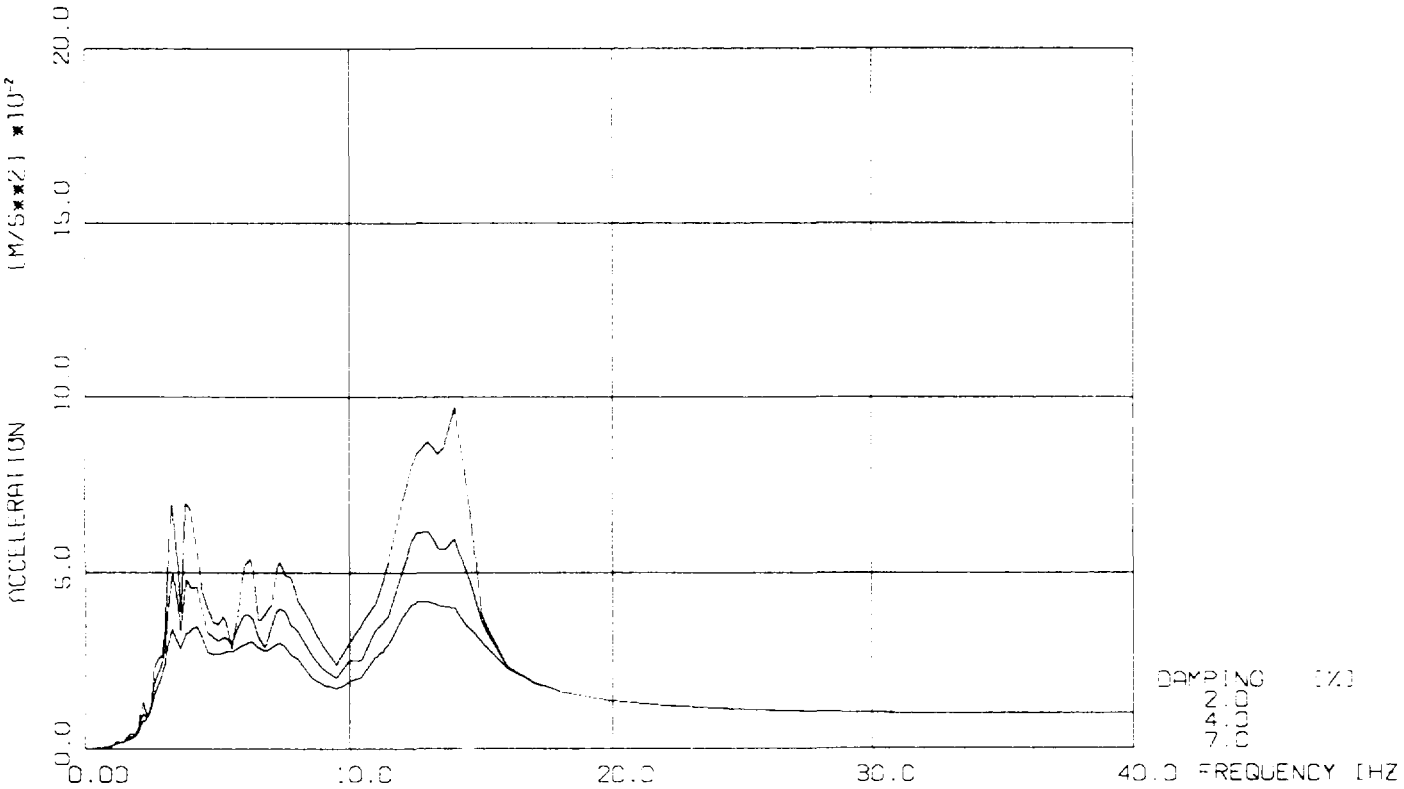
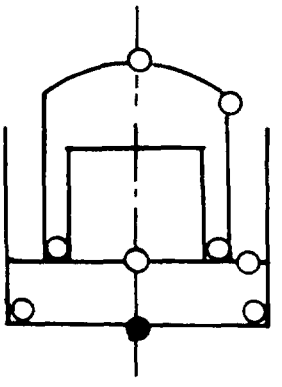


Fig. 5-2 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Found. Level - 6,5 m, Node 10, Direction 2
Instr. Points -



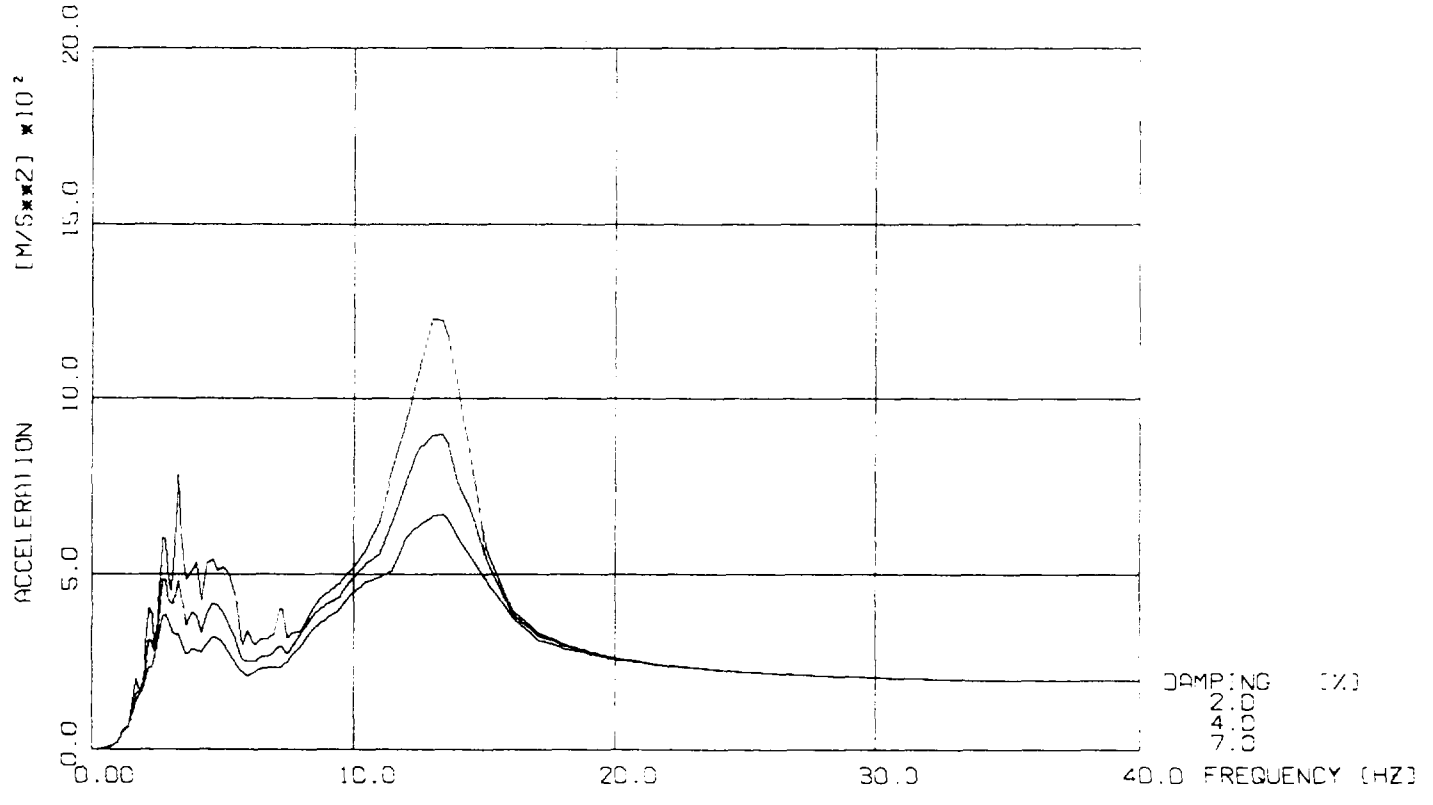
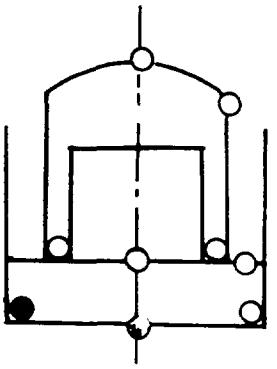


Fig. 5-3 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Found. Level - 6,5 m, Node 10, Direction 3
Instr. Points -



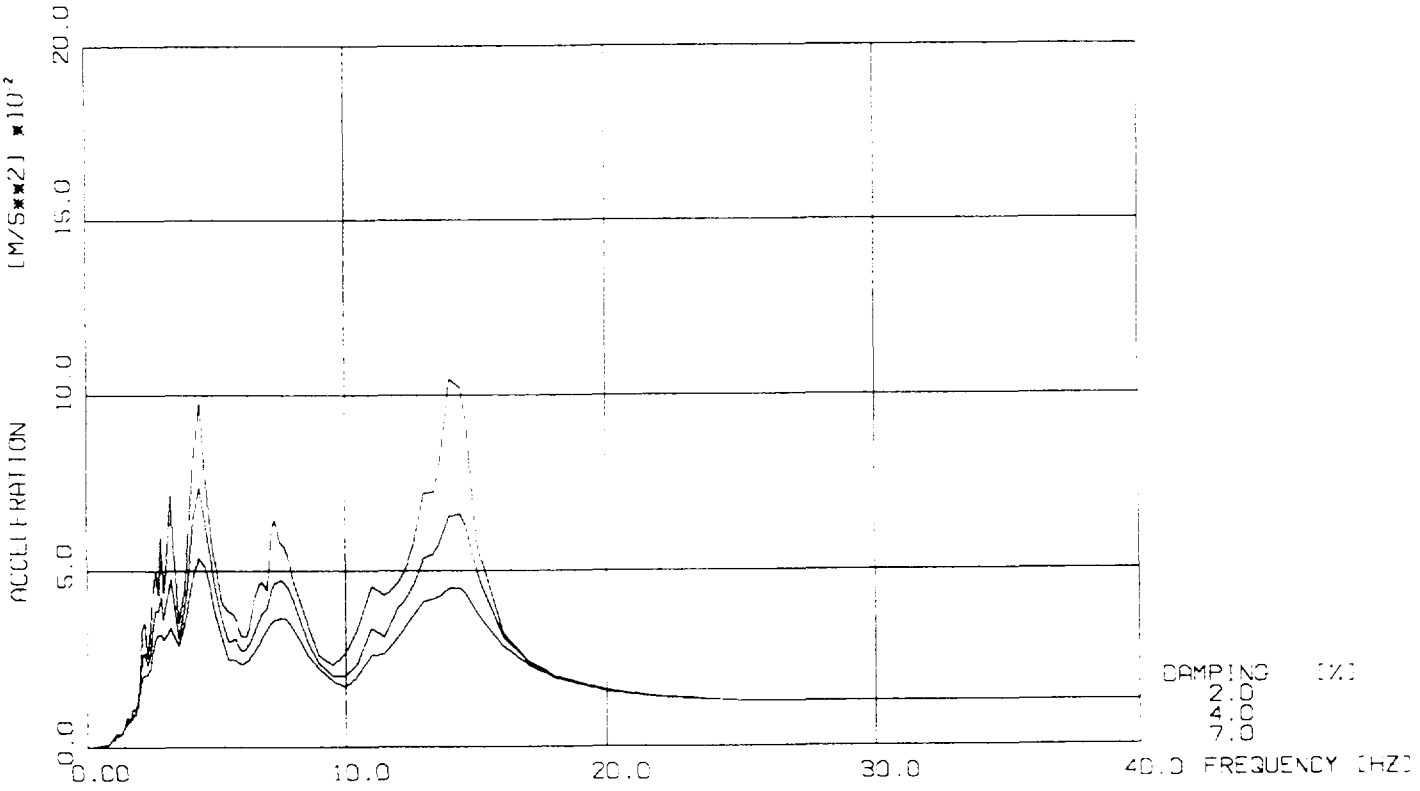
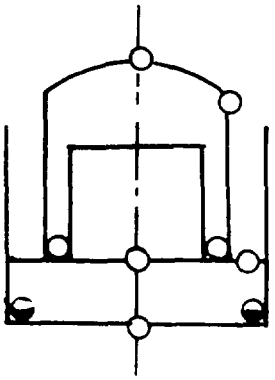


Fig. 5-4 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Found. Level - 6,5 m, Node 11, Direction 1
Instr. Points 8 and 6



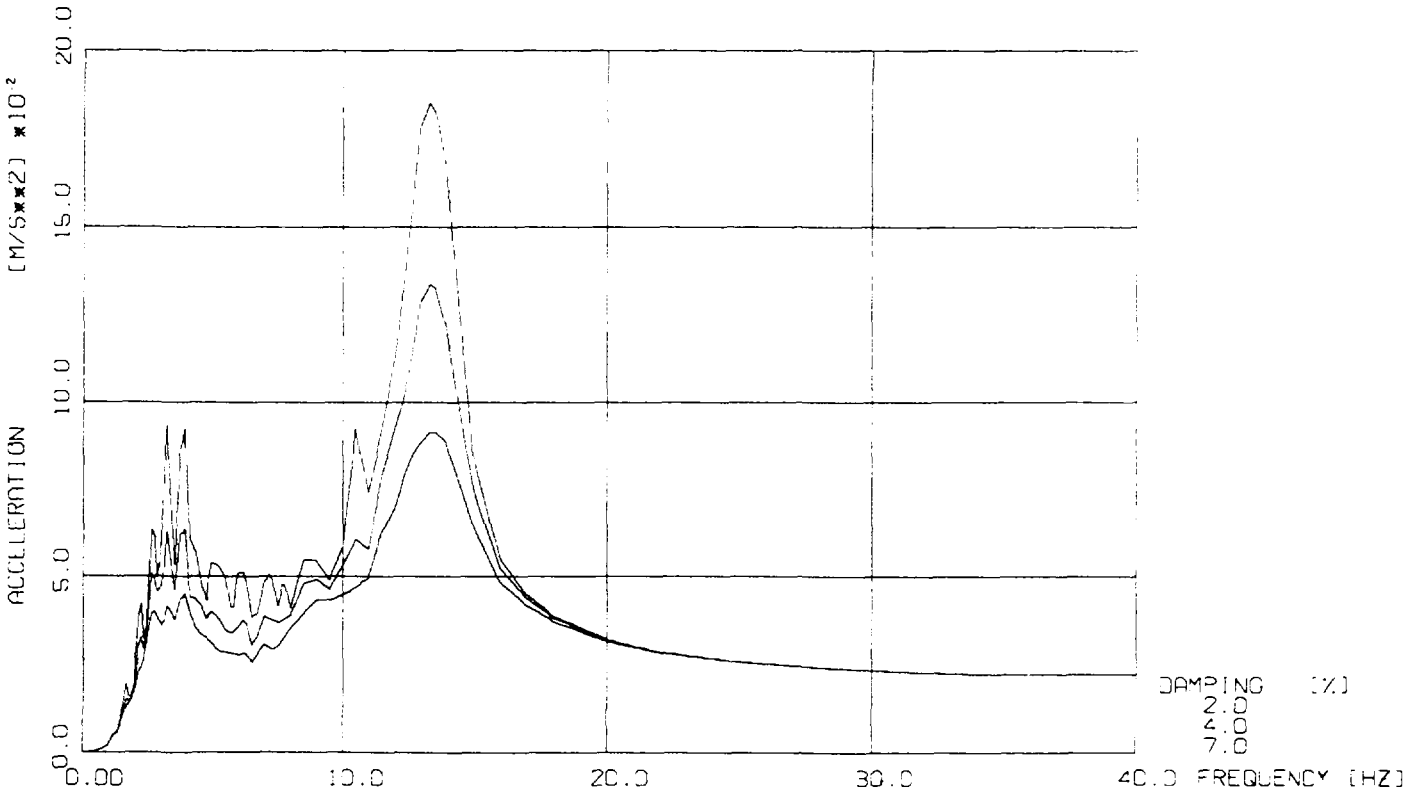
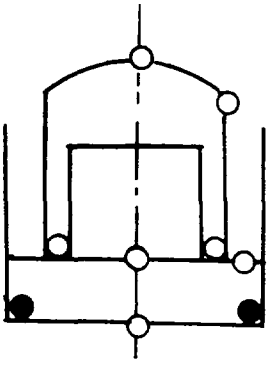


Fig. 5-5 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Found. Level - 6,5 m, Node 11, Direction 2
Instr. Points - and -



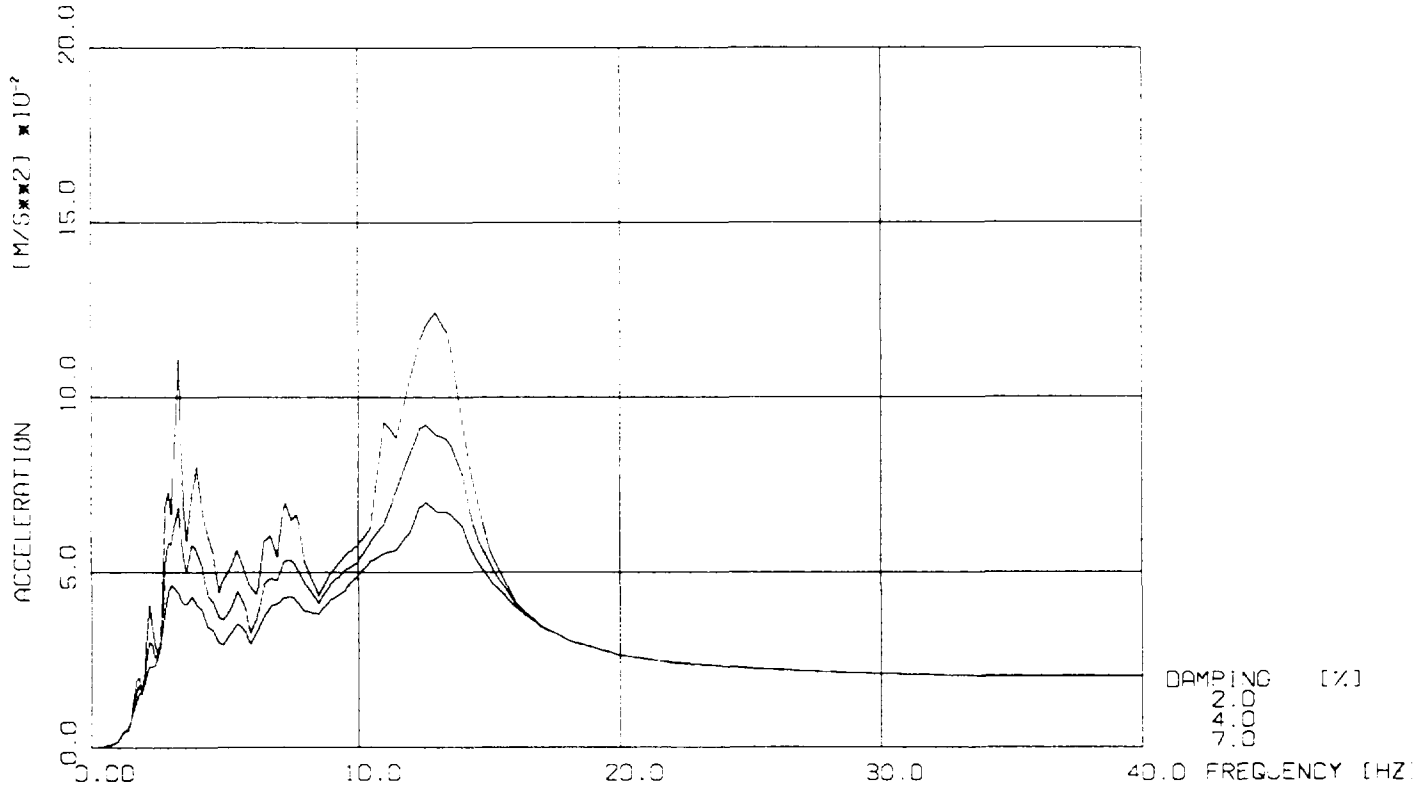
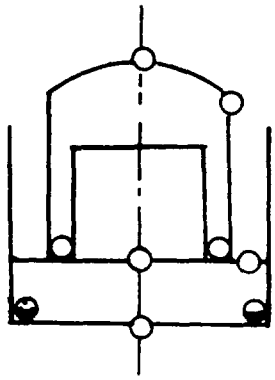


Fig. 5-6 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Found. Level - 6,5 m, Node 11, Direction 3
Instr. Points 9 and 10



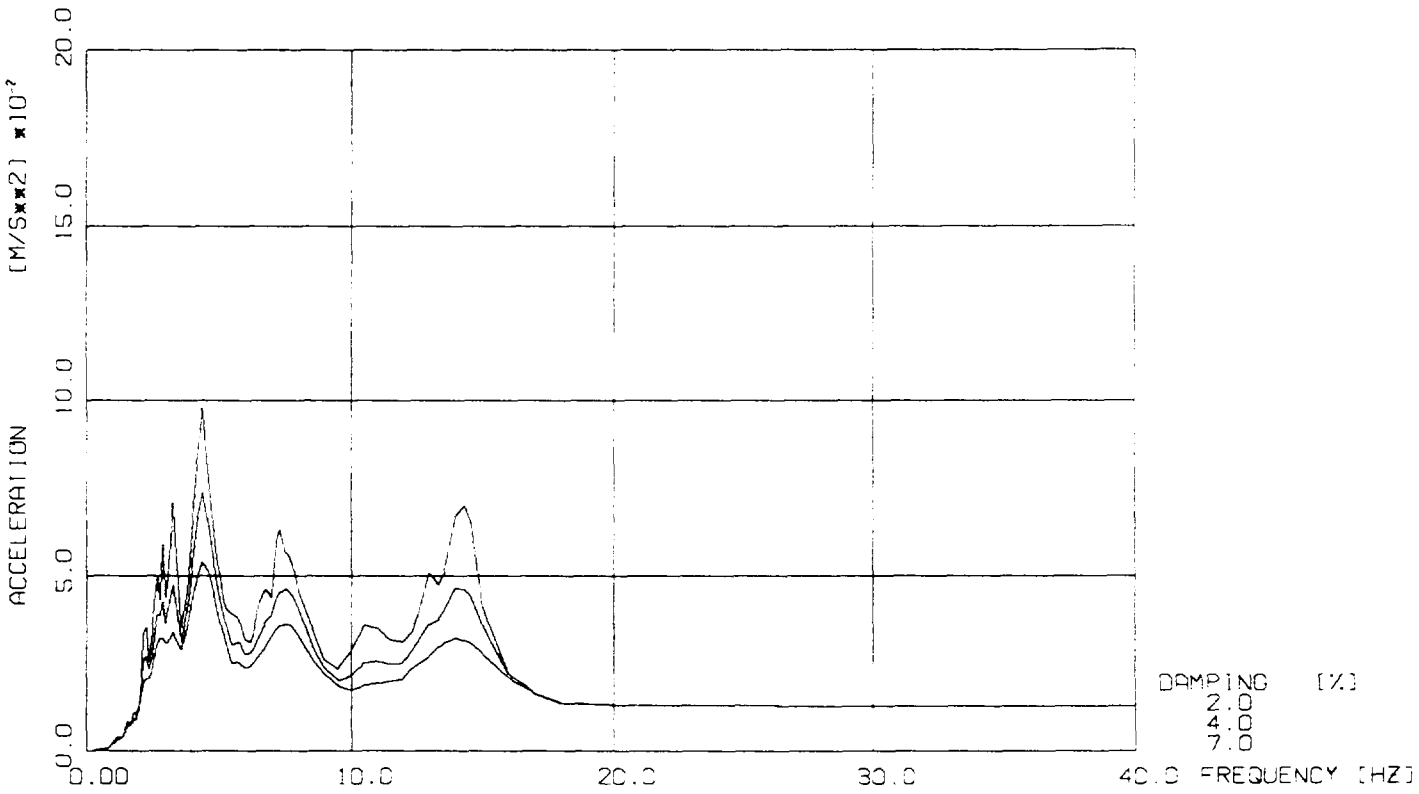
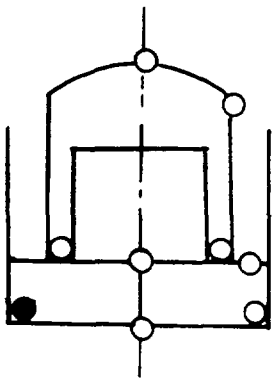


Fig. 5-7 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Found. Level - 6,5 m, Node 12, Direction 1
Instr. Point 8 and 6



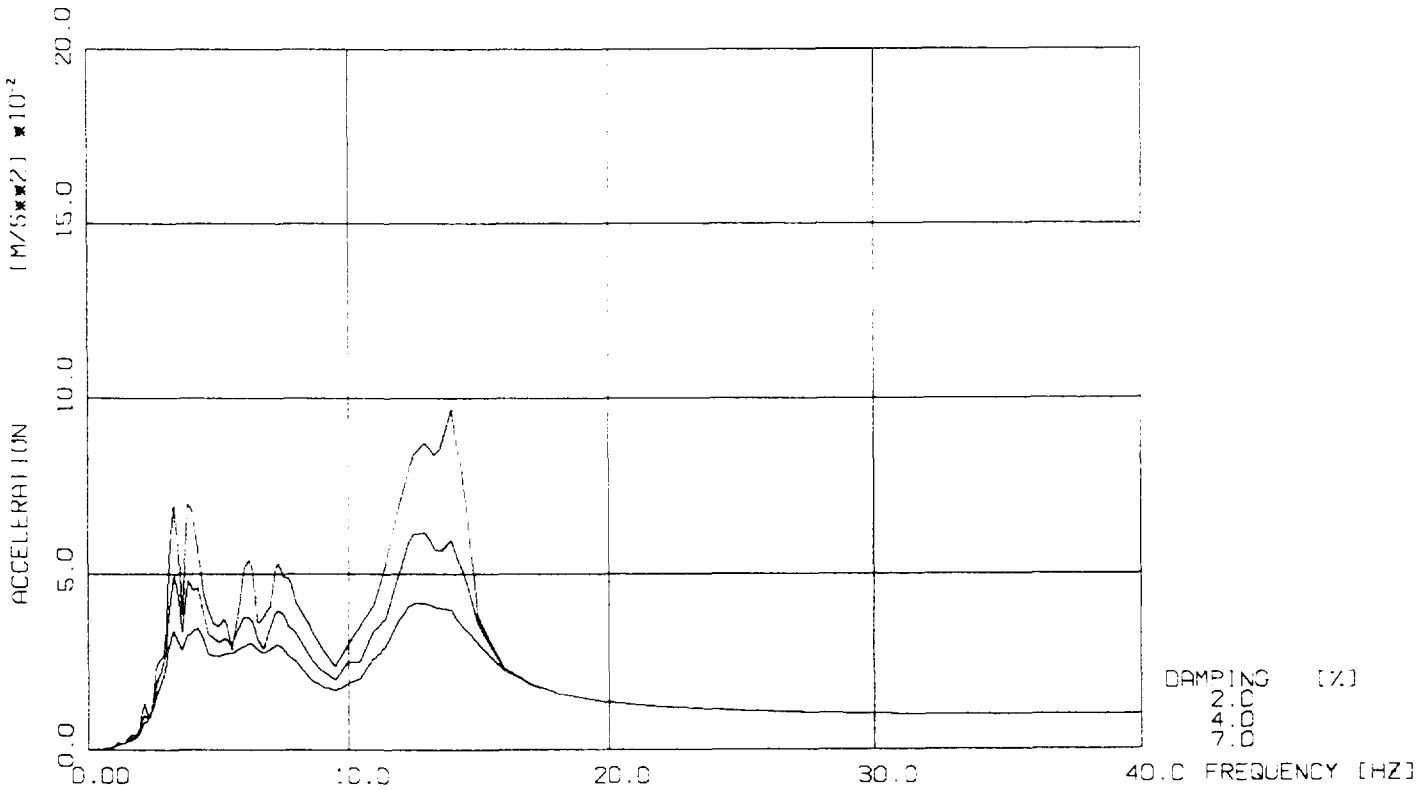
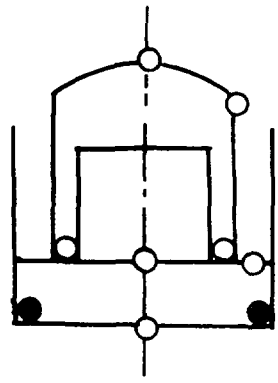


Fig. 5-8 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Found. Level - 6,5 m, Node 12, Direction 2
Instr. Points 4 and -



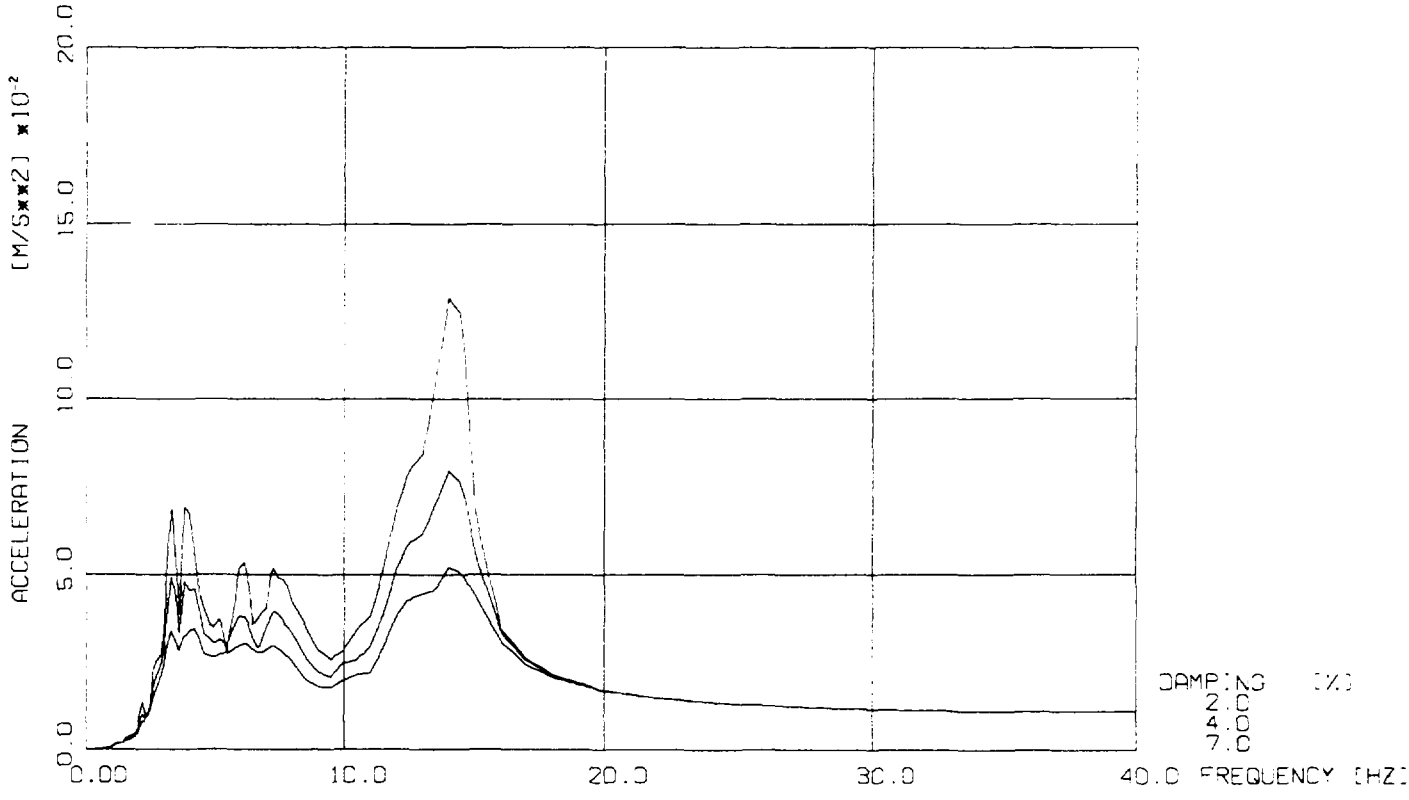
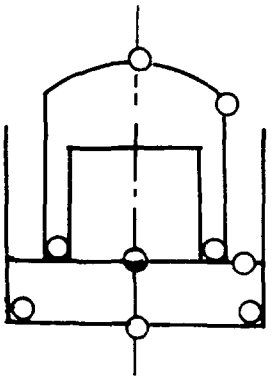


Fig. 5-9 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Found. Level - 6,5 m, Node 12, Direction 3
Instr. Points 5 and 7



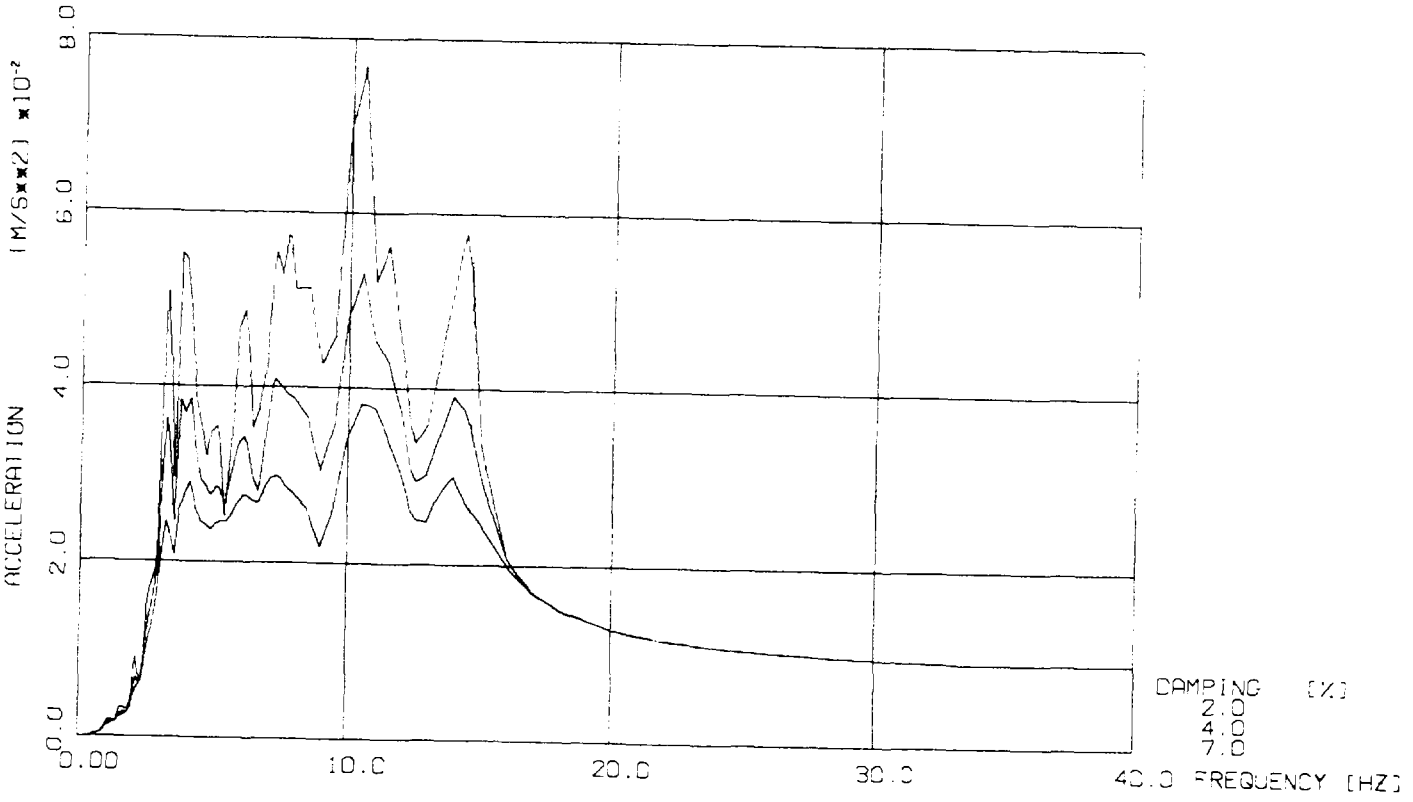
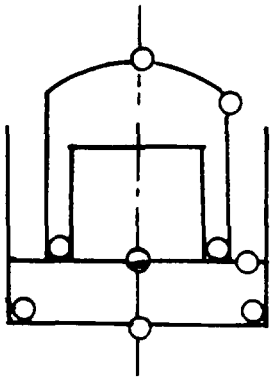


Fig. 5-10 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 13,2 m, Node 50, Direction 1
Instr. Point 11



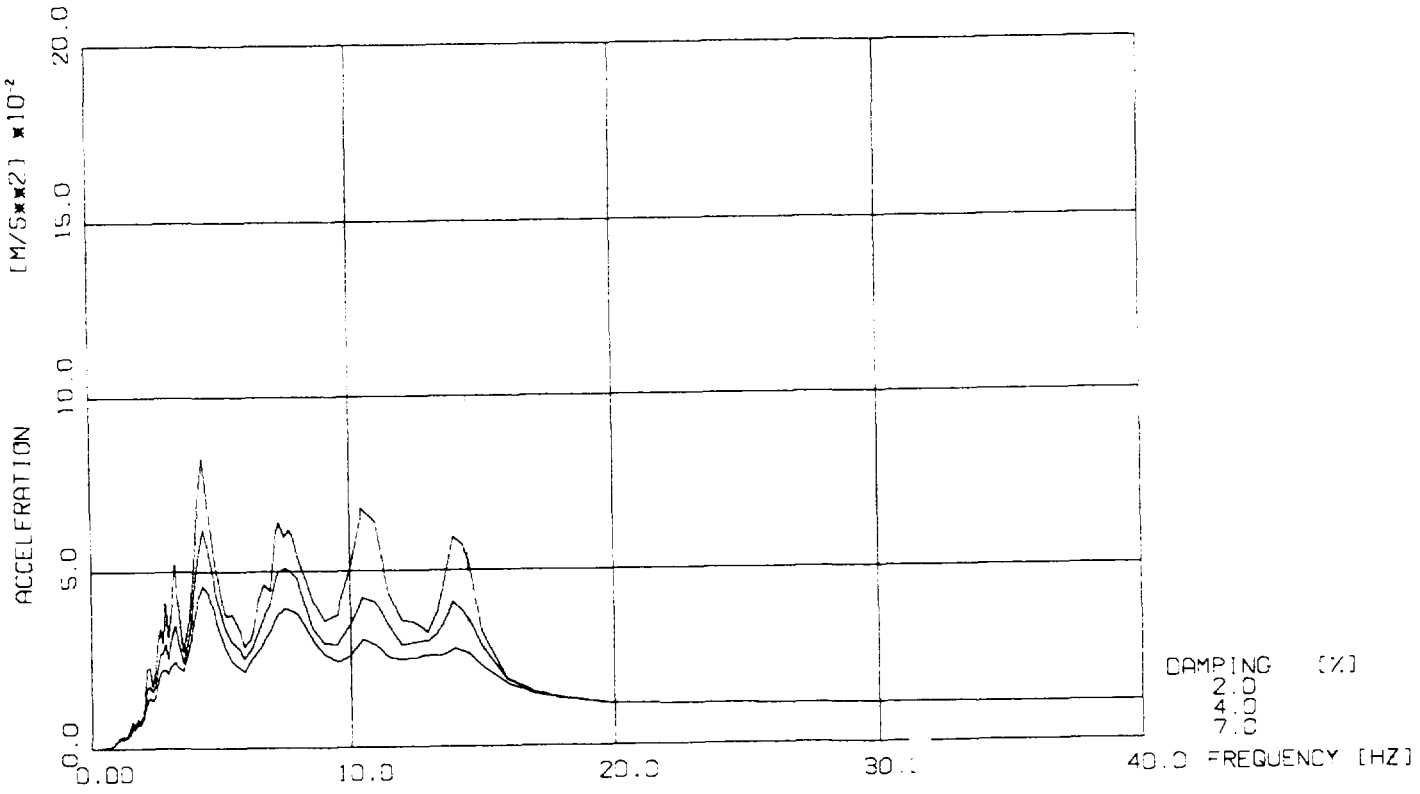


Fig. 5-11 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 13,2 m, Node 50, Direction 2 Instr. Points -

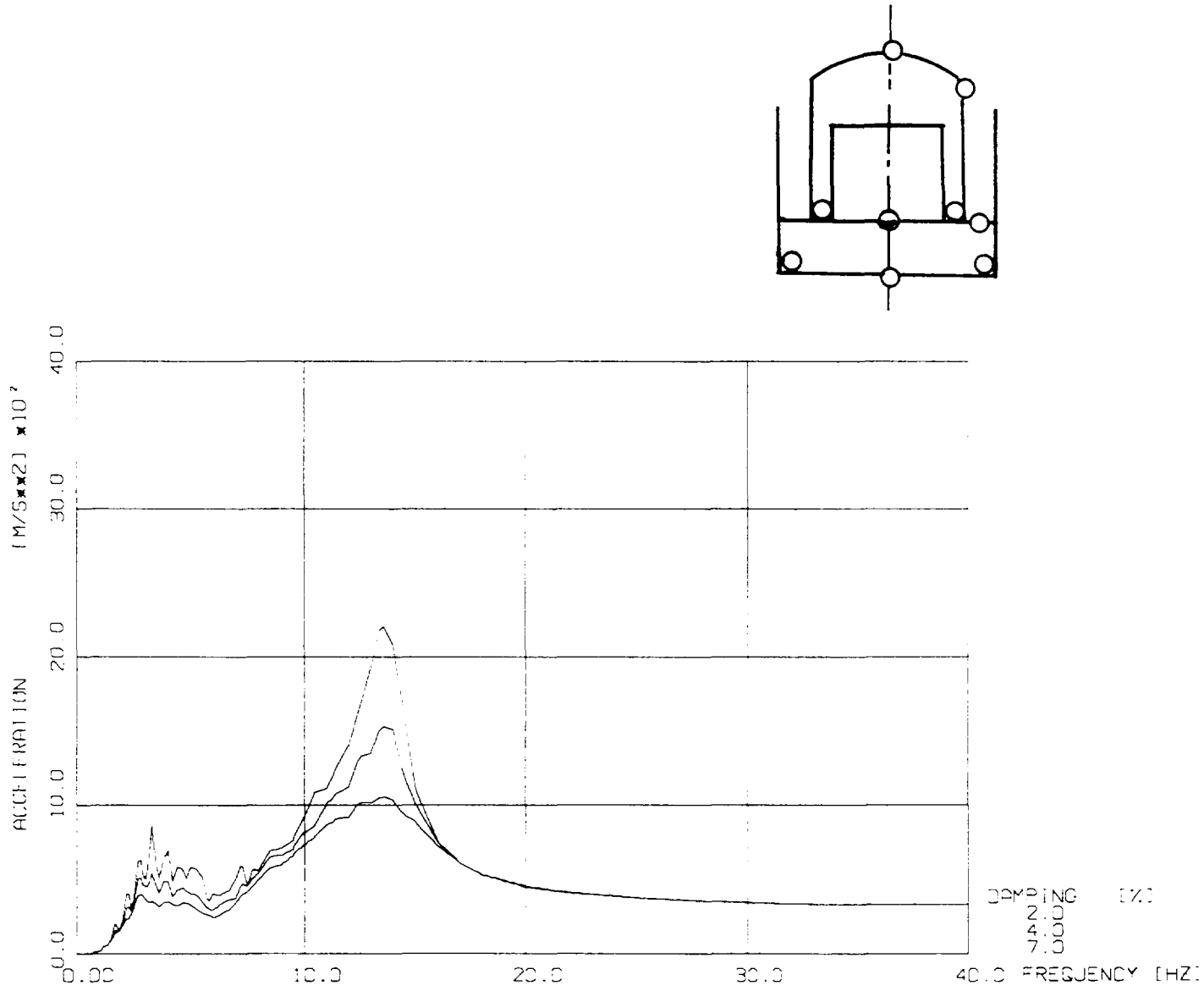


Fig. 5-12 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 13,2 m, Node 50, Direction 3 Instr. Points -

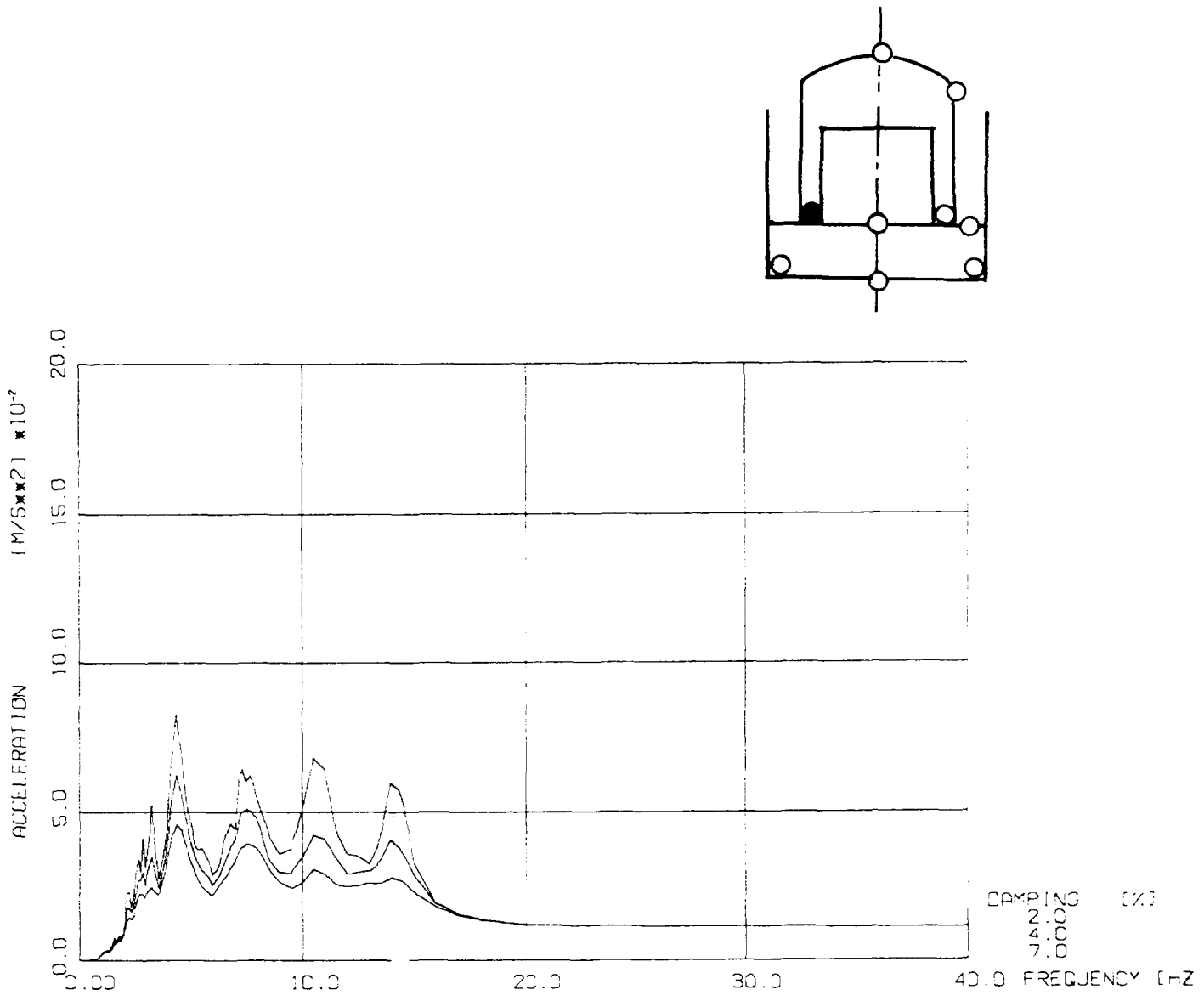
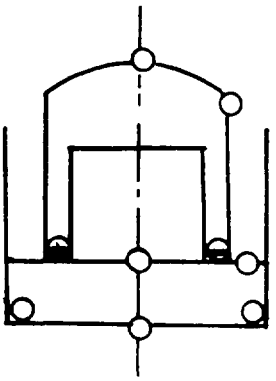


Fig. 5-13 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 13,2 m, Node 51, Direction 1 Instr. Points 16 and -



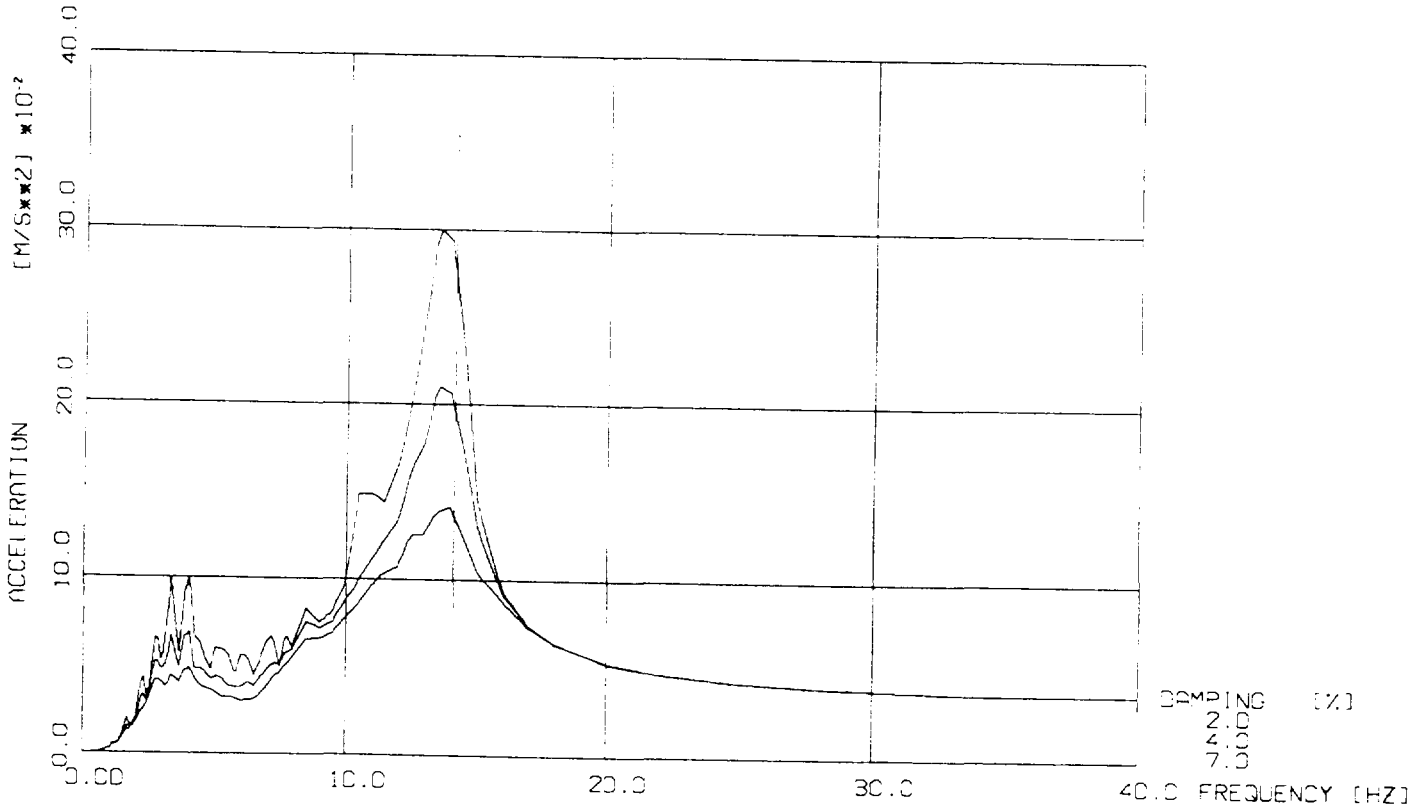
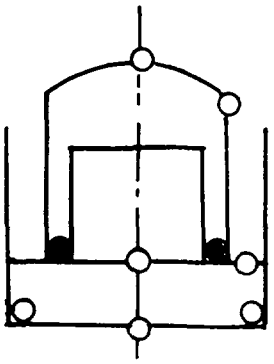


Fig. 5-14 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 13,2 m, Node 51, Direction 2 Instr. Points - and -



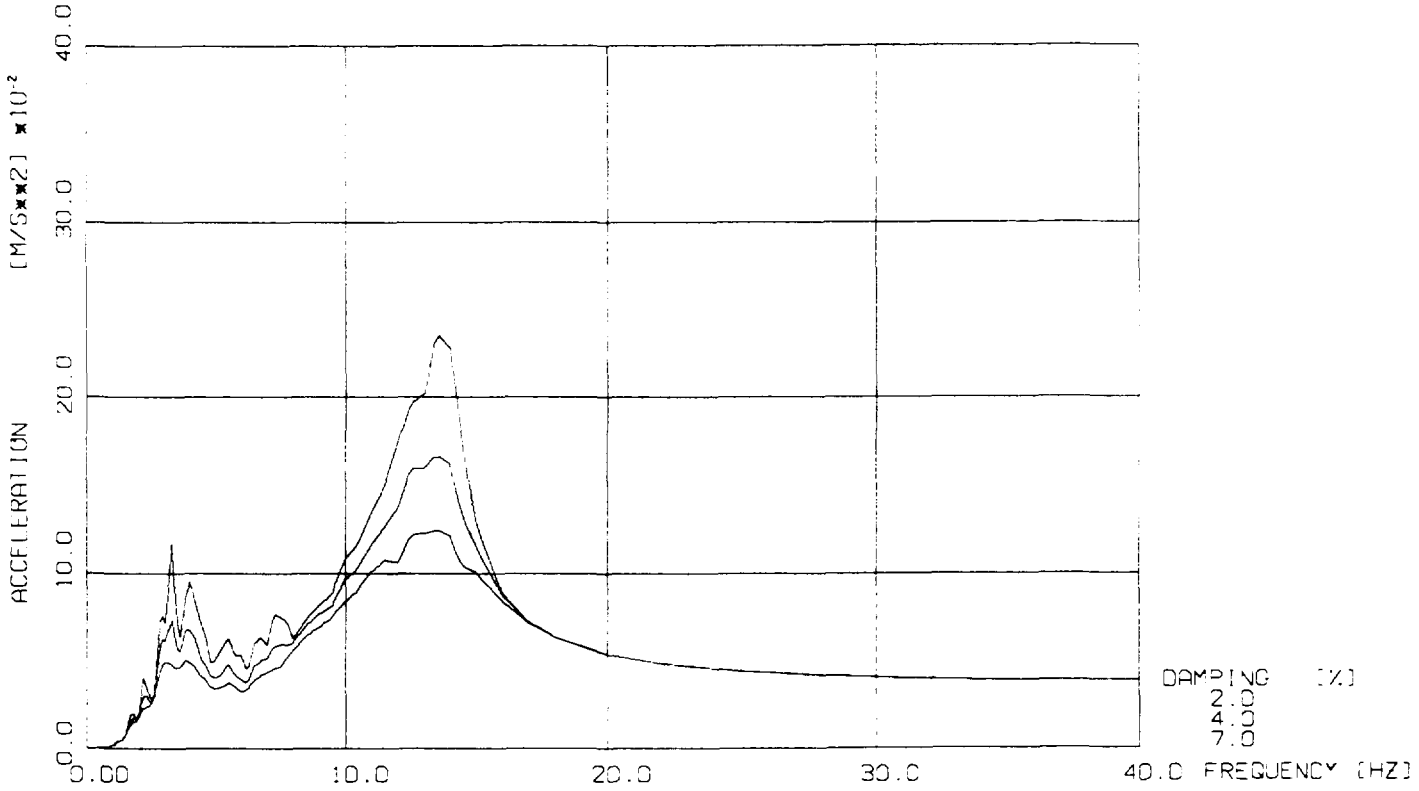
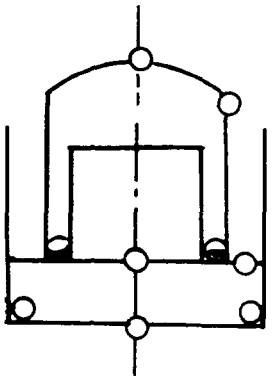


Fig. 5-15 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 13,2 m, Node 51, Direction 3
Instr. Points 15 and 17



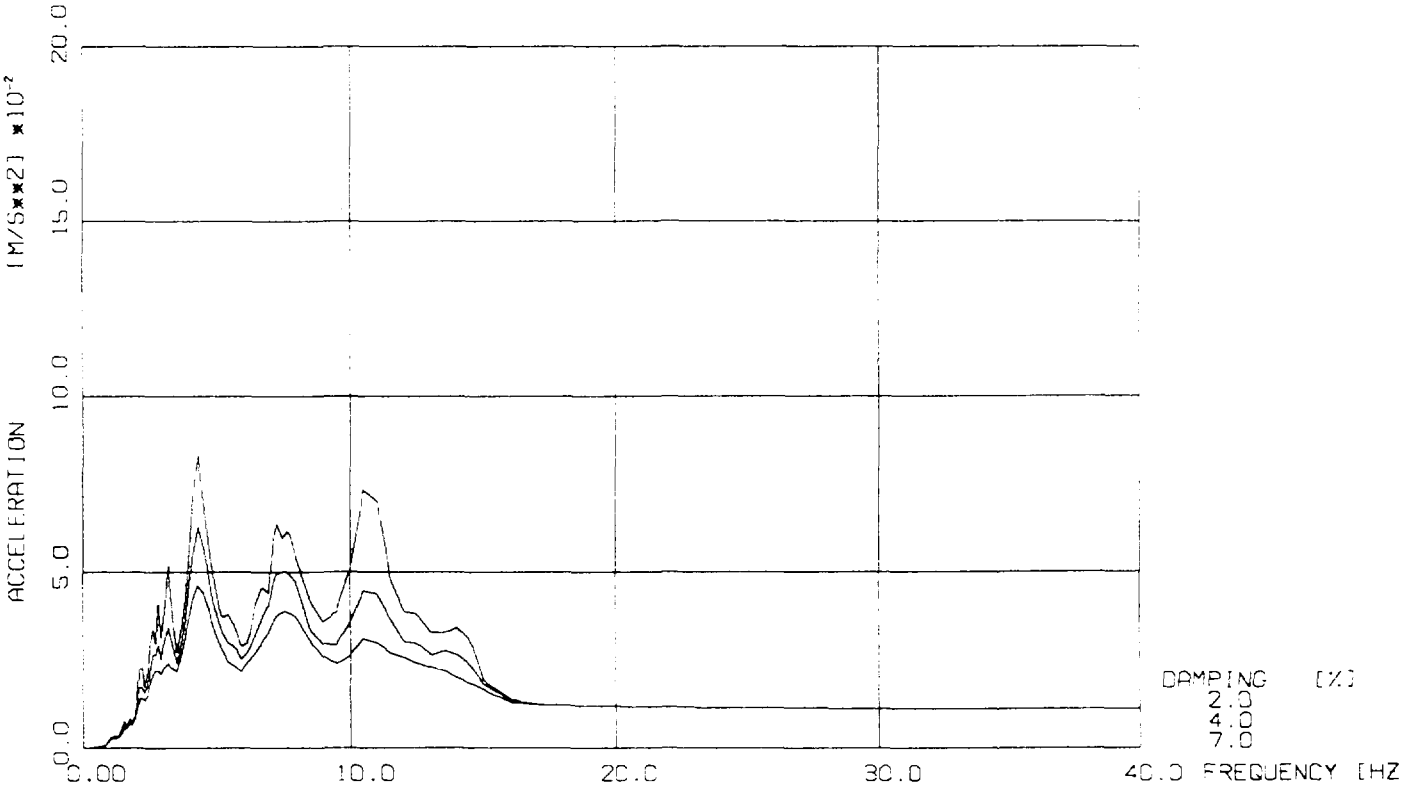
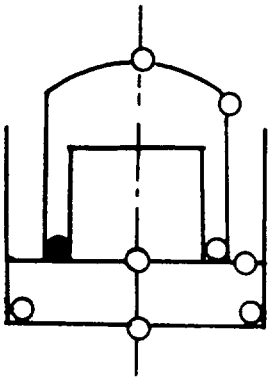


Fig. 5-16 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 13,2 m, Node 52, Direction 1 Instr. Points - and -



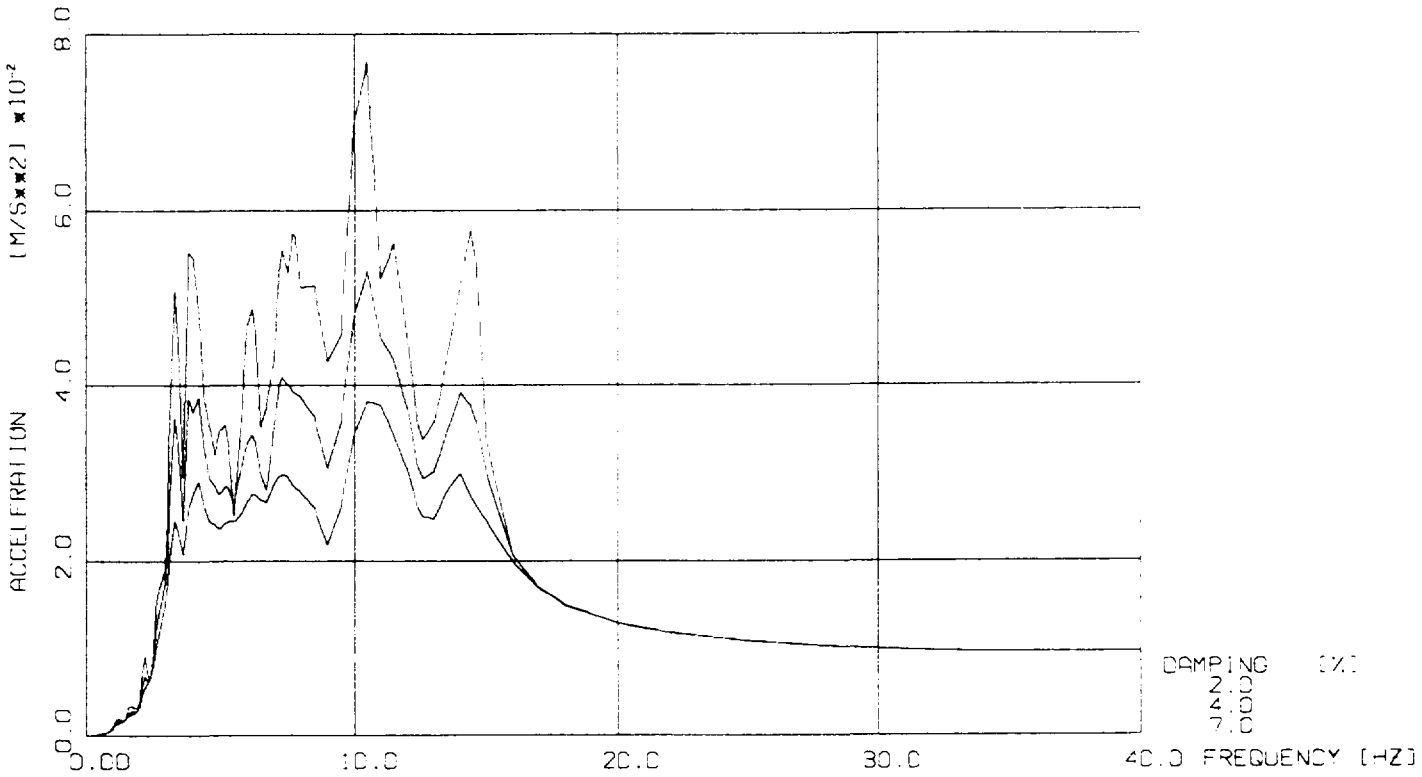
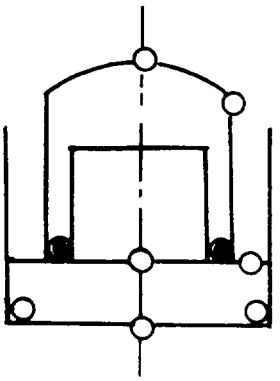


**Fig. 5-17 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 13,2 m, Node 52, Direction 2
Instr. Points 11 and -**



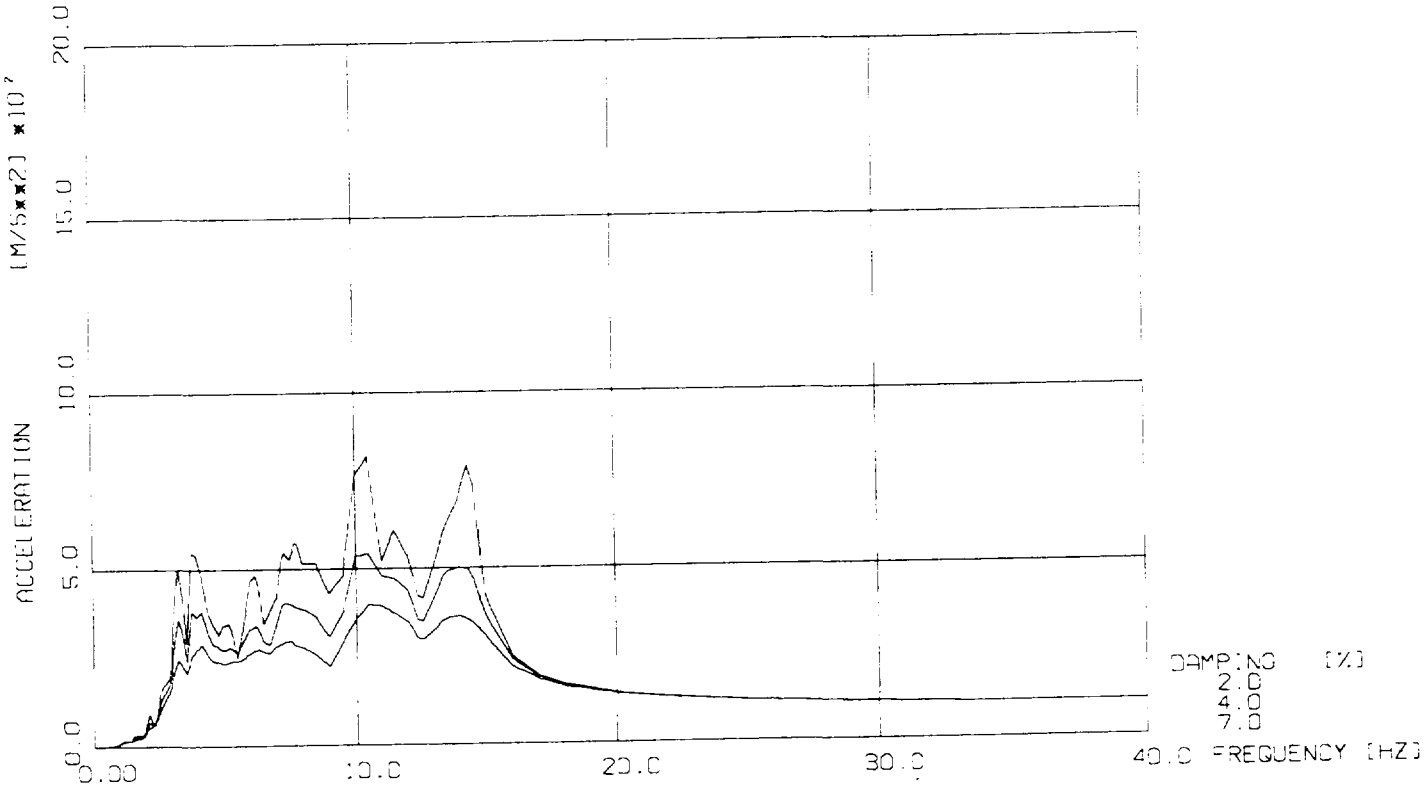
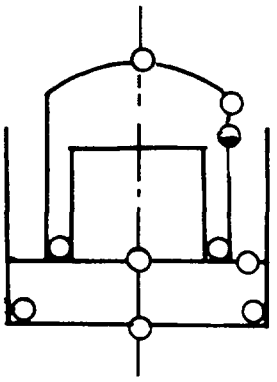


Fig. 5-18 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 13,2 m, Node 52, Direction 3 Instr. Points 12 and 14



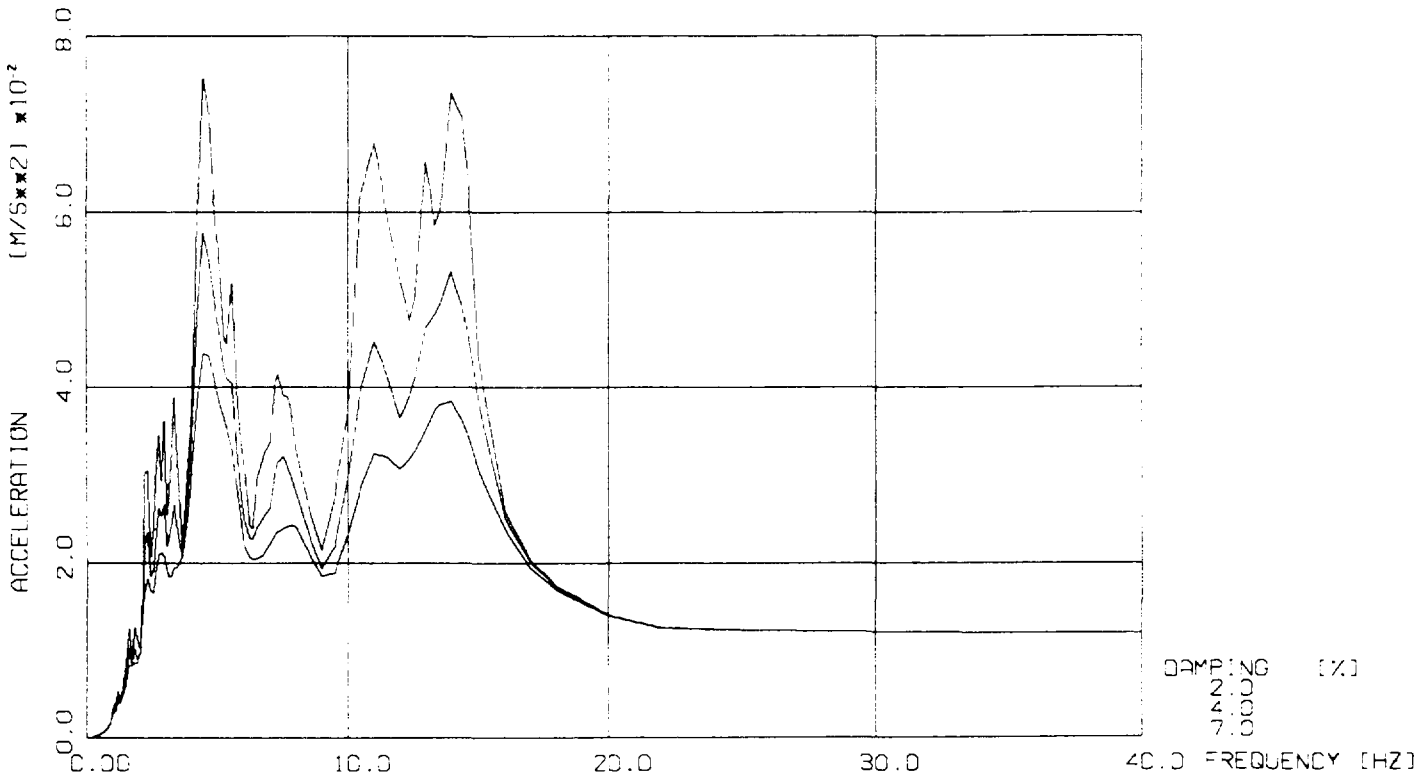
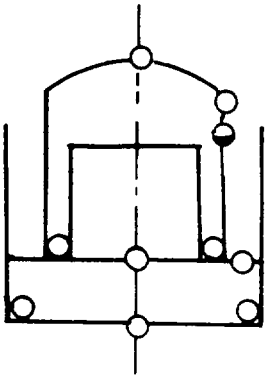


**Fig. 5-19 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 47,8 m, Node 340, Direction 1
Instr. Points -**



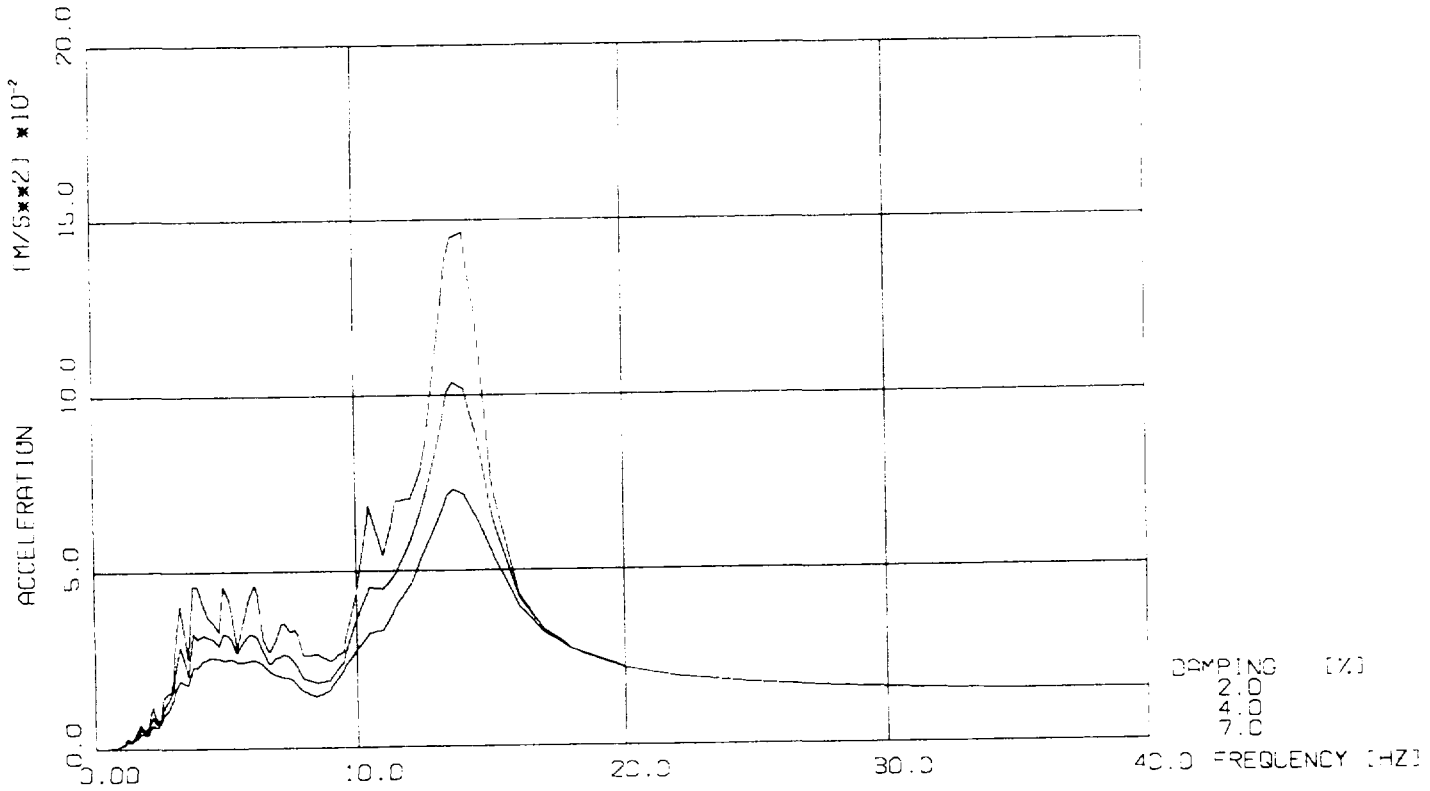
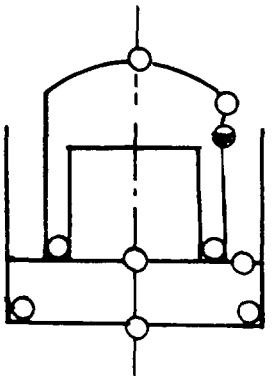


Fig. 5-20 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 47,8 m, Node 340, Direction 2
Instr. Points -



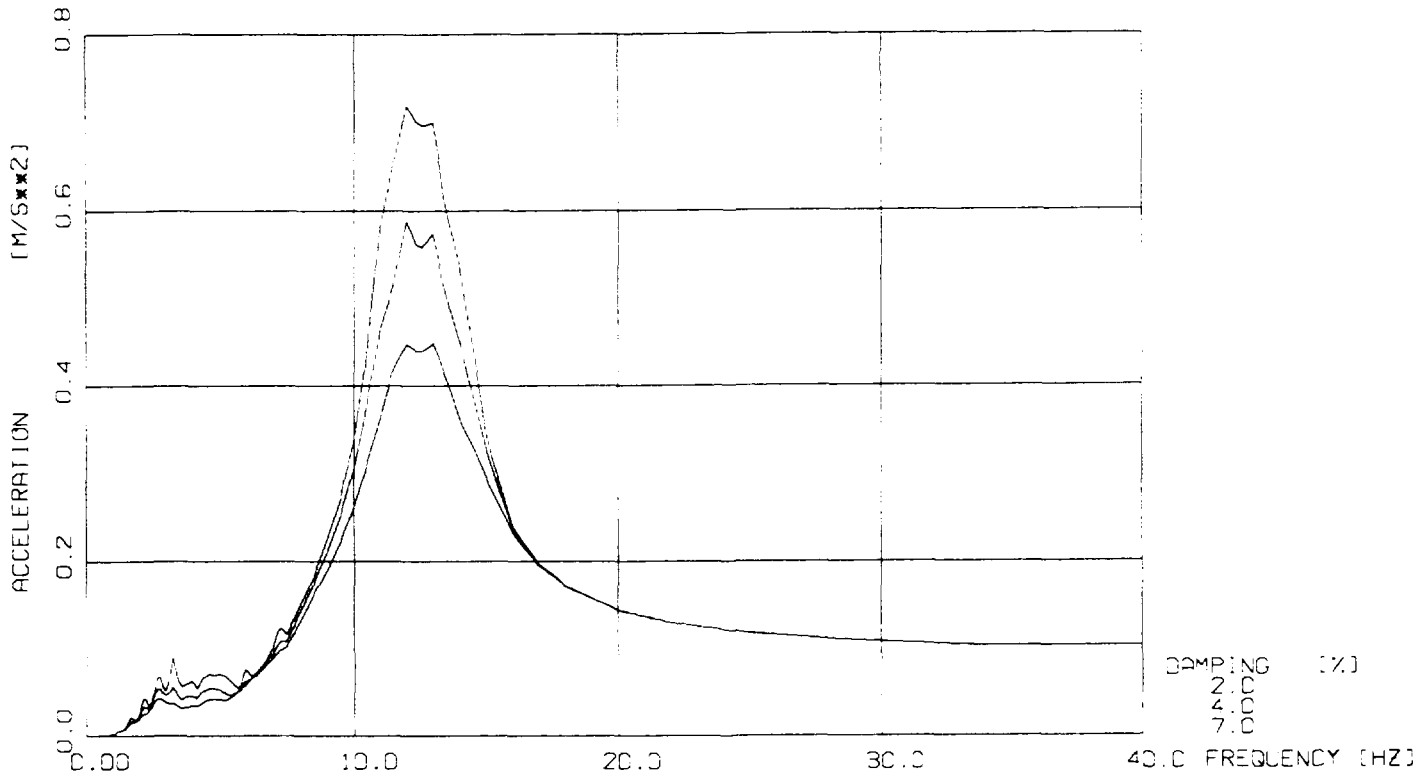
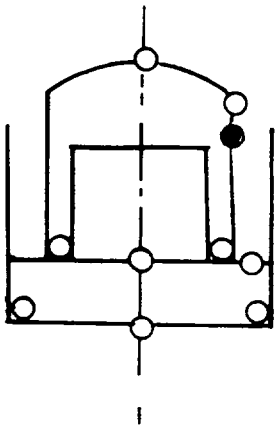


Fig. 5-21 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 47,8 m, Node 340, Direction 3
Instr. Points -



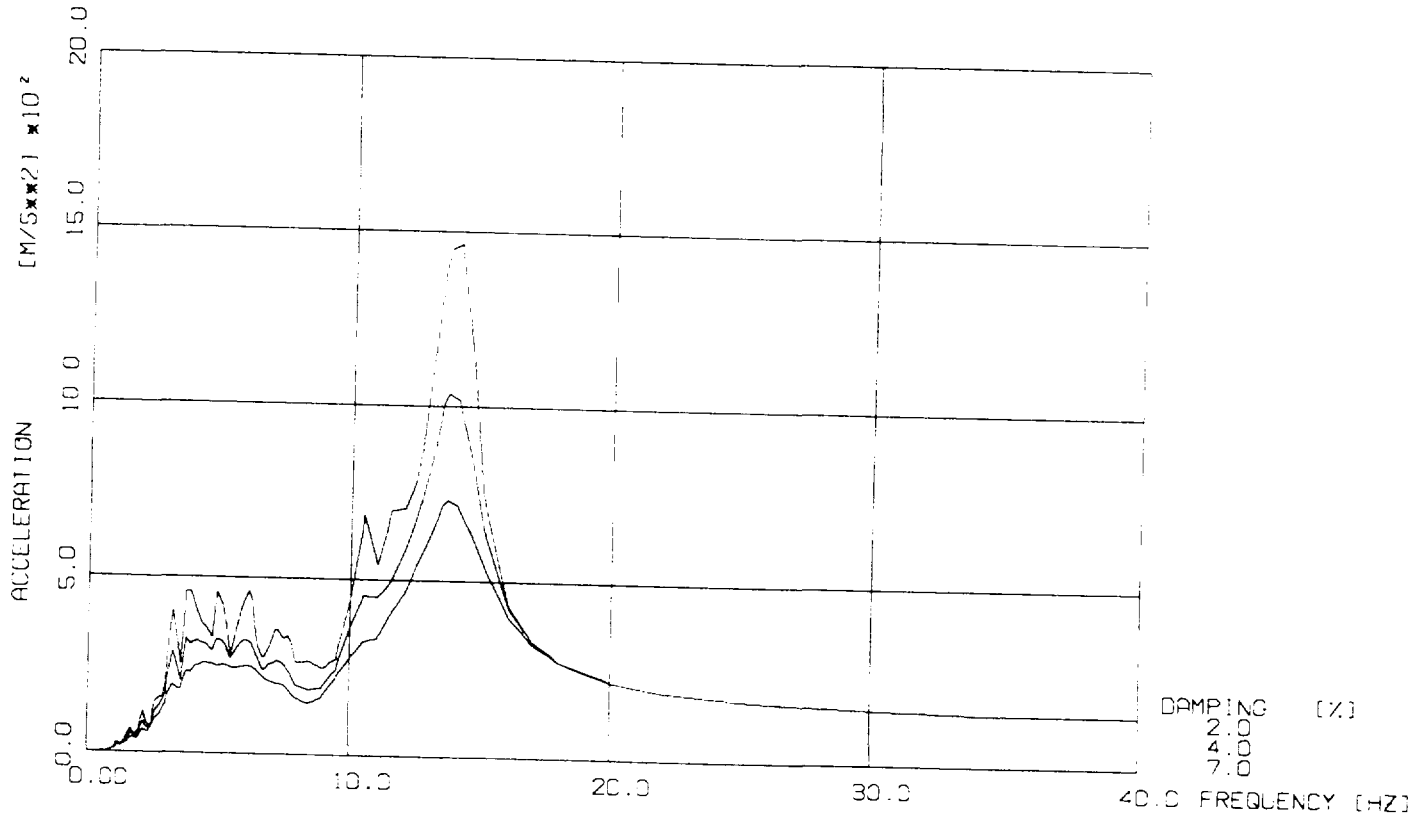
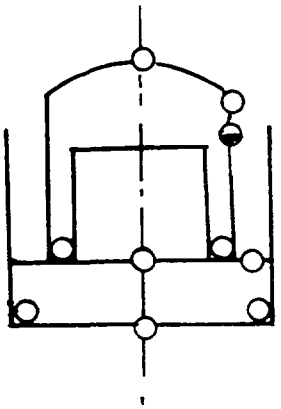


Fig. 5-22 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 47,8 m, Node 332, Direction 1 Instr. Points - and 28



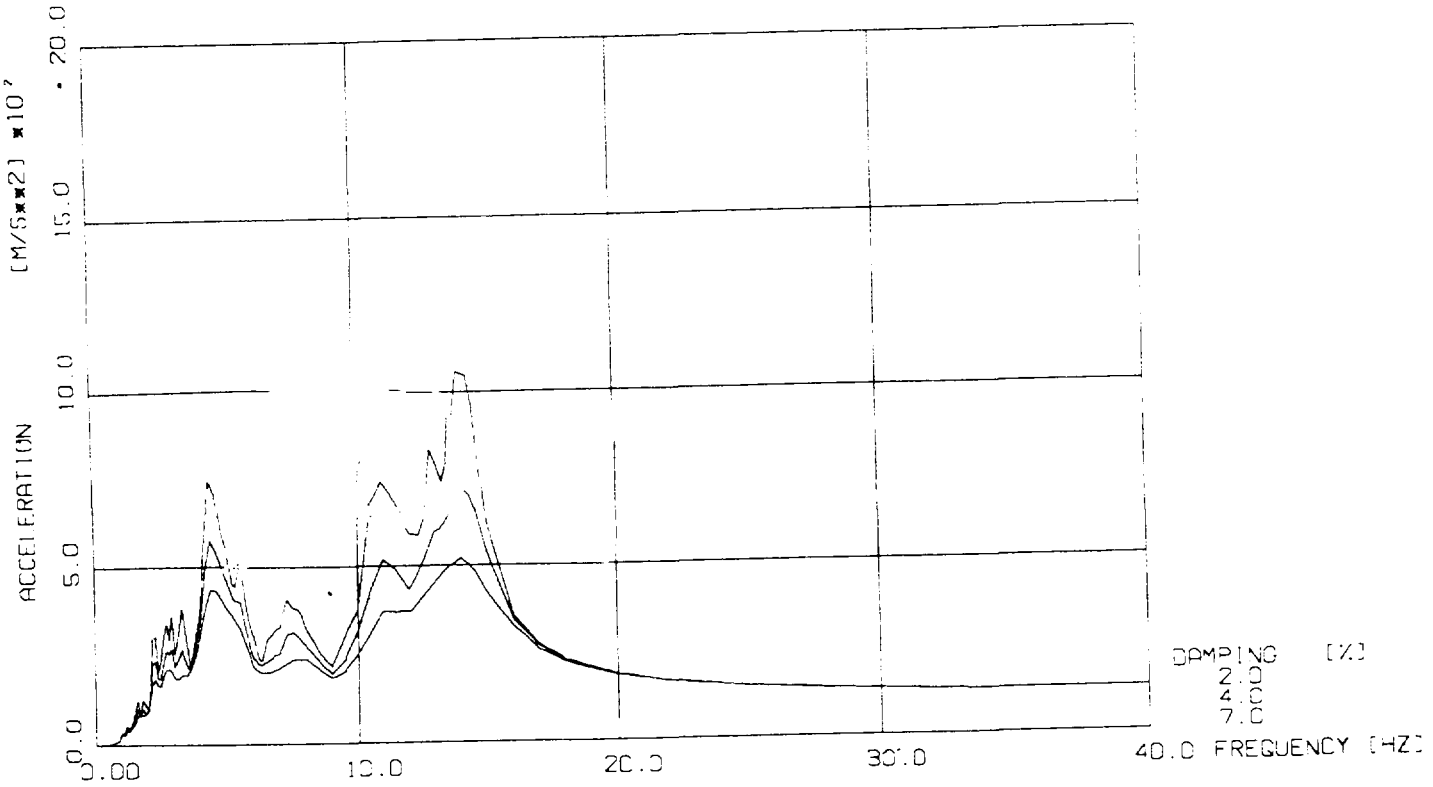


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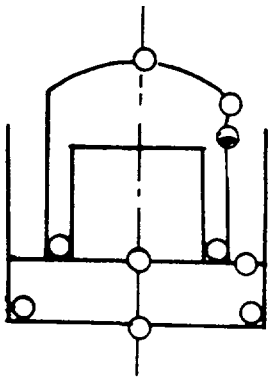
Fig. 5-23 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 47,8 m, Node 332, Direction 2
Instr. Points - and -27



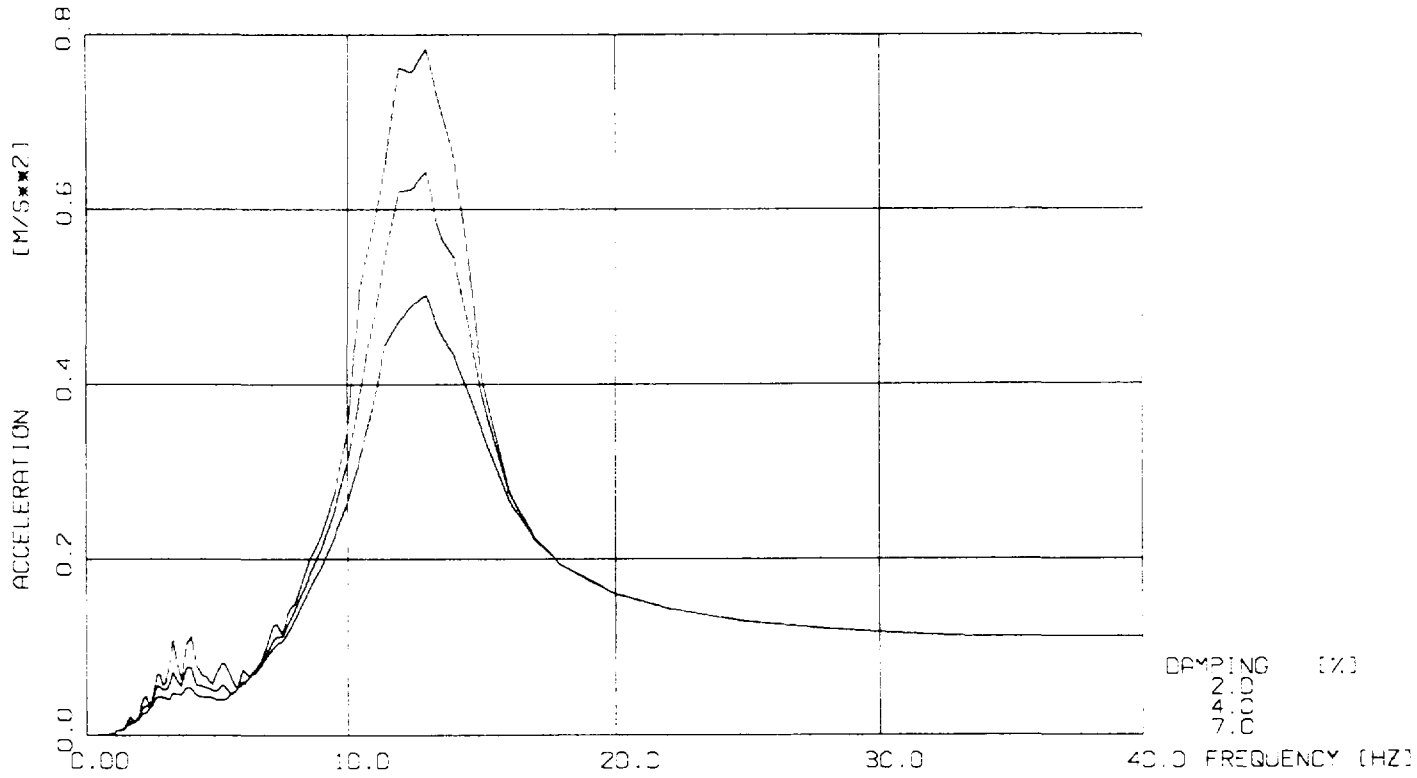


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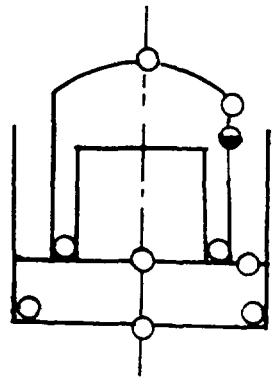
Fig. 5-24 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 47,8 m, Node 332, Direction 3 Instr. Points - and -



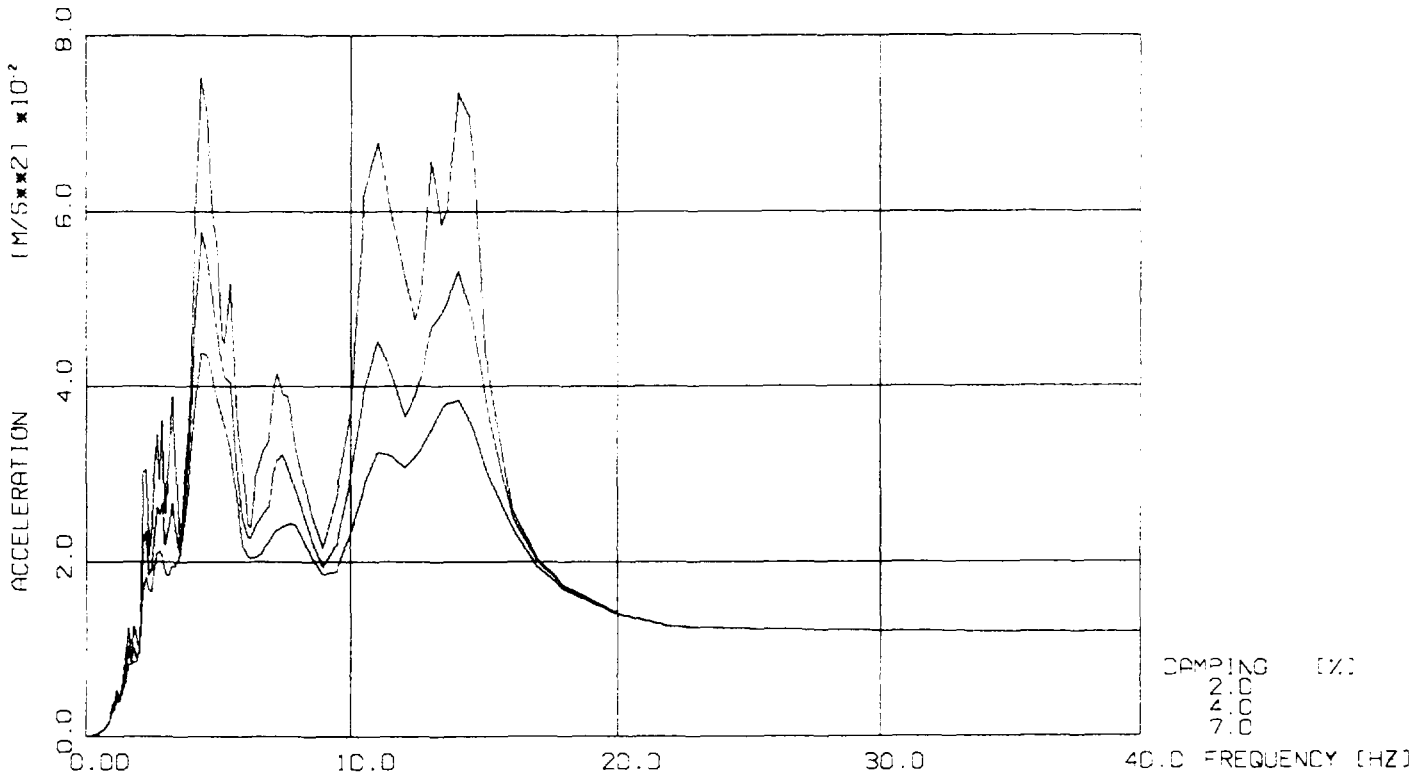
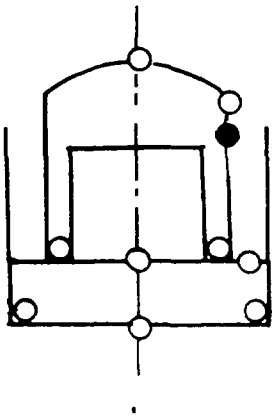


Fig. 5-25 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 47,8 m, Node 331, Direction 1
Instr. Points - and 28



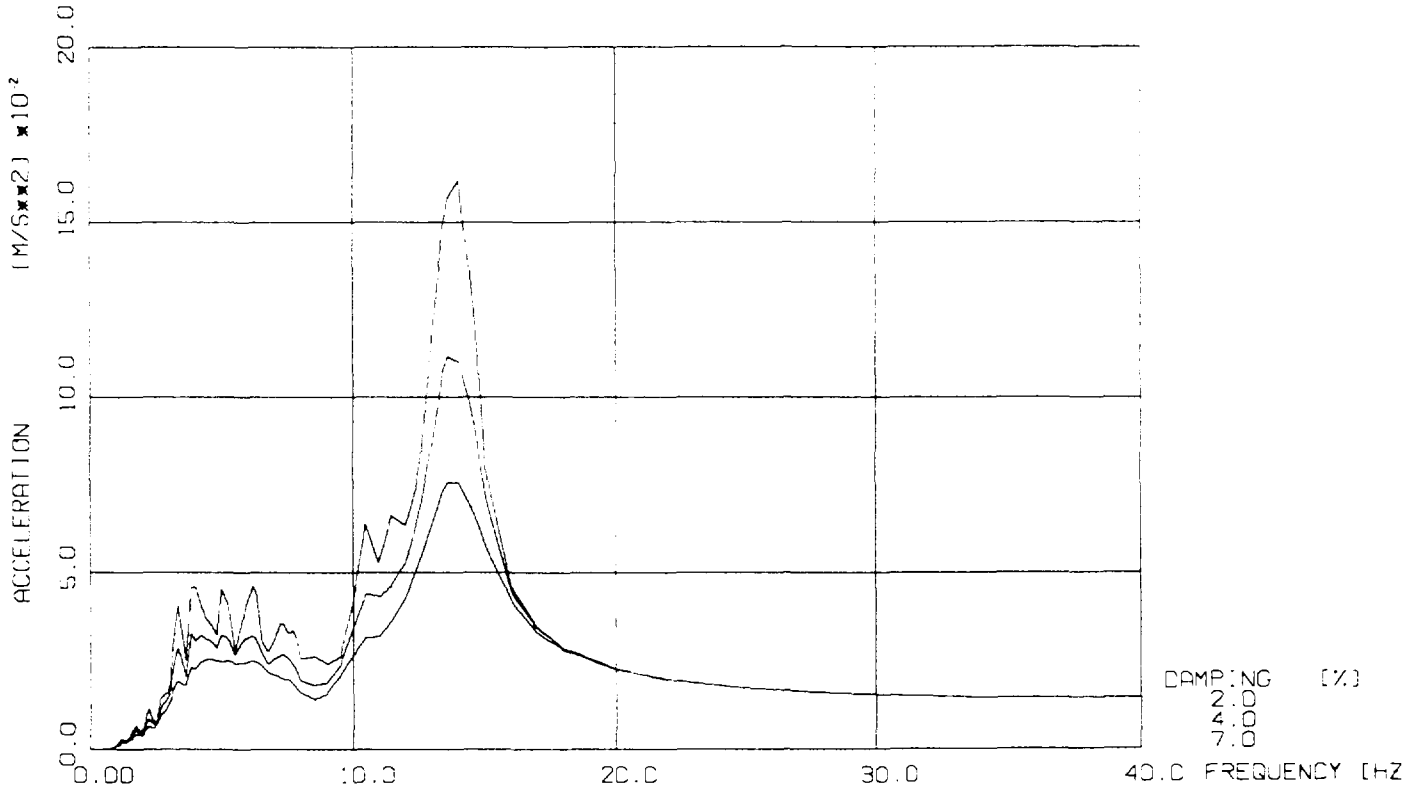
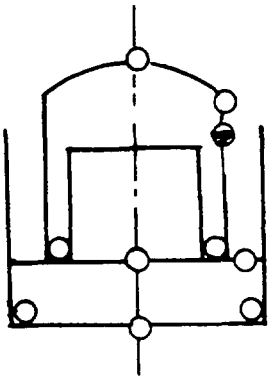


**Fig. 5-26 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 47,8 m, Node 331, Direction 2
Instr. Points 27 and -**



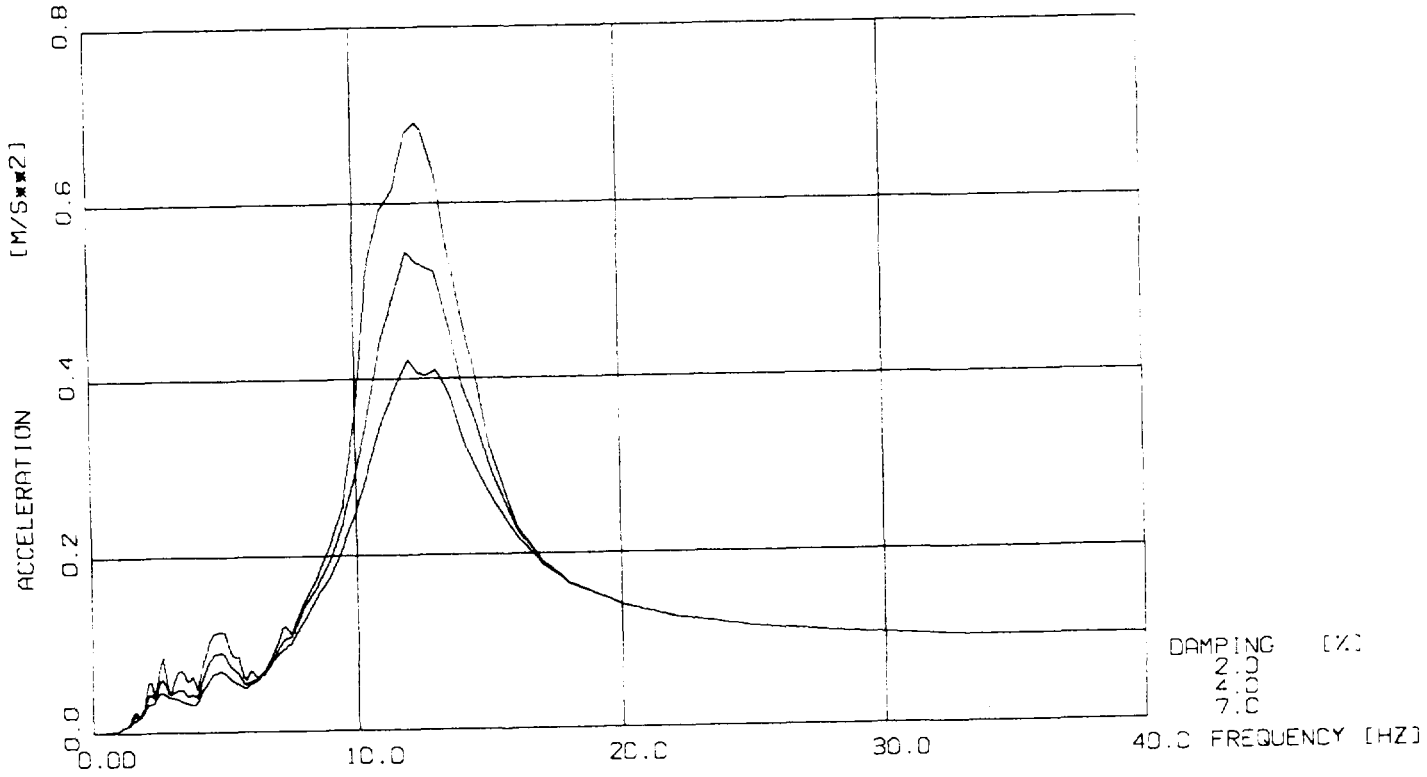
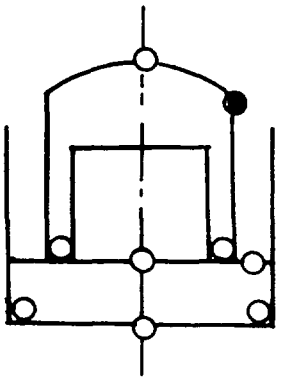


Fig. 5-27 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 47,8 m, Node 331, Direction 3 Instr. Points - and -



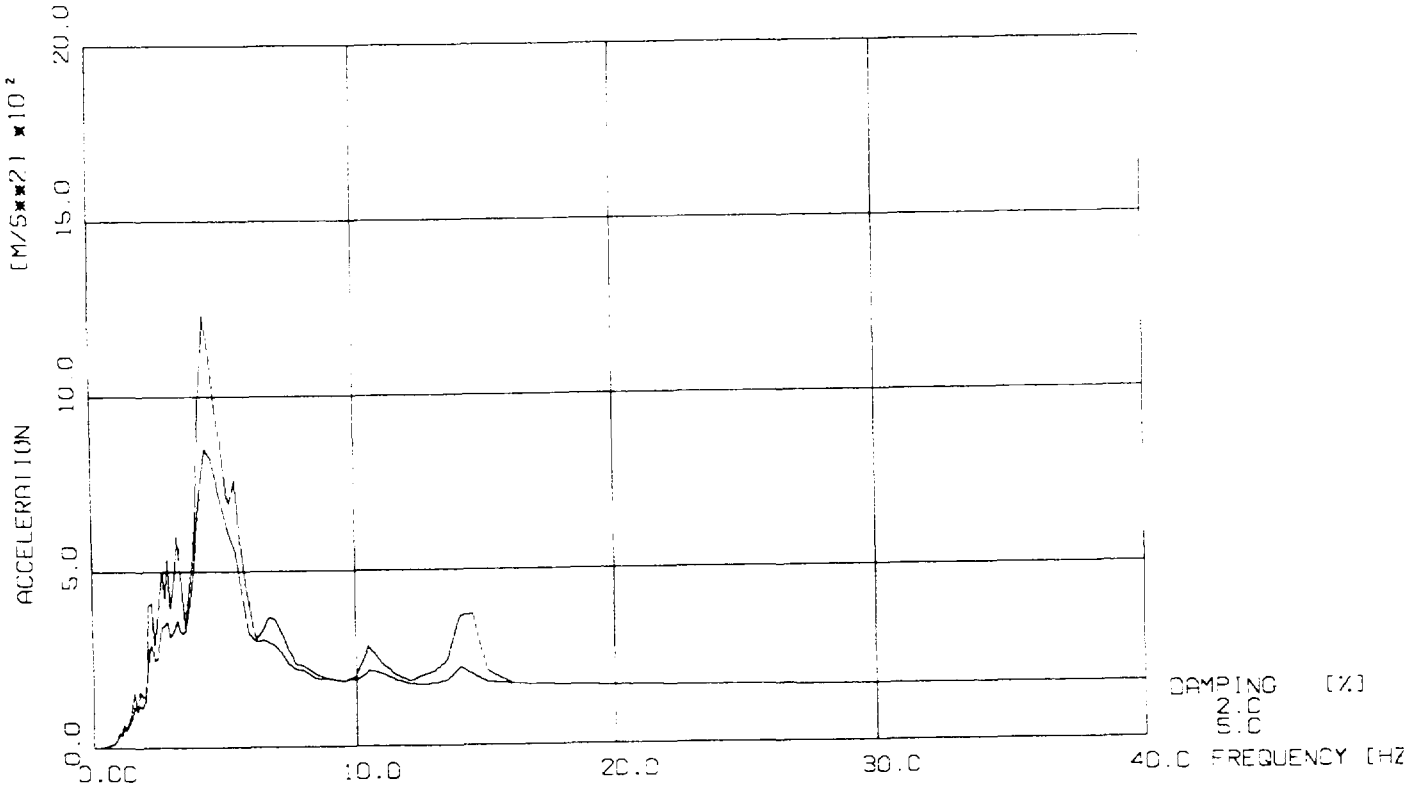
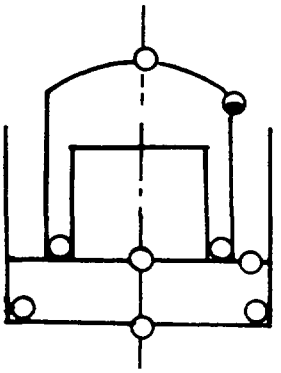


Fig. 5-28 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 61,0 m, Node 350, Direction 1 Instr. Points 25 and 18



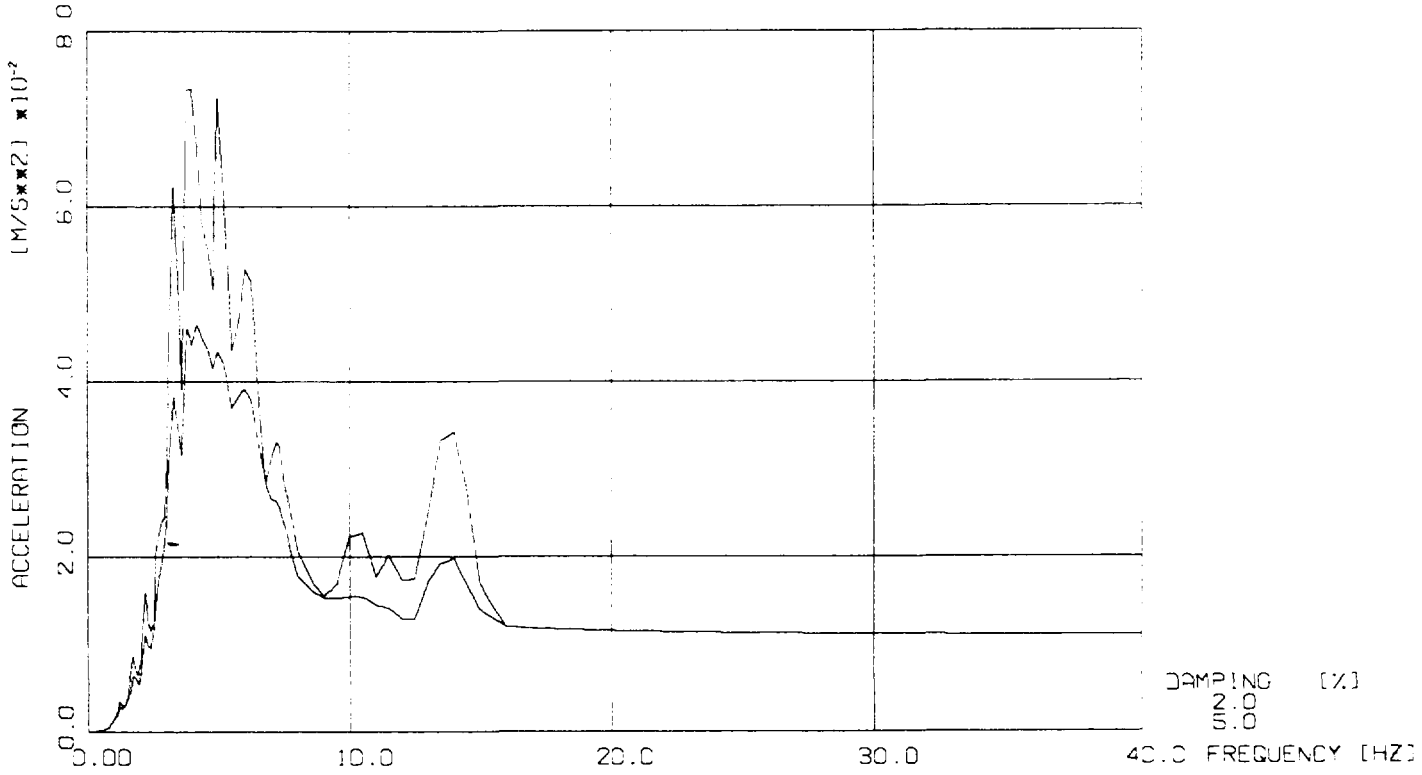


**Fig. 5-29 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 61,0 m, Node 350, Direction 2
Instr. Points - and -**

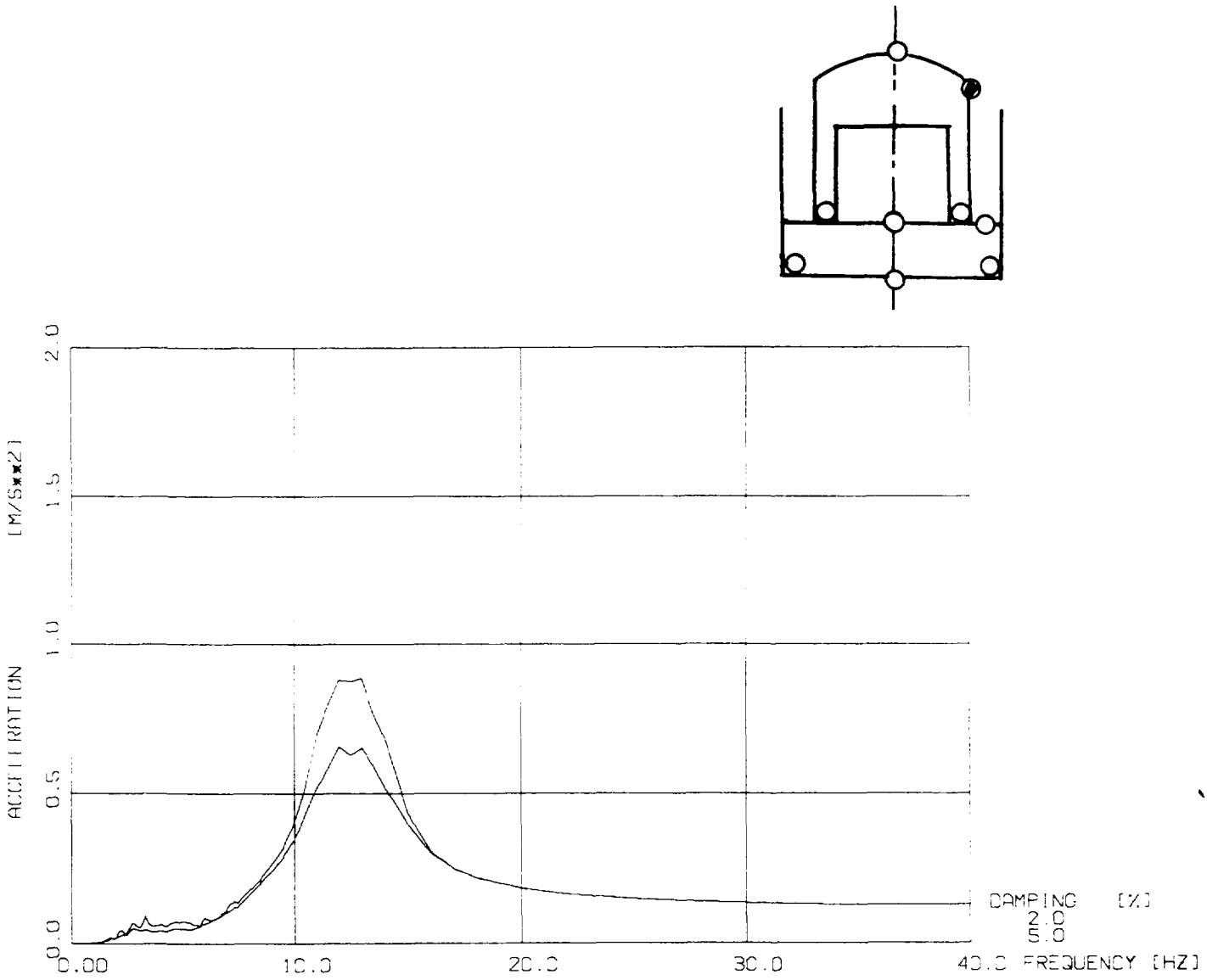
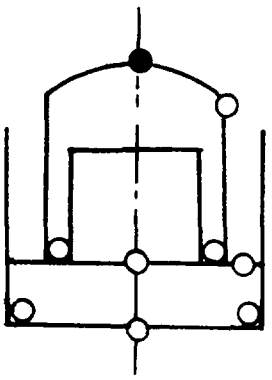


Fig. 5-30 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 61,0 m, Node 350, Direction 3
Instr. Points 24 and 26



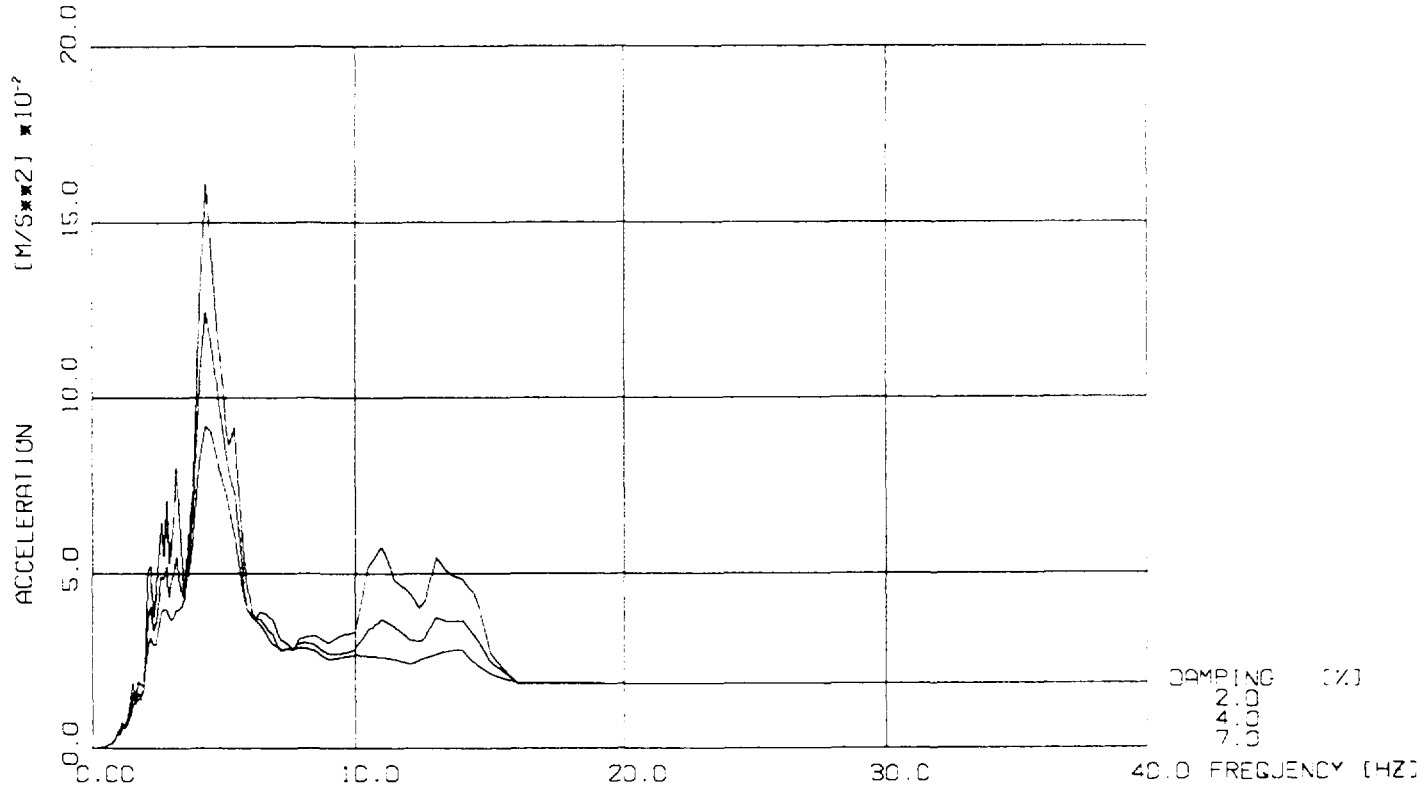
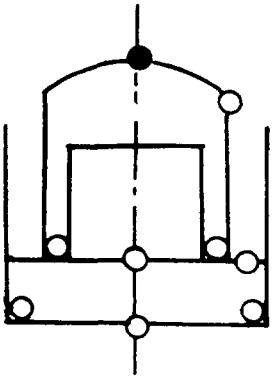


Fig. 5-31 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 67,45 m, Node 360, Direction 1
Instr. Points - and -



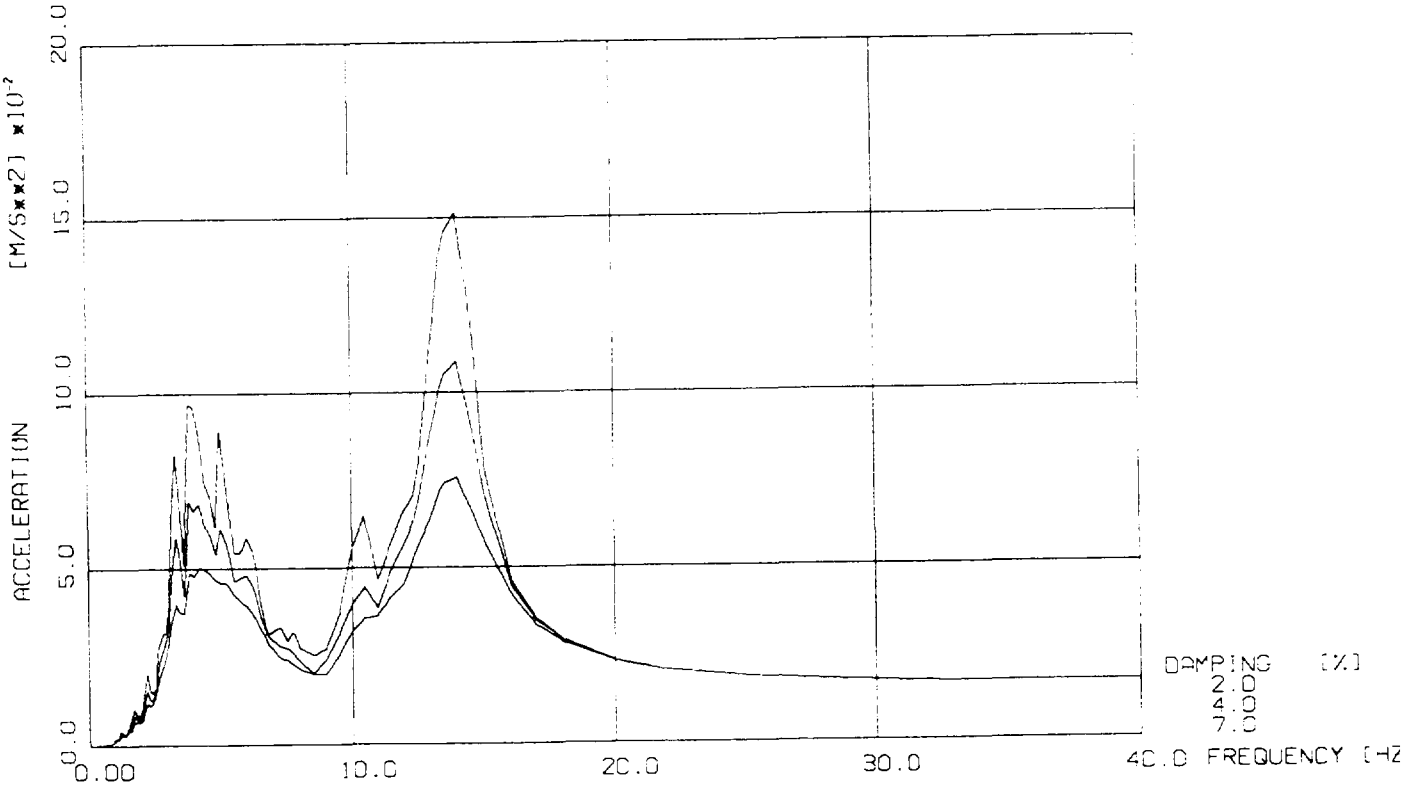
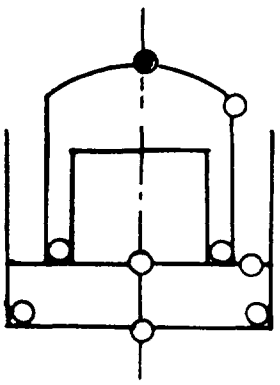


Fig. 5-32 VVER 1000 MW Reactor Building KOZLODUY Blind Preanalysis of Explosive Loading Tests Elevation Level + 67,45 m, Node 360, Direction 2 Instr. Points - and -



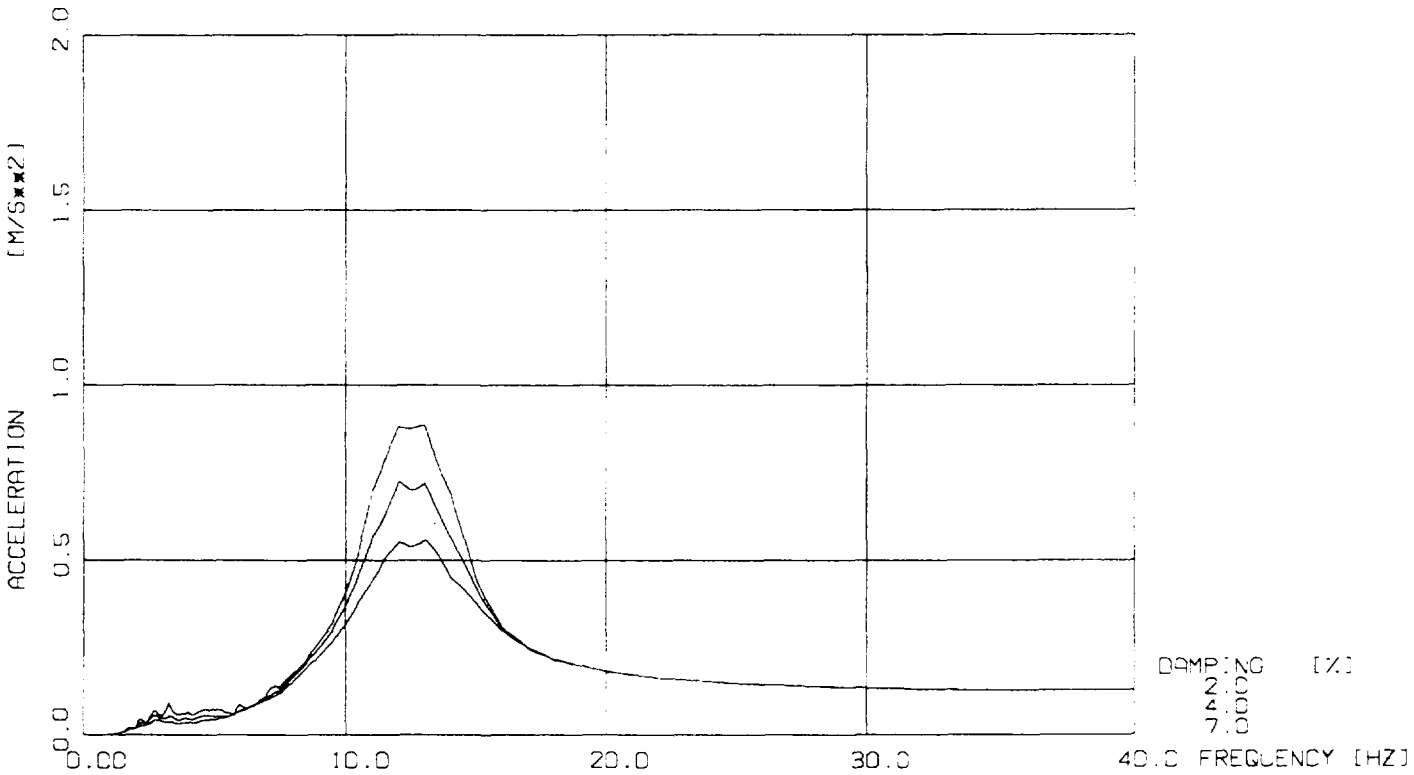
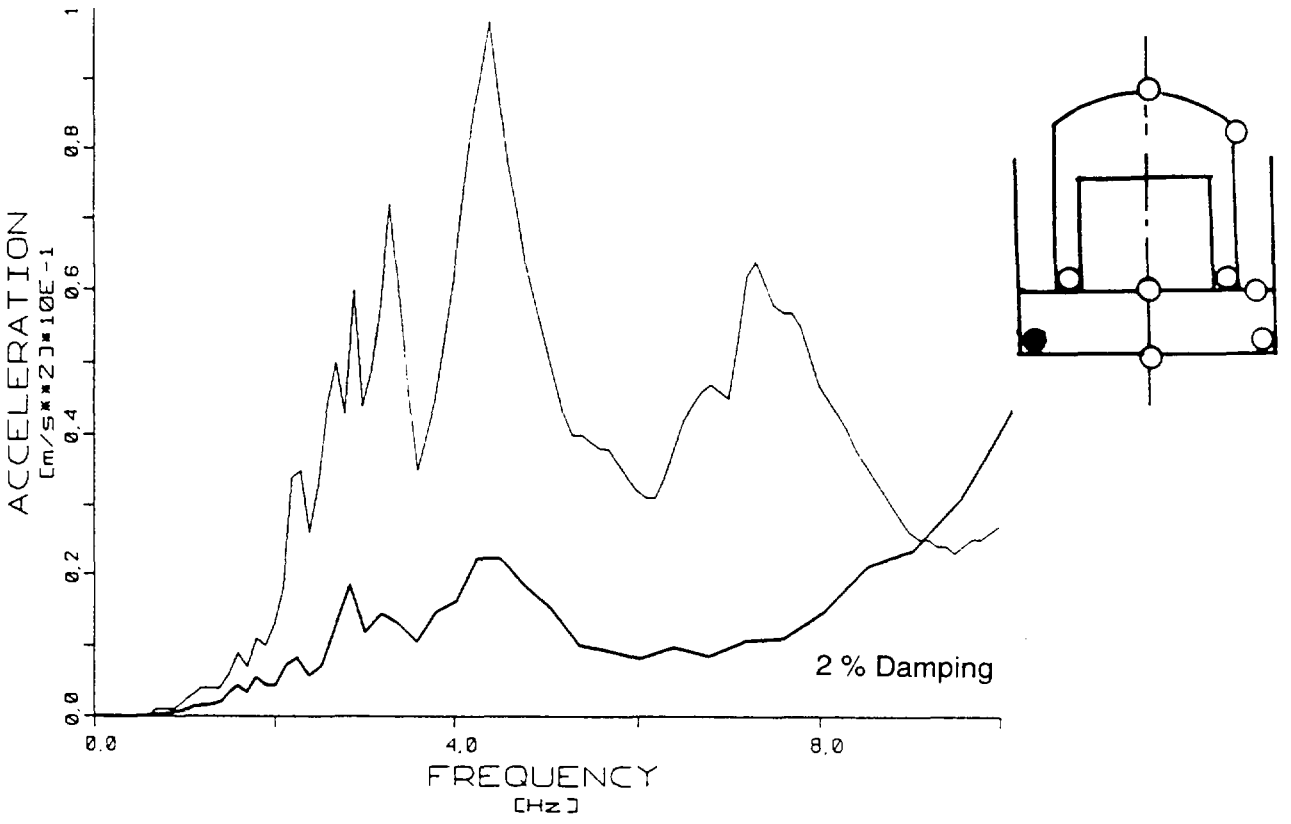


**Fig. 5-33 VVER 1000 MW Reactor Building KOZLODUY
Blind Preanalysis of Explosive Loading Tests
Elevation Level + 67,45 m, Node 360, Direction 3
Instr. Point 21**



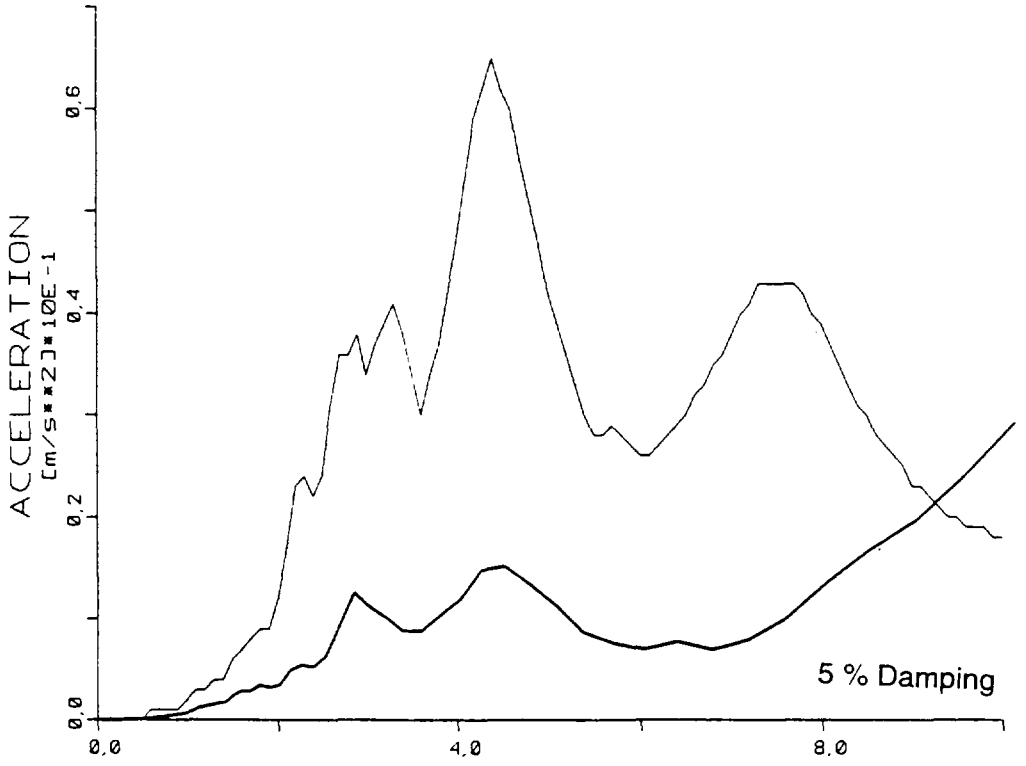


Fig. 6-1 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Foundation Level - 6.5 m, Node 12, Direction 1 Instr. Points 8 and 6

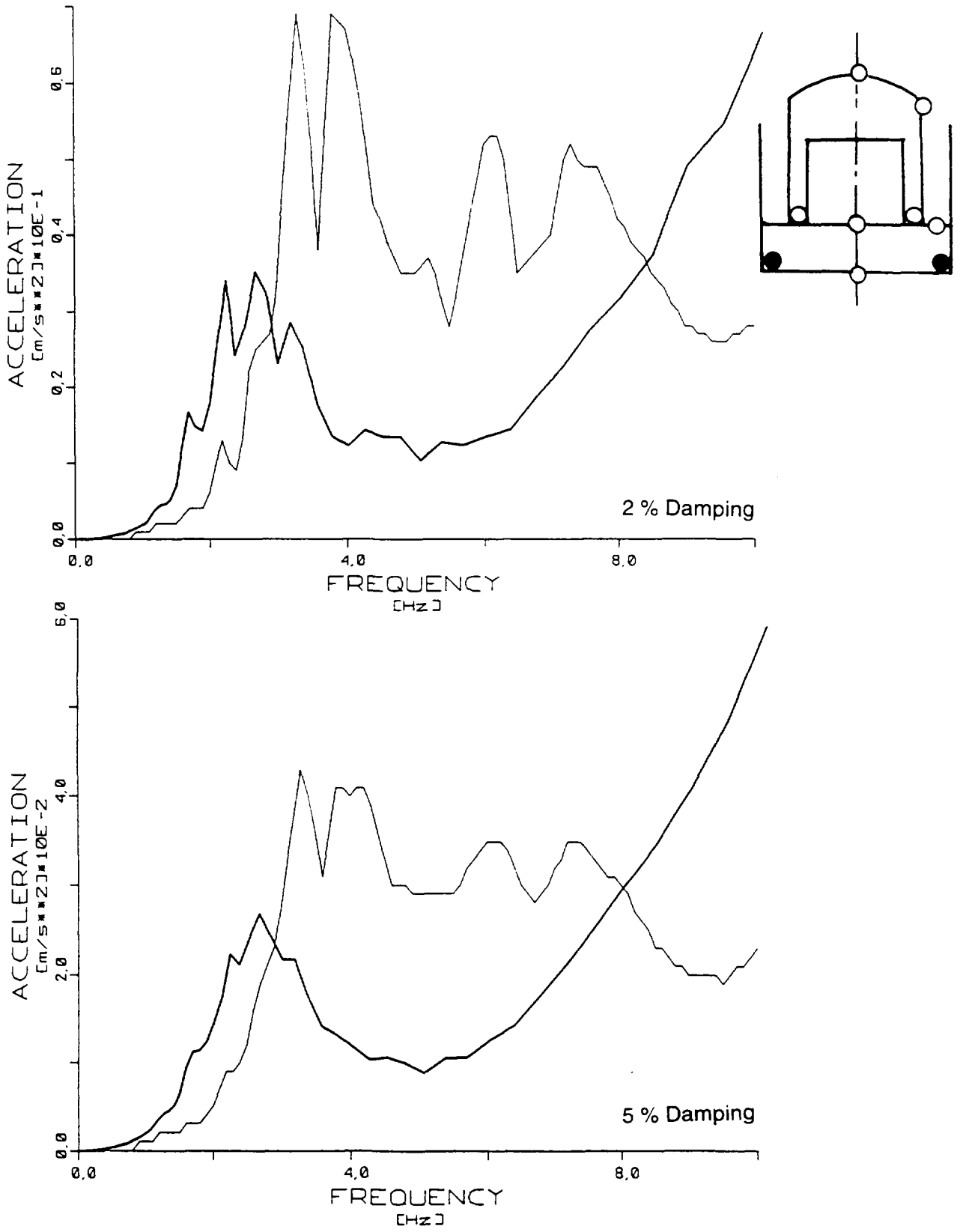


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Fig. 6-2 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Foundation Level - 6.5 m, Node 12, Direction 3 Instr. Points 5 and 7

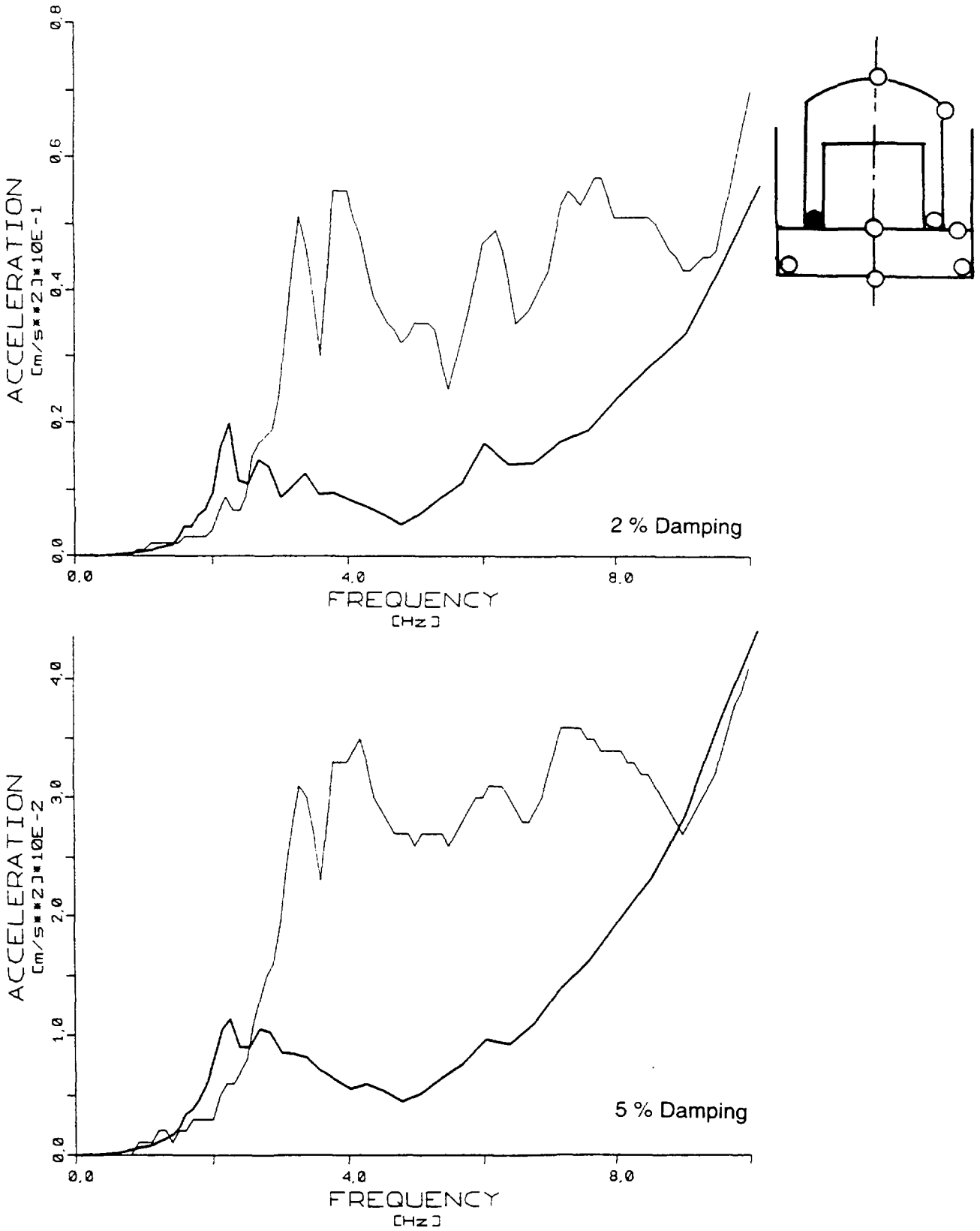

Fig. 6-3 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Elevation Level + 13.2 m, Node 51, Direction 1 Instr. Point 16

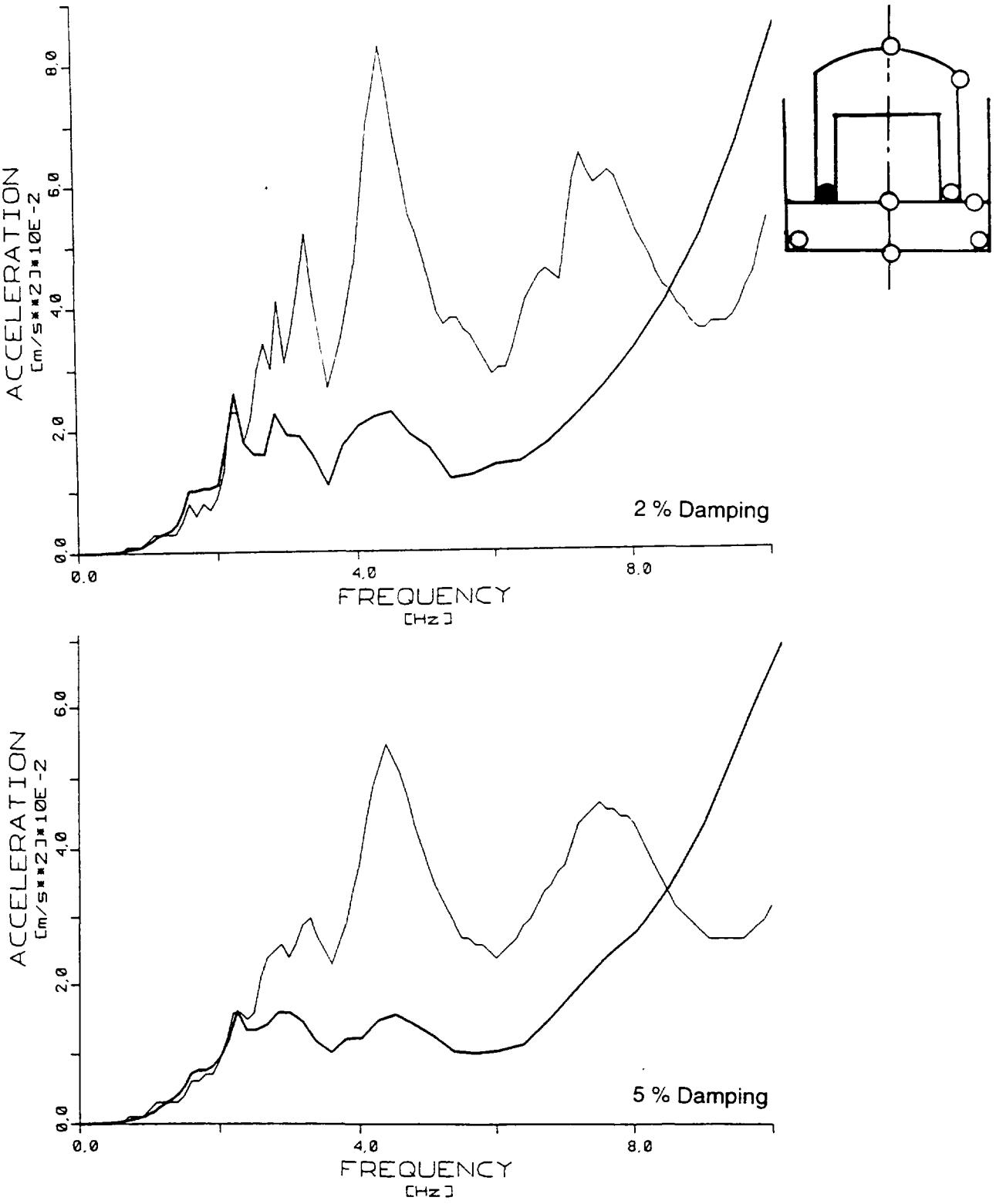

Fig. 6-4 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Elevation Level + 13.2 m, Node 52, Direction 2 Instr. Point 11

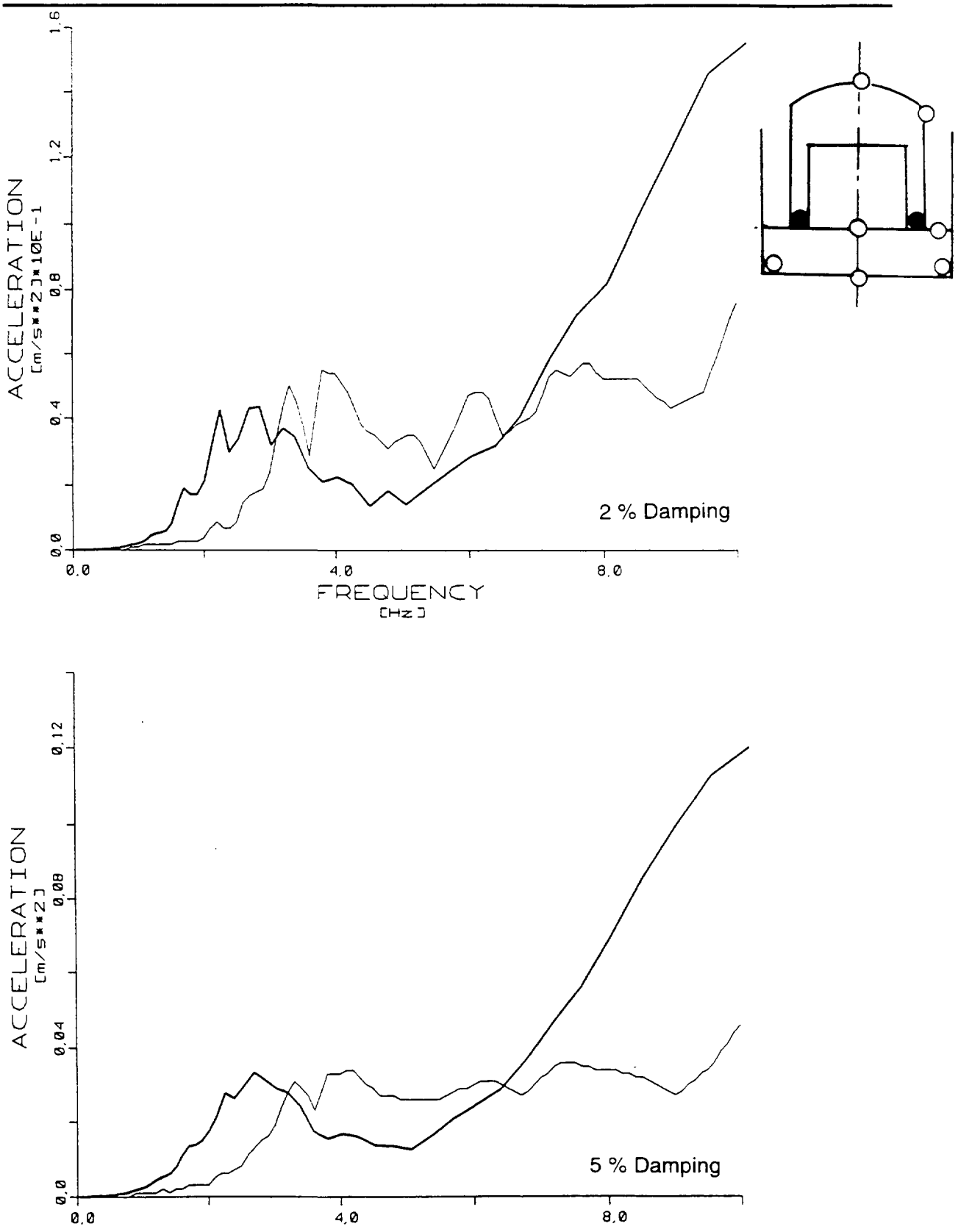

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Fig. 6-5 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Elevation Level + 13.2 m, Node 52, Direction 3 Instr. Points 12 and 14

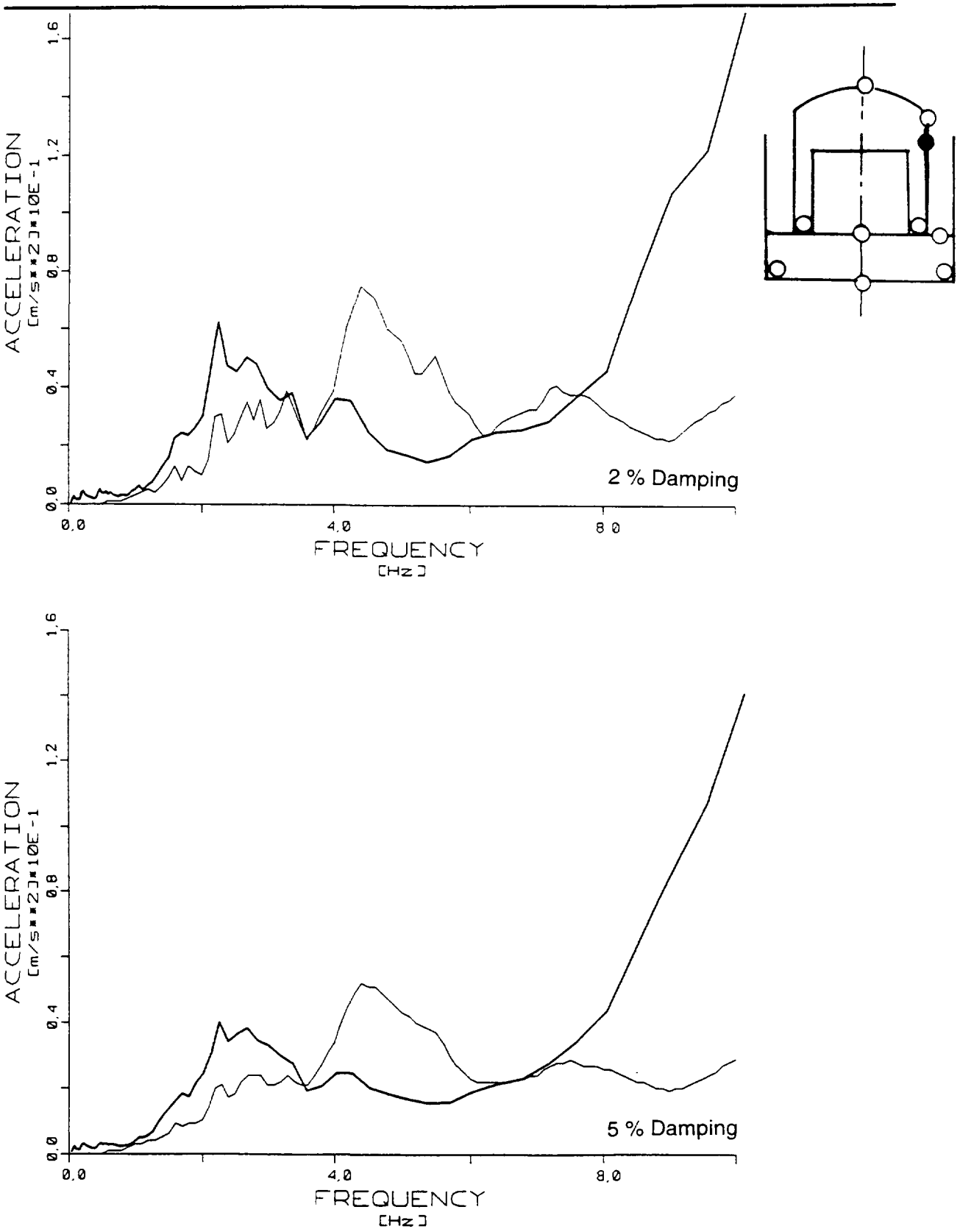

Fig. 6-6 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Elevation Level + 47.8 m, Node 331, Direction 2 Instr. Point 27

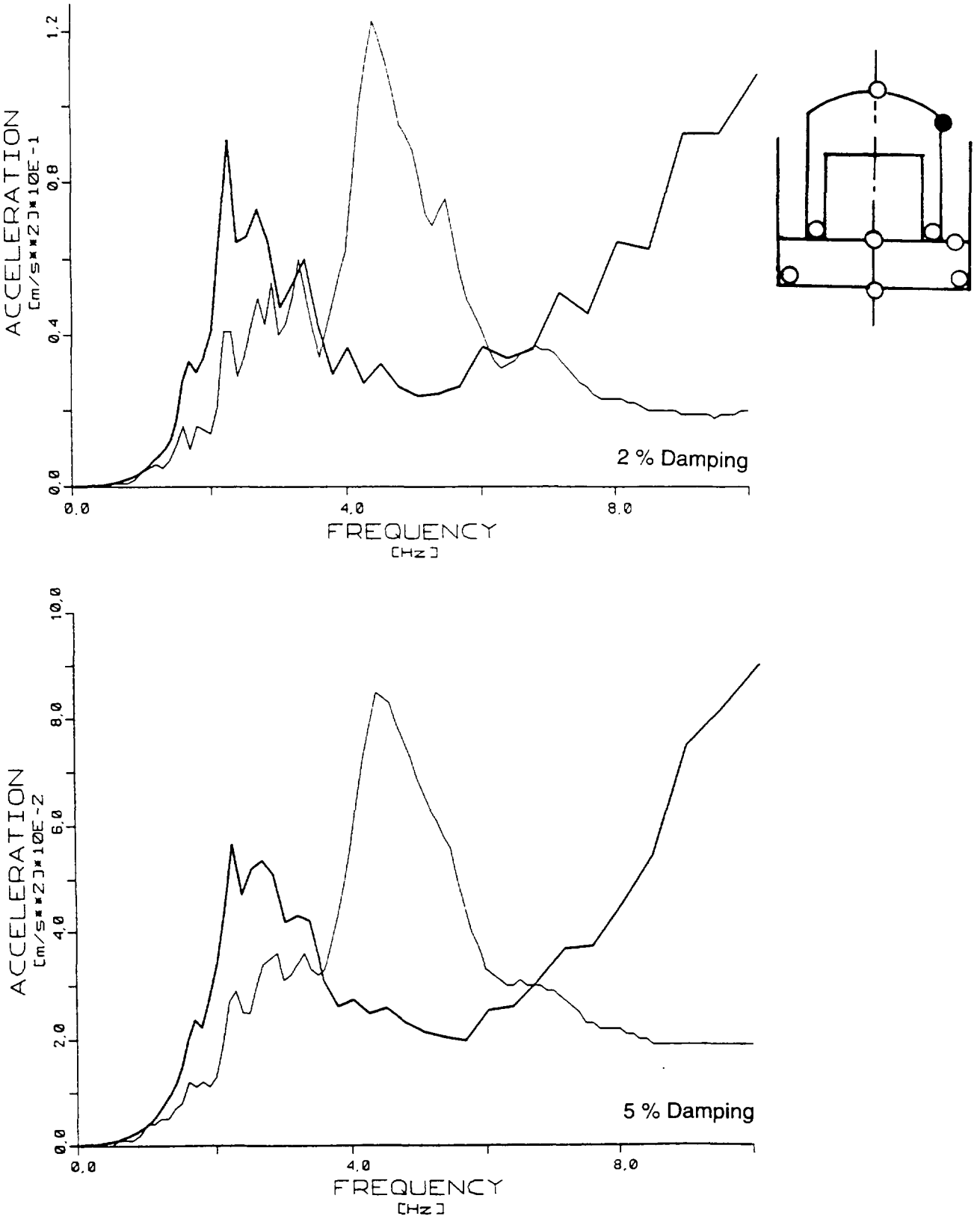

Fig. 6-7 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Elevation Level + 61.0 m, Node 350, Direction 1 Instr. Points 25 and 18

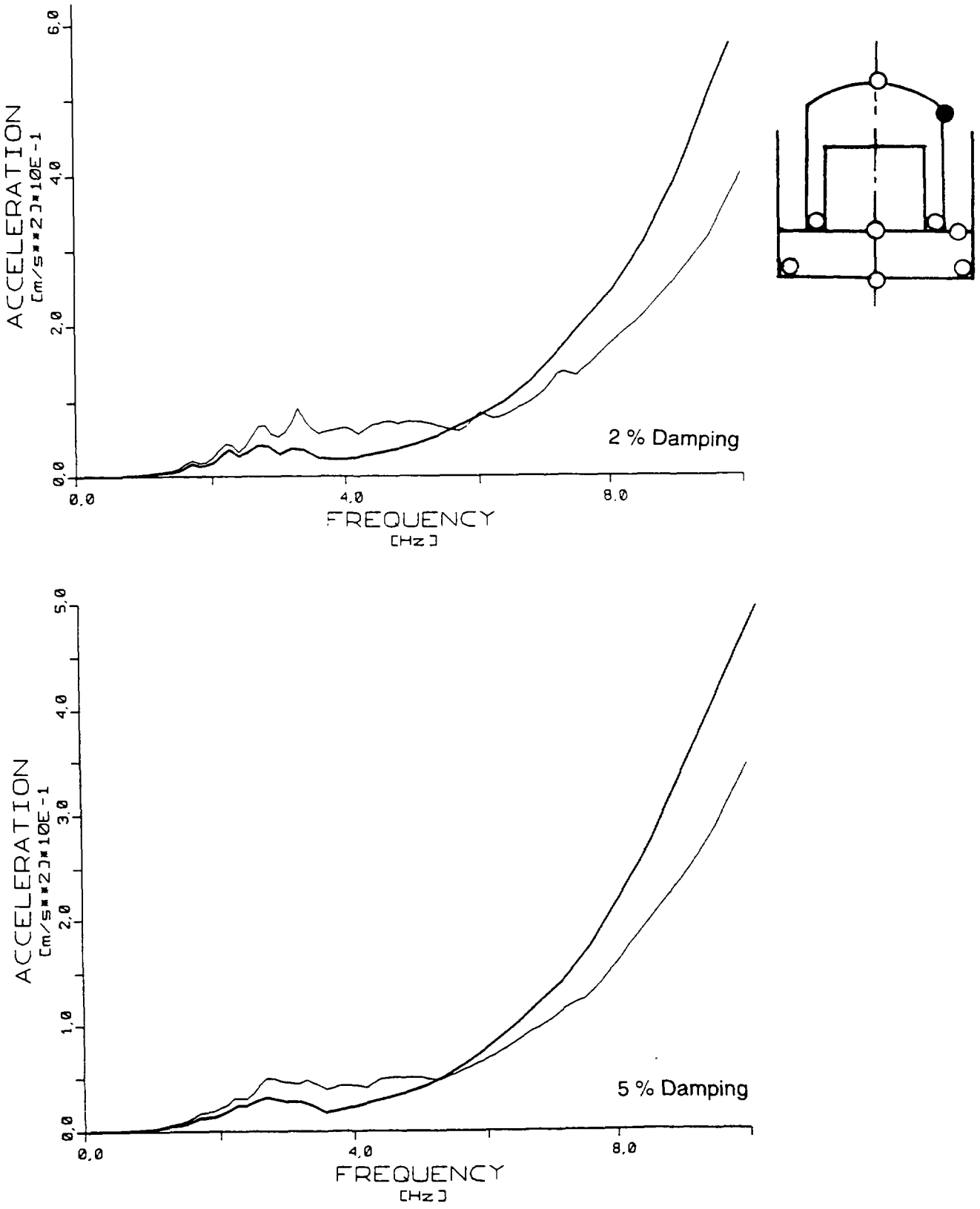

Fig. 6-8 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Elevation Level + 61.0 m, Node 350, Direction 3 Instr. Points 24 and 26

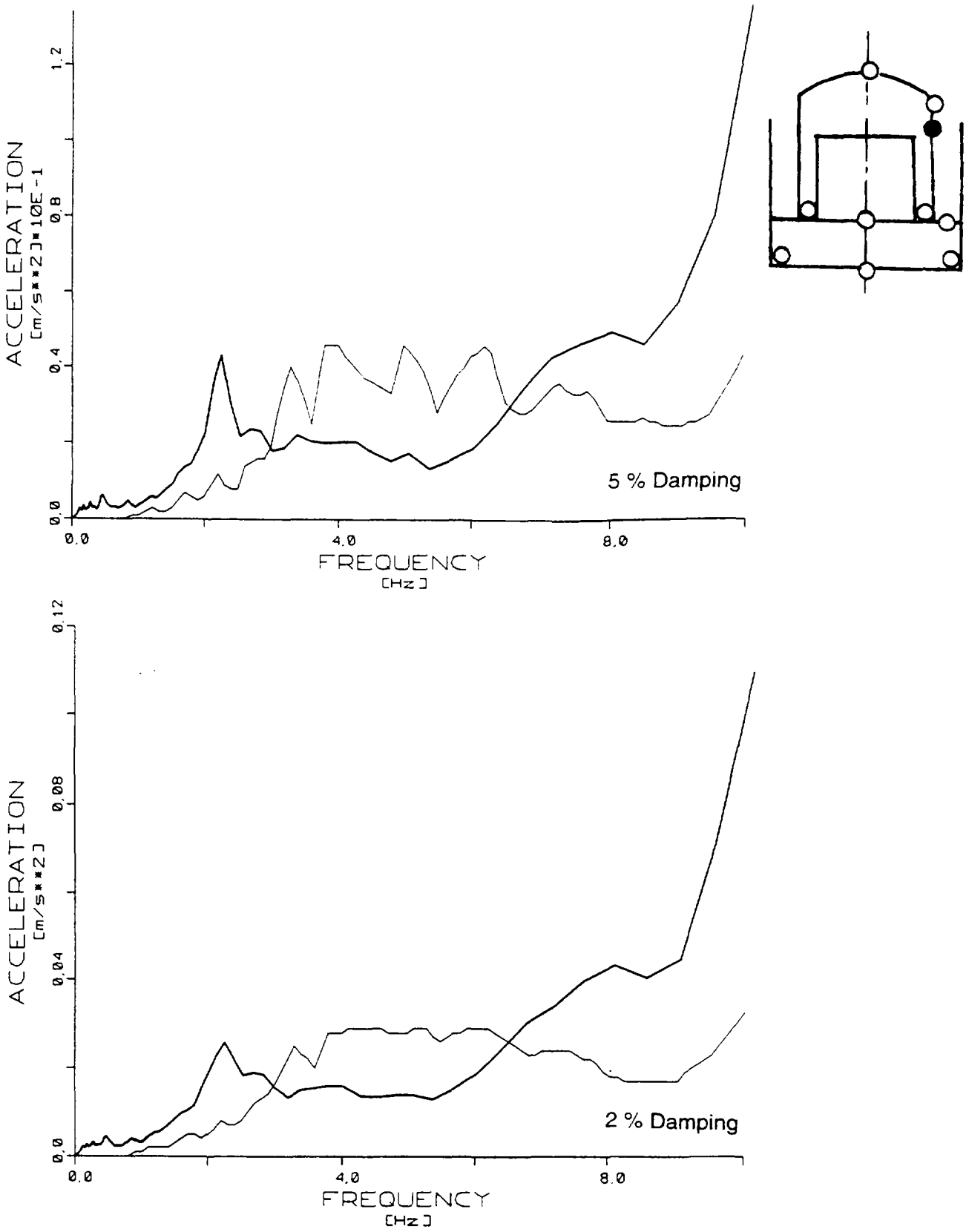

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Fig. 6-9 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Elevation Level + 47.8 m, Node 332, Direction 1 Instr. Point 28

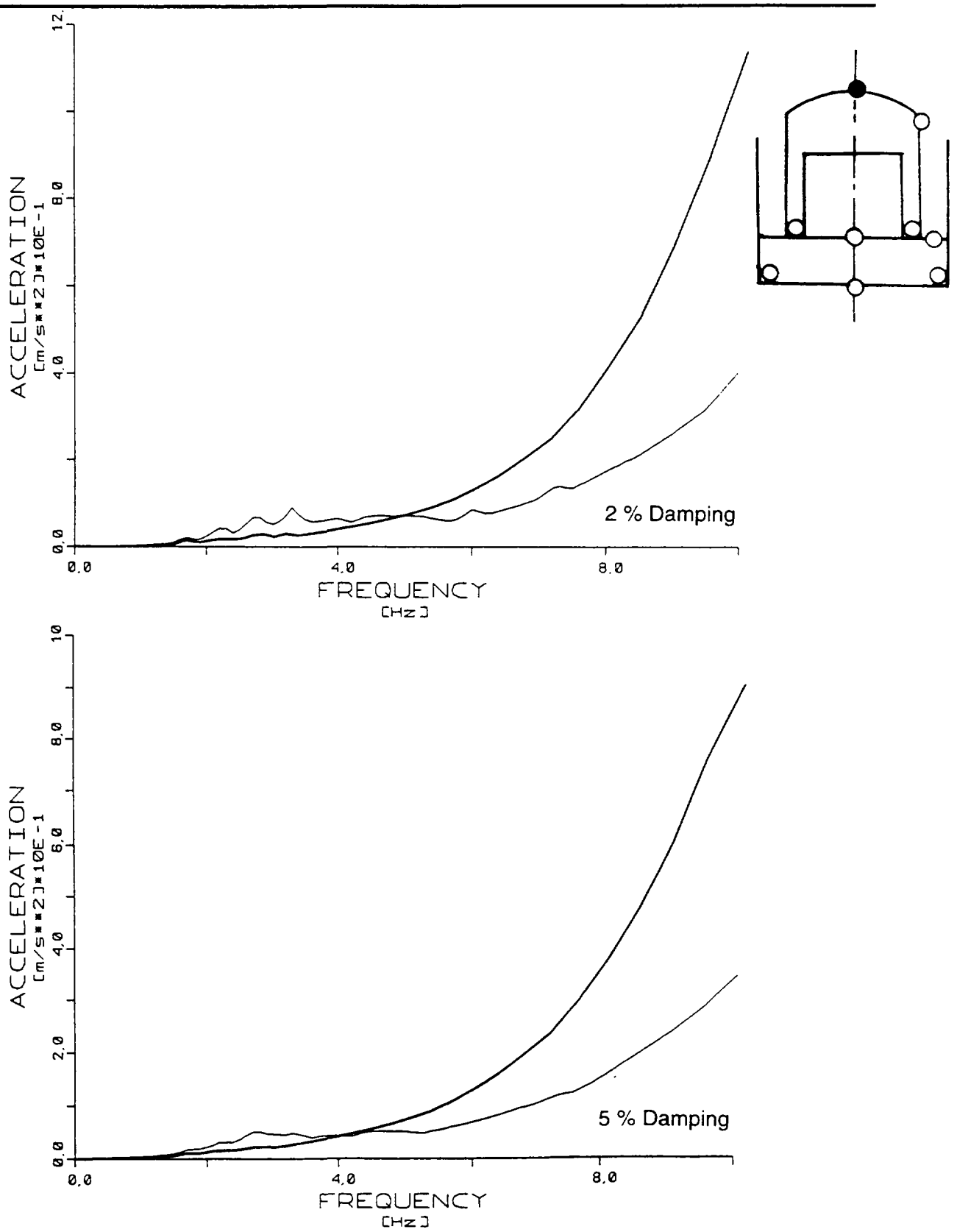

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Fig. 6-10 VVER 1000 MW Reactor Building KOZLODUY Explosive Loading Tests, Comparison of Results Elevation Level + 67.45 m, Node 360, Direction 3 Instr. Point 21