Title: Experimental Investigations and Seismic Analyses for Benchmark Study of 1000 MW WWER Type (Water-Cooled and Moderated Reactor) NPP Kozloduy

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FINAL REPORT

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EXPERIMENTAL INVESTIGATIONS AND SEISMIC ANALYSES FOR BENCHMARK STUDY OF 1000 MW WWER TYPE (WATER-COOLED AND MODERATED REACTOR) NUCLEAR POWER PLANT KOZLODUY

Part of coordinated programme :

Benchmark Study for Seismic Analysis and testing of WWER - type Nuclear Power Plants

Building Research Institute (NISI) Sofia, Bulgaria

Chief Scientific Investigator : Prof. Dr. S. Sachansky

15 June 1993 - 14 June 1994

Sofia April 1994

1. Description of research carried out

1.1. Preparation and compilation of all existing studies related to seismic safety assesment of Kozloduy WWER 1000 MW units.

The seismic intensity of NPP Kozloduy site was established in 1970 (MSK-64 scale) I= IV degree, and seismic effects for design and construction of 440 MW Units were not taken into consideration untill 1977 Vranchea earthquake.

WWER 1000 MW units 5 and 6 in Kozloduy were designed in Moskow for seismic intensity VII degree (MSK-64) with peak ground accelerations SSE (SL-2) =0.1 g, OBE (SL-1) = 0.05 g established in 1978 (after Vranchea earthquake of 4 March 1977 effected NPP Kozloduy site with intensity VI 1/2). Free field design response spectra were calculated from N-S accelerogram recorded in Bucharest (1977), scaled to peak ground acceleration 0.10 g.

The reevaluated in 1992 design seismic characteristics (IAEA Program for NPP Kozloduy) have been determined with two times higher peak ground acceleration (0.2g), longer response spectrum and longer time duration of the design accelerograms.

NPP Kozloduy 1000 MW units 5 and 6 sould be redesigned for the new design seismic characteristics taking into consideration the results form the 12 research reports [1-12], analyzed in the following aspects:

a.) The geological conditions around NPP's site changes significantly (fig.1);

b.) The geological characteristics of units 5 and 6 differ from those, of units 1 - 4, more specialy in the upper 30 m. Even the layers under the four corners of unit 5 foundation differ (fig.2);

c.) The experimental investigations for determination "in situ" of the seismic wave velocities in the layers, close to units 5 and 6 were carried out by dinamic polygon (fig.3) with bore holes depth from 10 to 500 m (fig.4) using upward and downward measurements of the wave propagation (fig.5). By this method, the velocities are measured from the bottom to the surface and back, and the velocities in the different layers cannot be diffentiated very precisely, so an additional interpretation of the results given in fig.6 is needed.

The geological profile with seismic wave velocities close to unit 3 (fig.7) differ significantly from unit 5 (fig.6). The shear wave velocities of the upper 20 m layers determined close to cooling water channels differ also from all other results.

d.) Laboratory testing of soil samples [11] have been performed for determination of shear module ratio G/Gmax and damping in function of shear strain deformation (fig.8.a-8.e). The obtained curves significantly differ from Seed and Idriss, of the reason of the specific soil layers of the Kozloduy site - combination between different sands, clays and gravels.

e.) Microtremor measurements for determination of predominant periods of soil layers [12] were performed, in respect to compare the analytical predominant periods of the ground with the experimental ones in the three places, where the seismic wave velocities have been measured in bore holes : unit 3 [7] (1992), unit 5 [2] (1979) and cooling water chanels (CWC) [4] (1989).

1.2. Previous full scale testing of 1000 MW unit No 5

1.2.1. Structural characteristics and scope of investigations

The 1000 MW WWER reactor buildings were designed in Russia as monolithic reinforced concrete structures. During construction, many elements were modified and replaced by prefabricated ones in a combination with monolithic. After many modifications, the real structures do not correspond to the initial drawings and design.

In 1986, after Chernobil NPP accident, started the experimental investigations for checking the real dynamic behaviour of "AS BUILT" 1000 MW unit No5, as well as the turbine hall.

The reactor building consists of 4 principal substructures connected monolithically (fig.9 - 11) :

1. Substructure with thick foundation plate - from elevation -4.20 to +13.20 (fig.10).The interior walls are 3m wide and 0.6 m thick, constructed by a combination of two precast panels (8 cm) used as forms. After reinforcement, cast in place concrete is poured between the panels.

2. Cotainment - from level+13.20 to 67.45 - cilindrical wall (thickness 1.2 m) with an eliptical cap dome. The wall is prestressed by a total of 96 post-tensioned tenders arranged in a helical pattern at an angle of 35 degree from the horizont. All tendors are anchored at a ring girder at the top of the wall. The dome (1.1m) is from prestressed concrete. The containment is lined inside by a 8 mm steel plate.

3. Internal structure (fig.11) is reinforced concrete with many walls interconnected by concrete floor slabs at elevation 19.34, 25.7, 29.0, 36.9

4. Auxilary building - is placed from level 13.20 to 41.40 around the containment, and is isolated from it by gaps, reportedly 110 mm wide.

The experimental investigations were carried out for establishing of :

* dynamic behaviour and dynamic characteristics (natural periods, mode shapes, damping) of the containment and auxilary building;

* functioning of the gaps between the containment and the auxilary building;
* soil-structure interaction effects;
* dynamic characteristics of the turbine hall

1.2.2. Experimental investigations "in situ"

The first dynamic excitations were produced (1986) by the dynamic impacts from the cranes, moving in the two directions : in the turbine hall and polar cran in the reactor containment. The vibration of the structures were registered by 24 transducers. Only the first mode of vibration in the containment was registered and new experiments were carried out in 1991 by forced vibrations (resonanse method) [9].

The two actuators were placed on the top of the containment. Their location is given on fig.12.a and 12.b, where also are shown the locations of some of the transducers.

The results of the second testing are very simmilar to the first one, performed in 1986, because the excitation was applied on the same place - on the top of the containment.

Experiments by vibration of the ground with vibrators or explosions, simulating real earthquakes, for registration of structural response and soil structure interaction were not performed, becauseof the lack of financial support.

1.2.3. Testing of steel samples from containment tendors in a laboratory

One of the weakest places in 1000 MW units are the 96 postensioned tendors in the reactor containment.

During the control pretensioning some of the tendors were destroyed at 60-80 % of the designed load. The Building Research Institute (Sofia) has tested in the last 2 years samples from tendor steel wires and analyzed technological proceses in preparation and instalation of the new tendors.

2. Obtained results

2.1. Analysis of the geological conditions

A lot of geological investigations on NPP Kozloduy site were performed in the last 25 years. From the present analysis it is established, that the geological conditions are changing from place to place mainly in the upper 20 - 30 m., where there are loess, sands, clays and gravels in different combinations.

The total depth of the alluvial complex increases in the site from Sought to the North. The thickness of the alluvial in the area of unit 5 is 6 - 8 m. and in the area of unit 6 (North from unit 5) the thickness is 12 - 14 m.

For the present analysis the data about unit 5 and 6 are investigated and compared with the data about unit 3.

Three geological profiles were analyzed - one for a free field and two under the reactors 5 and 6, where some alluvial deposits were replaced with loesscement and gravel bedding (fig.2).

The depths of the geological profiles should be defined from bore holes 500 m (fig.3) [5] and compared with fig.7. Several variants with different depths of the "baserock" have been analyzed.

2.2. Analysis of the seismic wave velocities in the soil layers

Comparing the P and S wave velocities [2] fig.6 (close to unit 5) with these, in fig.7 (close to unit 3) [6,7], as well as compared with those, close to the water channel [4], located at 4 km East from unit 3, a significant differencies can be seen. The reason for this are not only in the different soil characteristics, but also the methodology of the measurements and interpretations of the results.

It is evident, that the data for seismic wave velocities should be reinterpreted by the same criteria using the original records.

2.3. Analyses of the data for G modules determined in laboratory [11]

The curves for G-modules and damping in function of the shear strain (fig.8.a -8.e), differ from the standard ones (Seed and Idriss and others), but they correspond to the specific characteristics of the NPP Kozloduy soils - mixed sands, clays and gravels in different proportion.

2.4. Analysis of the predominant natural periods of the ground

In table 1 are given some of the natural periods of the ground registered at unit 5, water channels (CWC) and unit 3. It is evident, that they differe and this corresponds to the different geological conditions of the investigated places.
These data can be used for comparing the analitically calculated natural periods by mathematical models with the experimental data and for verification and improvement of the mathematical models.

2.5. Dynamic characteristics of the 1000 MW unit No 5

a.) Frequency response curves for containment level 61 m in E-W direction are given in fig. 13.b with a maximum at 2.17 Hz, damping 13.1 %. The response of the auxilary substructure in E - W direction at level 45.60 (fig.13.c) is with the same peak at 2.17 Hz, like the containment. The same results are obtained in N - S direction for both substructures at frequency 2.0 Hz (fig.13.a). Both structures response simultaneously, because the gaps between them do not work. The same results were obtained in the first experiment (1986) by polar crane.
b.) The torsional response of the containment (fig. 13.d and fig.14) is with 2 peaks at 4.50 and 4.70 Hz damping 7.7%. The auxilary structure follows the rotation of the containment (fig.14), neverless they are "separated" by gaps.
c.) Comparision of dinamic characteristics from the experiments in 1986 and 1991
In both experiments the containment and auxilary substructures response as an unique structural system. Only the fundamental frequencies in both directions and torsion were identified.
In table 2 are compared some of the dynamic characteristics. It is evident, that the first natural periods from both experiments are the same, but the determined dampings are very different.
In 1986 experiment the damping was calculated by the method of the logarithmic decrement, in 1991 experiment - by the resonanse curves.

2.6. Soil-structure interaction

Two teams have measured the displacements for determining the soil-structure interaction. According to the first team (fig.15 and fig 16), there are not data for deformation in the structures. The data for displacements in the ground (left and right from the building) can not be used for soil structure interaction analysis.

According to the second team (fig 17 and 18), there are significant deformations in structures at very low excitation (less than 40 kN) on the top of the containment.
In both reports there are not interpretations of any data for soil structure interaction. During the experiments in 1986 [8], were determined about 20 % displacements in structures, due to structural deformations, and 80 % - due to deformations in the soil.

2.7. Laboratory testing and analysis of the 1000 MW reactor containments tendors

The Building Research Institute (Sofia) has presented to NPP Kozloduy results from :
a.) data from laboratory testing of steel wire samples from reactor containment tendors;
b.) factors which reduce the strenght and deformation;
c.) analysis of the previous technology for preparing and instalation of the tendors;
d.) proposal for next steps in improving and establishing new technology for step by step replacing of all tendors of uints 5 and 6.

3. Conclusions

3.1. NPP Kozloduy units 5 and 6 were designed for peak ground acceleration 0.1 g. The new peak acceleration is 0.2 g.

3.2. Geological profiles and data for ground mathematical models

From the analysis of the preliminary experimental data (1986) [8] performed on 1000 MW unit No 5 it was established, that about 80 % of the reactor building response (displacements) are due to the ground conditions and high rigidity of the structure.
On the other hand, there are significant differences between the seismic wave velocities (P and S) in the three investigated places (water chanels, unit 3 (fig.7) and unit 5 (fig. 6). These were the reasons, the following more precise reinterpretations and analyses to be proposed in February 1994 to the CUAEPP and NPP Kozloduy :
a.) The data for P and S wave velocities in the respective layers should be reinterpreted by same criteria on the basis of the real records in the bore holes;
b.) One geological profile for free field and two profiles under units 5 and 6 should be established after reinterpretation of the data;
c.) The depth of the mathematical models (in 2 - 3 variants) should be determined from the 500 m bore hole near to unit 5 [5];
d.) The data from ground predominant natural periods (table 1) could be used for verification and improvement of the mathematical models;

e.) Analysis for avoiding resonance in ground mathematical models and structural models should be performed.

3.3. Full scale testing of 1000 MW NPP Kozloduy unit

1. From the previous investigations (1986, 1991), only some dynamic characteristics were determined. Soil-structure interaction and floor response spectra were not investigated.
2. For Benchmark programme, the establishing, verification and improvement of the structural mathematical models and analytical results is necessary to be performed full scale testing by explosions in the ground for :
* recording the floor response spectra and verification of the analytical ones;
* determination of the impendance matrix of the foundation soil and comparing with the analytical;
* evaluation of the damping capacity of the soil-structure system;
* establishing the influence of the ground conditions on the response of the rigid structure.

3.4. Indentifying finding and weakness

From observations and testings, the following weaknesses were marked :
a.) destorsion of some of the containment tendors during pretensioning at 60-80 % of the designed force;
b.) replacement of the destroyed tendors with new ones do not increase the safety because of the technology for prestressing is not improved yet;
c.) the strenght and deformation characteristics of the tendor steel wires are reduced from several factors;
d.) the data from the previous stress-strain analyses should be reinterpreated;
e.) the vertical vibrations of the turbine hall roof during horizontal shaking are very large. Combination of the horizontal and vertical excitation can produce large displacements and damages in the roof trusses, like in unit No 2 during Vranchea 1977 earthquake at peak acceleration about 0.1 g.
f.) there are many weaknesses in the auxilary building (electrical, diesel generator etc). The including of this buildings in the Benchmark program should be discussed.

4. Work plan

for new testing and investigations of 1000 MW unit 5 or 6 NPP Kozloduy

The characteristics which were not determined in previous investigations and are necessary for Benchmark program are planed to be investigated by this work plan.

The testing of 1000 MW NPP Kozloduy unit is posponded from the IAEA for the begining of 1995. The start of the testing depends of the.plan for exploatation of units 5 and 6 and their stoping for refueling. The following main activities are planed :

1.) Determination of two or three places for ground explosions;

2.) Preparing program and project for explosions in ground - modelling real earthquakes :

a.) preparing project for location of transducers for recording of the seismic wave propagation and modification;

b.) selection of instruments and system for recording and data processing;

c.) calibration of instruments and systems;

d.) establishing methodology and selecting computer programs for data analysis.

3.) Preparing program and project for :

a.) Recording of the 1000 MW unit structural response from blasting for determination of :

* time history input motion close to the foundation and on the foundation;
* time histories and response spectra on different levels (floors);
* response of critical equipment:
* soil-structure interaction;
* spring and dashpot characteristics of the soil;
* radiation of material damping;
* impendance matrix of the foundation soil.

b.) Appointing of the system for : recording, data aquisition, data analysis and respective computing programs

c.) Calibration of the recording and other systems;

d.) Work plan for location of transducers for determination of the subjects specified in item 3a;

e.) Work plan for preliminary data analysis.

Table 1 Predominant natural periods of the ground measured by microtremors

points	Natural periods [sek] for		
	unit No 3	unit No 5	CWC
1	0.07423	0.08193	0.07242
5	0.09983	0.11019	0.09983
10	0.14105	0.16766	0.19930
15	0.21999	0.23113	0.34311
20	0.34311	0.34311	0.52208
25	0.6361	0.59068	0.73768
30	1.54734	0.99210	1.30172
35	3.24565	1.70791	2.08100
37	5.18865	2.13302	2.41332
38		2.29703	2.86868
39		2.53550	3.16649
40		2.73045	4.25857
41		3.94451	5.17765
42		4.93864	

Table 2 Experimental results for 1000 MW unit No 5

Building	direction	Natural periods [sek]		damping [%]	
Experiment - year		1986	1991	1986	1991
Reactor	X-X	0.46	0.46	6.1	12.1
Reactor	Y-Y	0.493	0.50	5.9	8.2
Turbine hall mode 1	X-X	1.02		5.7	
Turbine hall mode 1	Y-Y	0.56		4.5	
Turbine hall mode 2	X-X	0.54		3.5	

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3. Sachanski S. et all "Seismic Microzonation of NPP Kozloduy Site", GI, Sofia,1979

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5. Ivanov R., Boev S. "Kozloduy 3 NPP. Results of the Geophisical Investigations In the Area of the Main Building Units V and VI"), Geological Archives, Sofia, 1980

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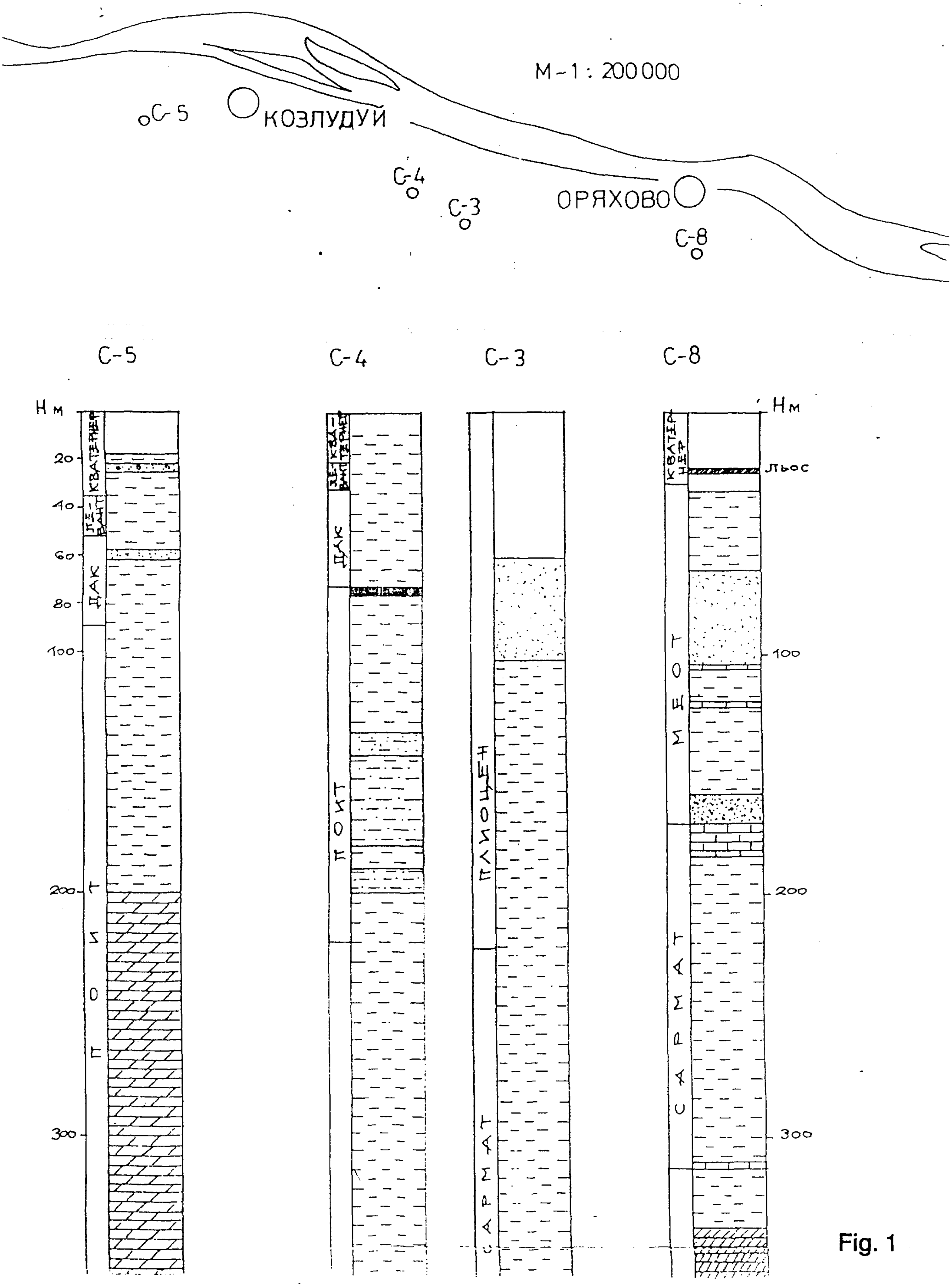
11. Talaganov K., et al "Dynamic Laboratory Testing and Investigations of Soil Samples for Determination of G-modulus and Damping of the Soil Layers As Strain Dependent", IZIIS,Skopie, 1991

12. Stoikovitch M. "Investigation of the Stationary Characteristics of Microtremors and Equivalent Geotechnical Models for NPP Kozloduy", IZIIS Skopie, 1991.



M-1 : 200 000
C-5
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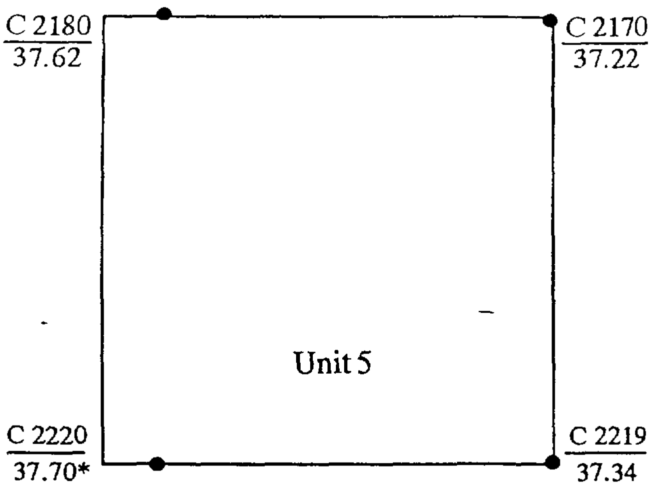
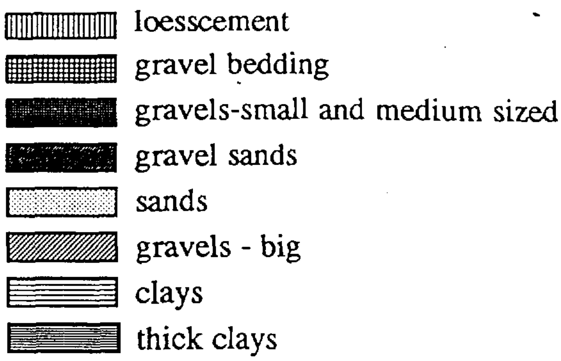
Fig. 1

Scheme of location of boreholes under Unit 5



Absolute elevations of natural terrain before planning, at drillings tests

Conventional symbols



Geological bar charts of boreholes under level of foundation (elevation 28.00)
Sc 1"200

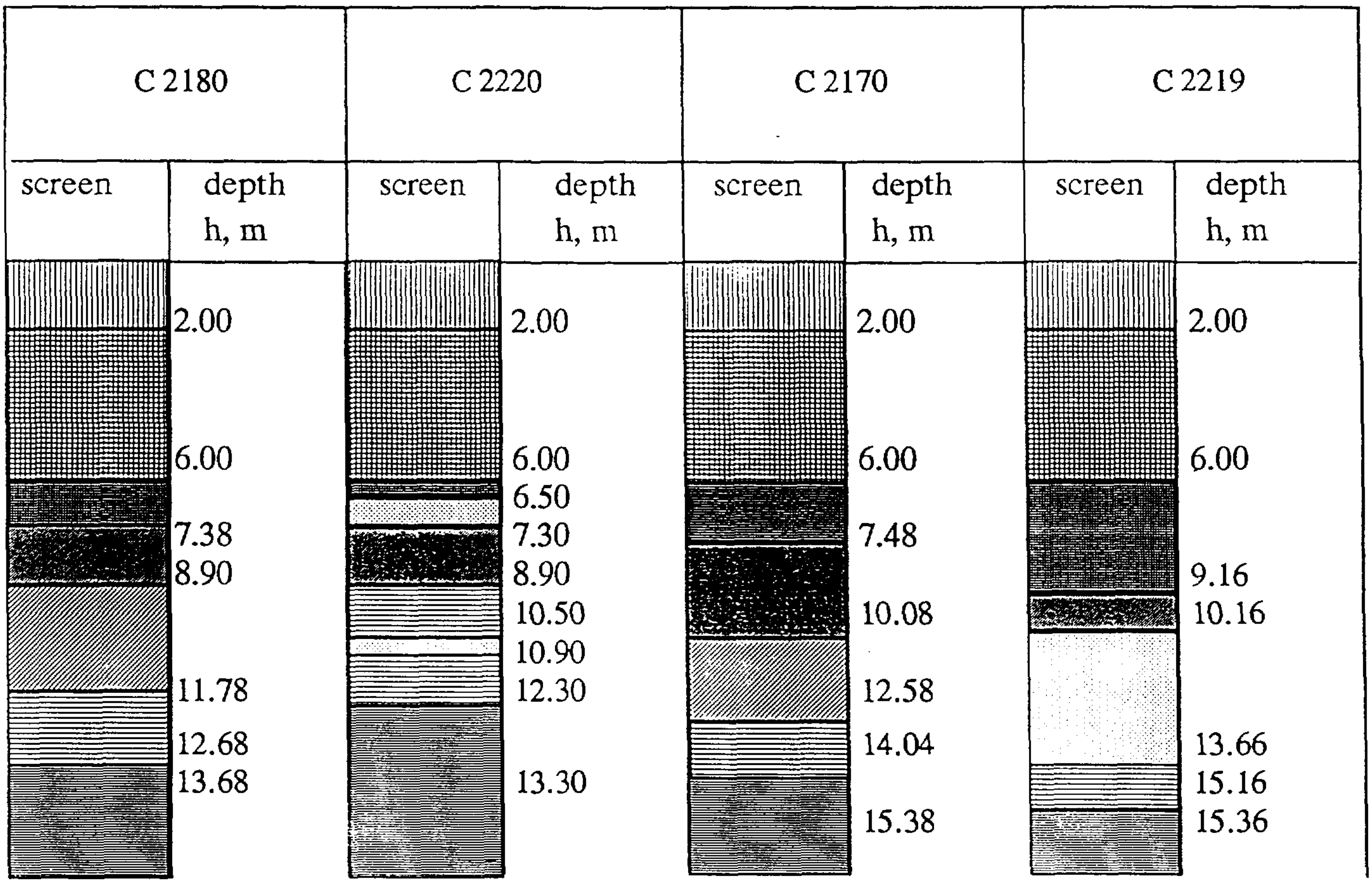


Fig. 2

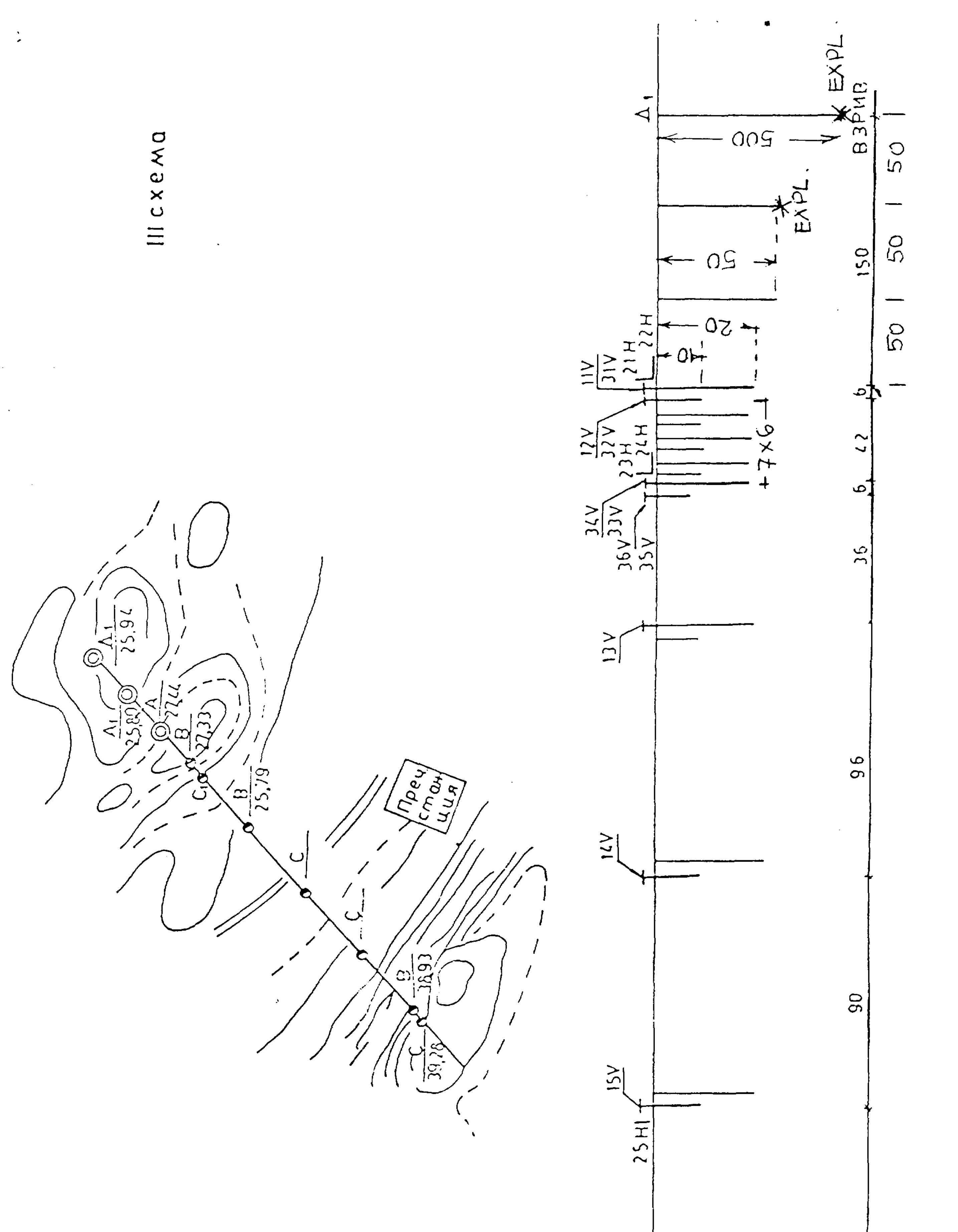


Fig. 2.1 Dynamic polygon units 5, 6 NPP Kozloduy, Shema III

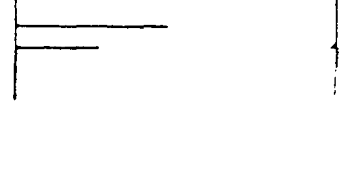


Fig. 3

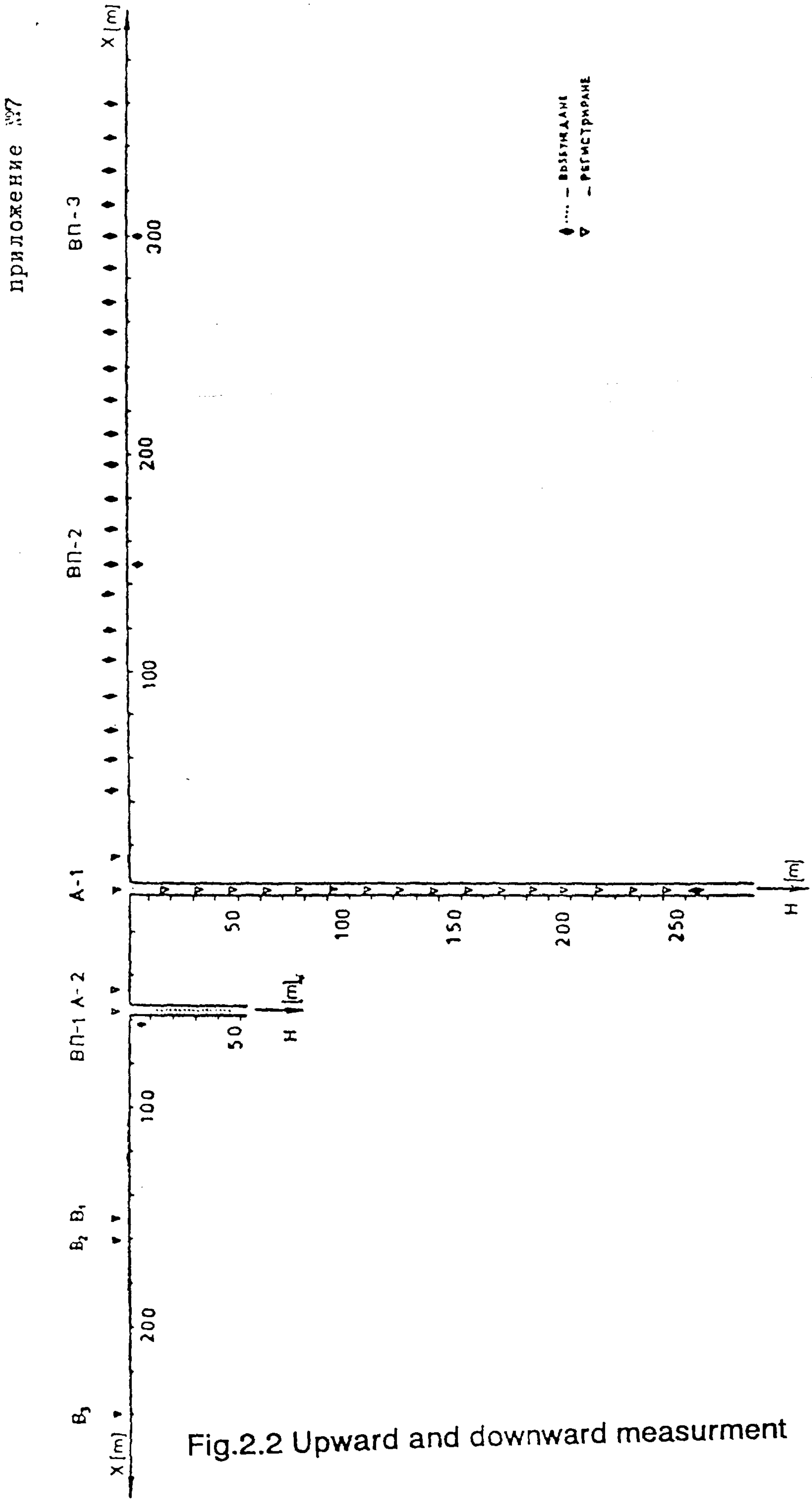


Fig.2.2 Upward and downward measurment

excitation
registration

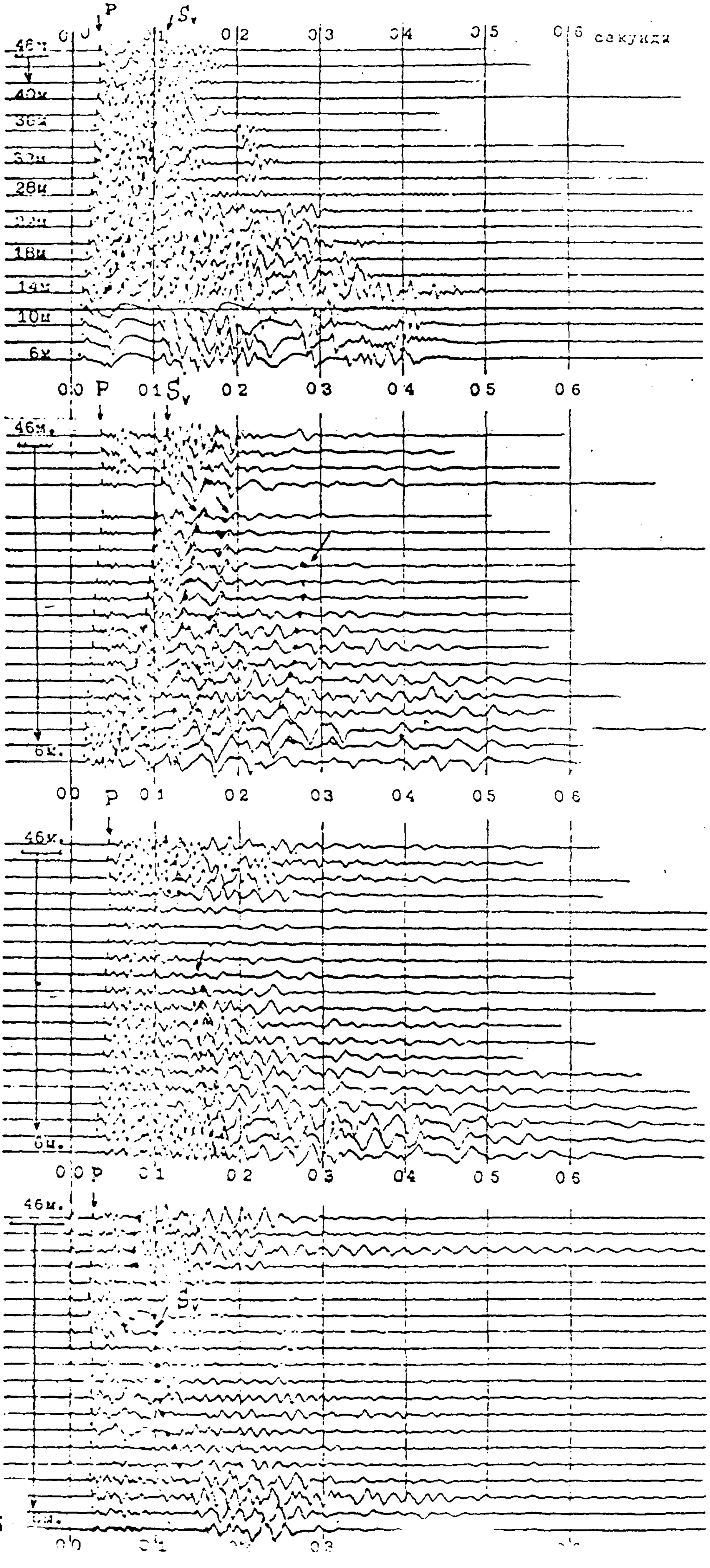

P
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Fig 5

приложение №6

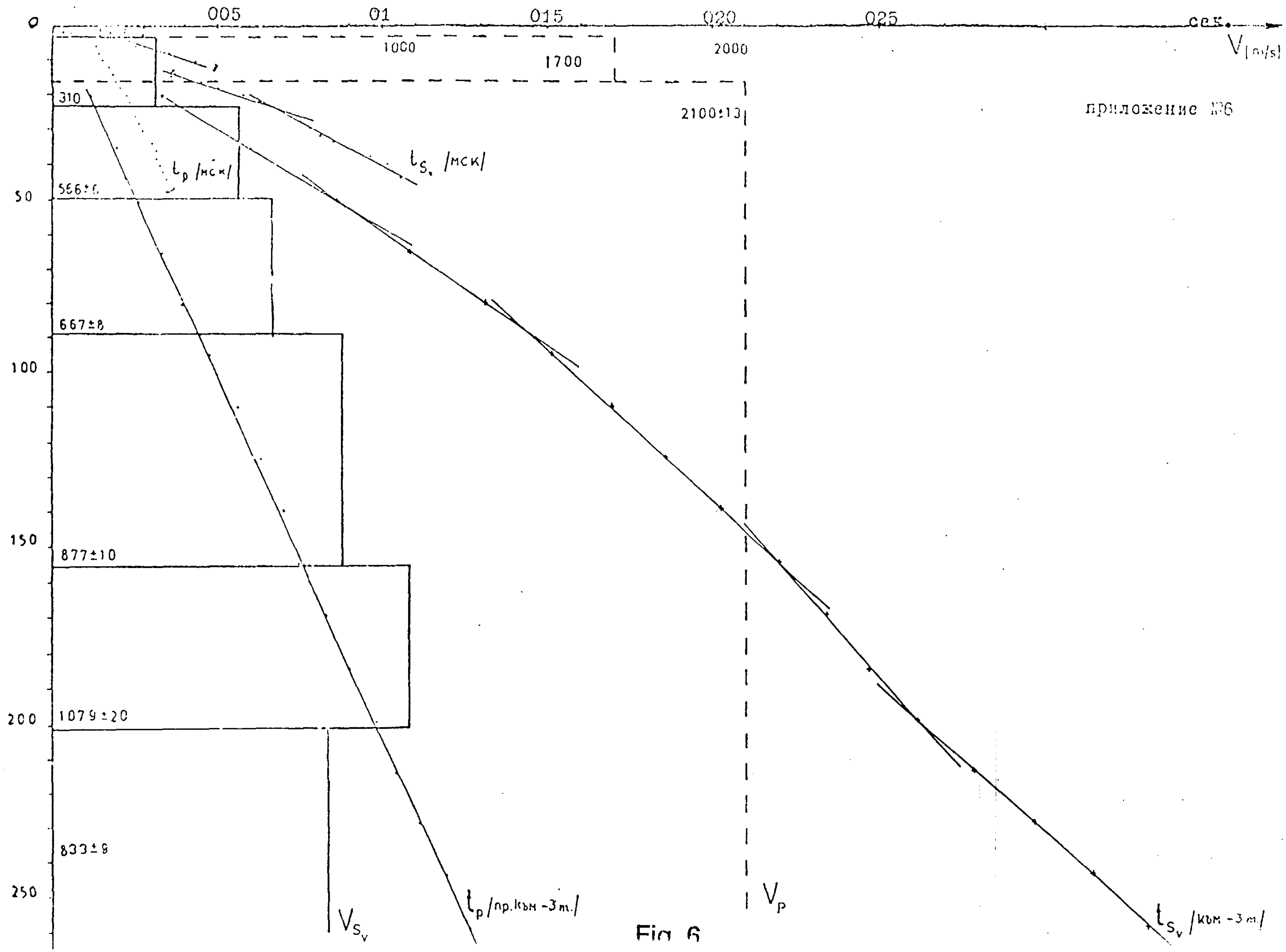


Fig 6

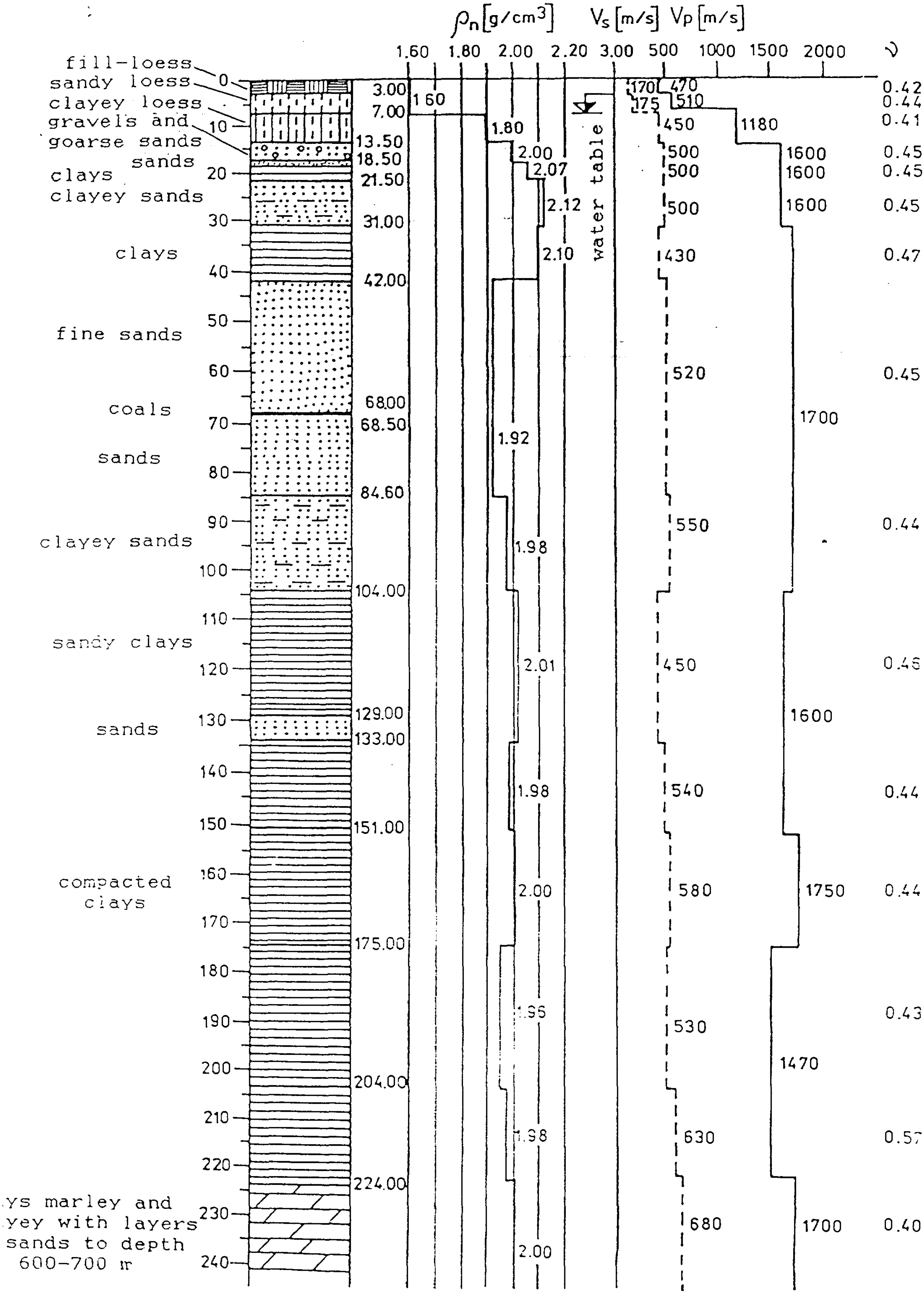
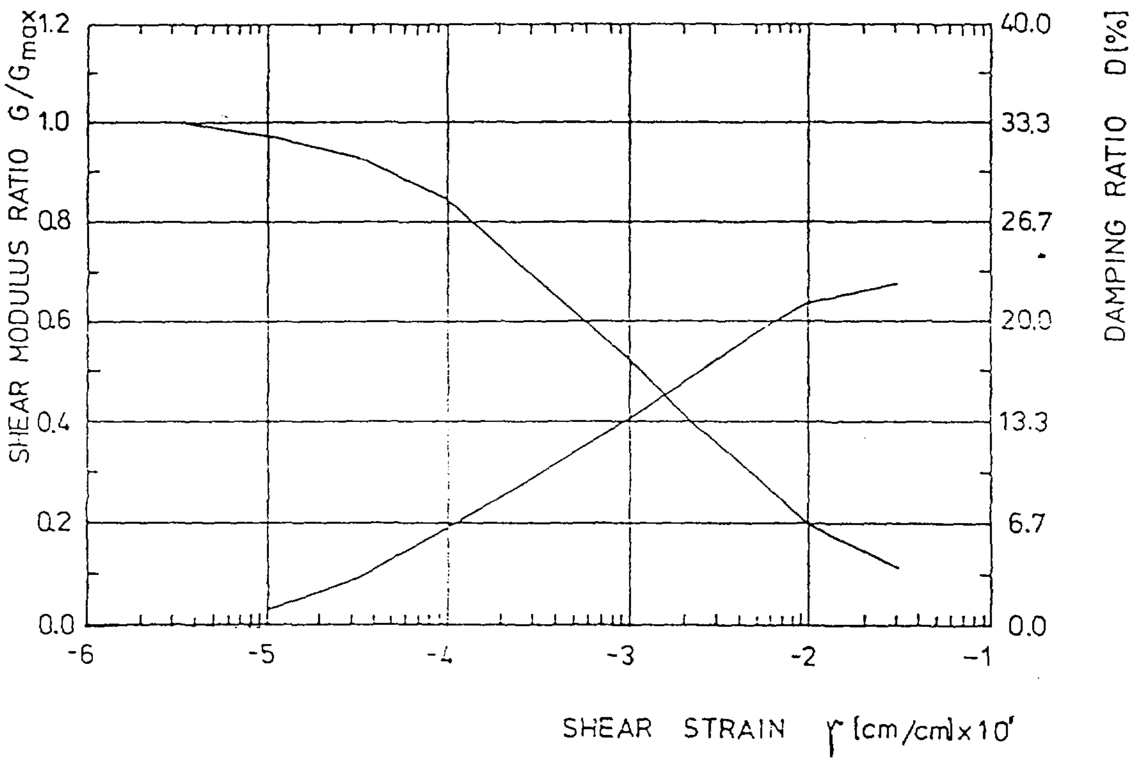


Fig. 7

SYNTHESIS ... TECHNICAL SEISMIC MODEL OF THE SITE ... -ELEVATION 34.70) M 1:100...



RELATIONSHIP FOR CLAYS AND CLAYEY SANDS

Fig. 8.b

АЕЦ „Козлодуй" – ВВЕР 1000 – бл. 5 и бл. 6

РЕАКТОРНОЕ ОТДЕЛЕНИЕ

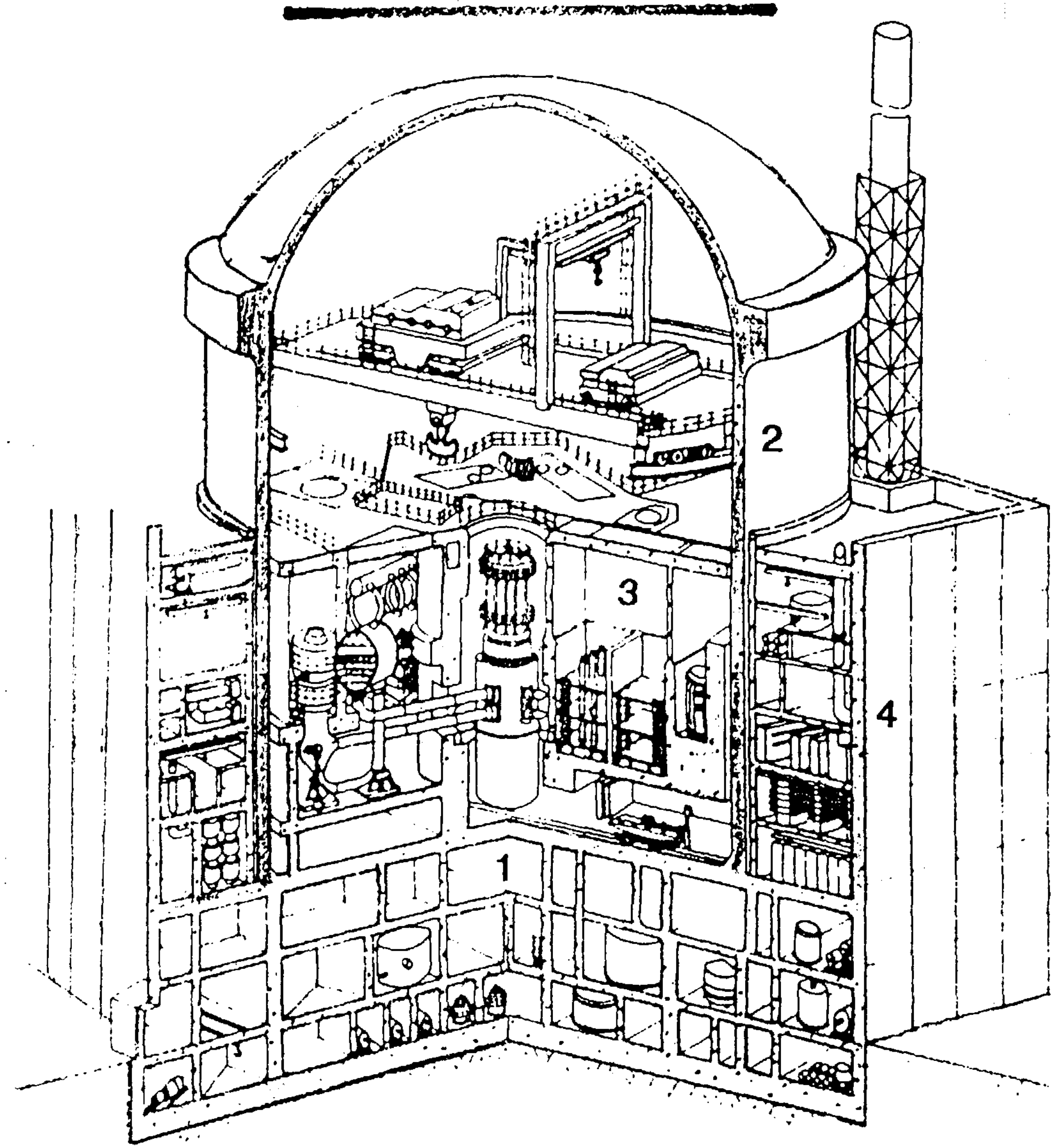
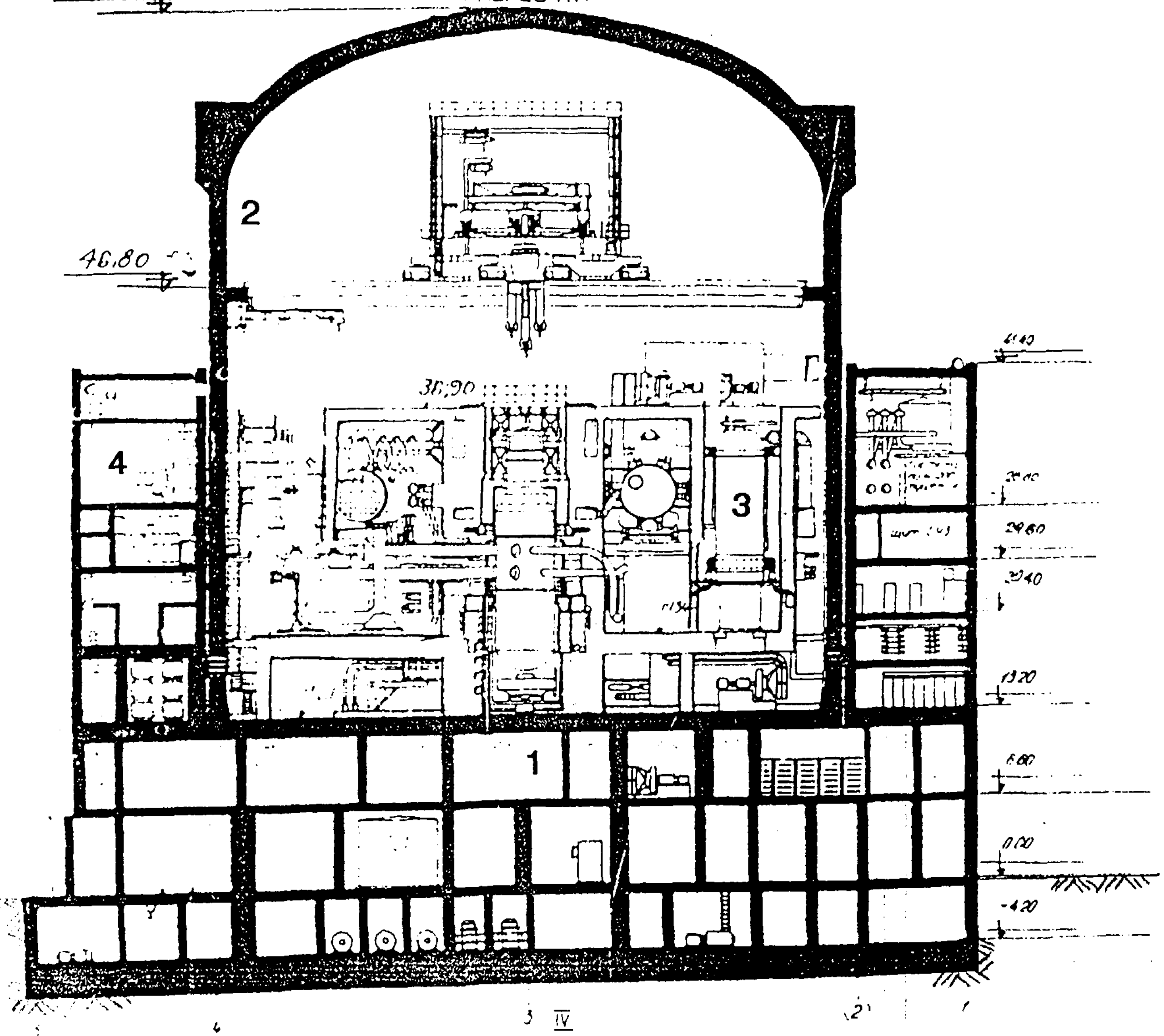


Fig. 9

РЕАКТОРНОЕ ОТДЕЛЕНИЕ
РАЗРЕЗ АА



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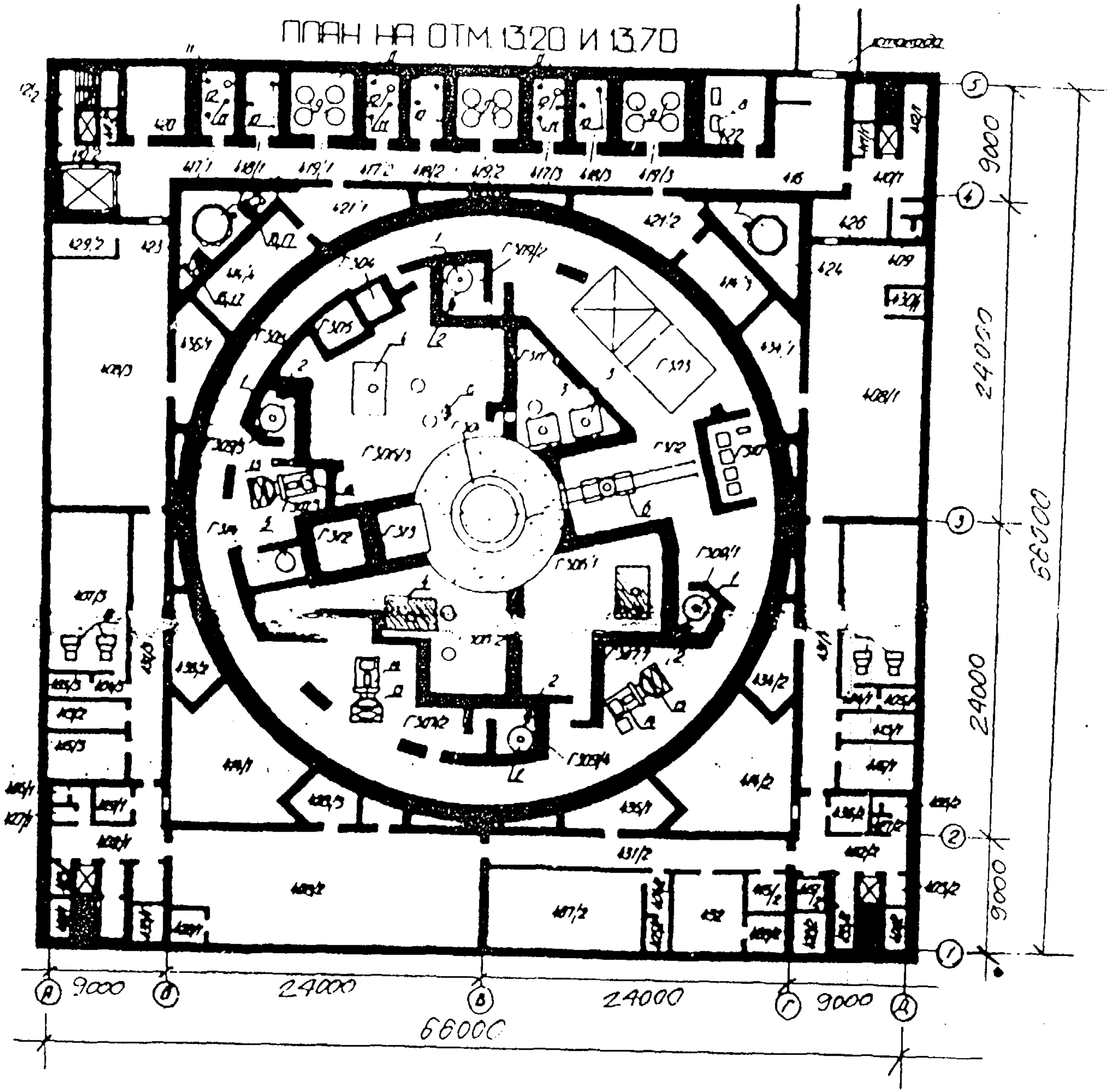
ПЛАН НА ОТМ. 13.20 И 13.70
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Fig. 11

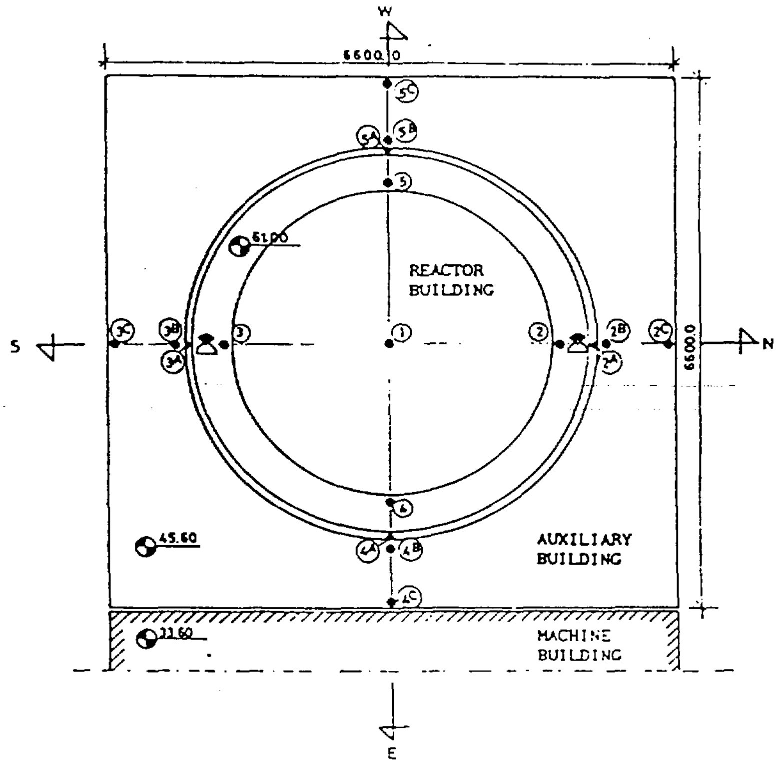

Fig. 12.a *Plan View of 1000 MW Reactor Building (Block V) at NPP Kozloduy and Disposition of the Equipment and Instrumentation*

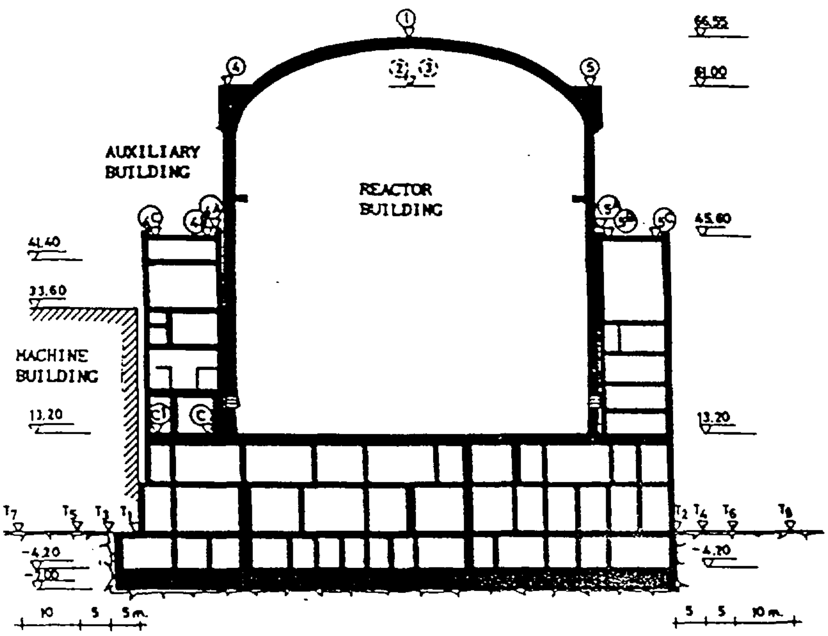

Fig. 12.b *Cross Section of the 1000 MW Reactor Building (Block V) at NPP Kozloduy and Disposition of the Instrumentation*

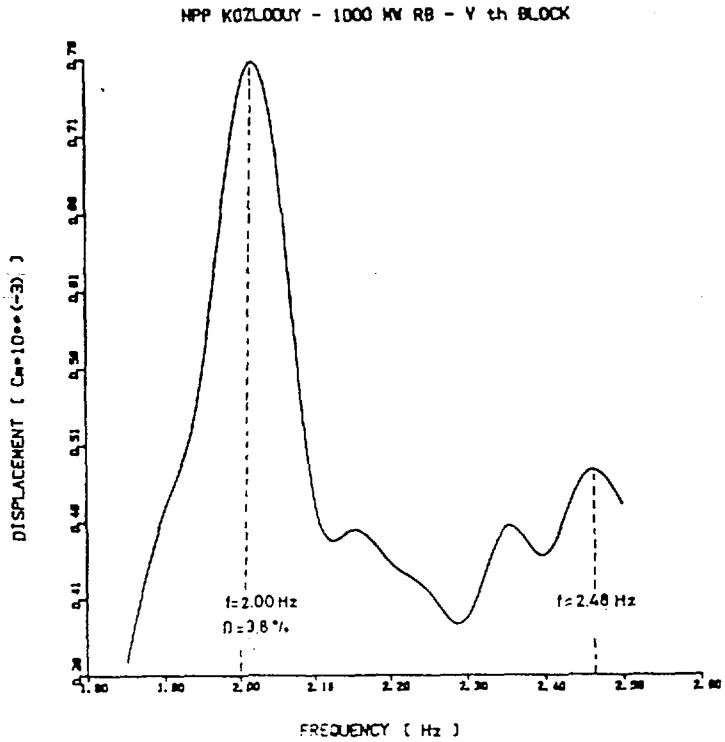

Fig. 13.a *Frequency Response Curves in N-S Direction Recorded at Point 3c (level 45.60) on the Auxiliary Building*

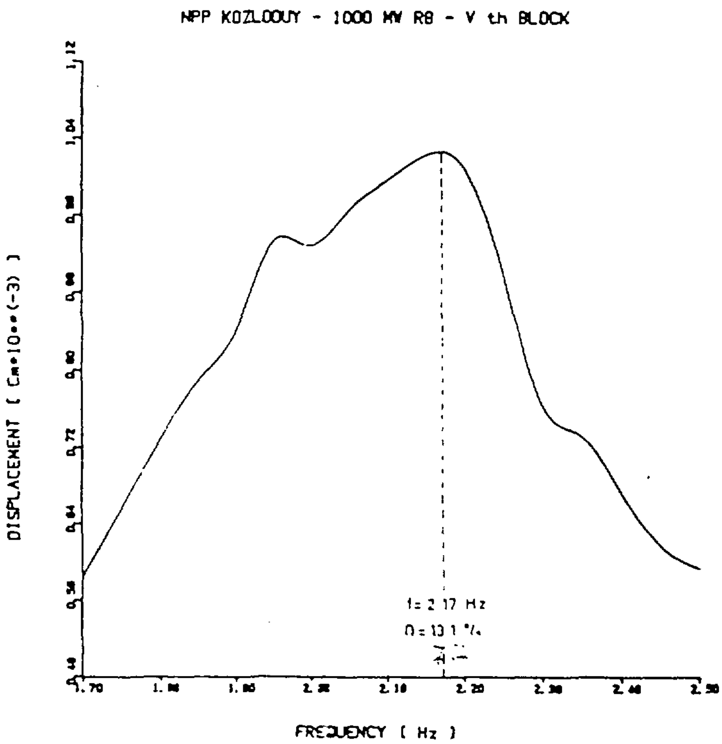

Fig. 13.b *Frequency Response Curves in E-W Direction Recorded at Point 3 (level 61.00) on the Reactor Building*

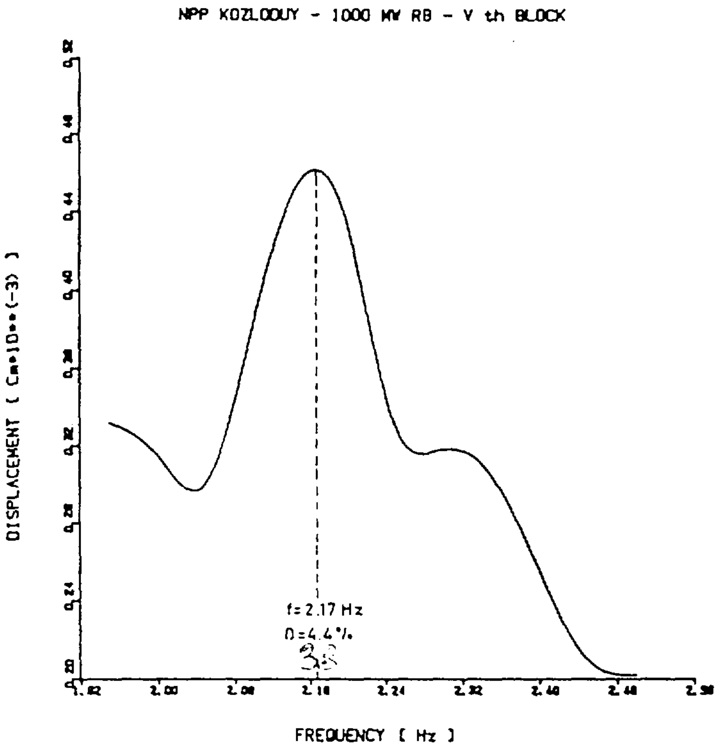

Fig. 13.c *Frequency Response Curves in E-W Direction Recorded at Point 4[c] (level 45.60) on the Auxiliary Building*

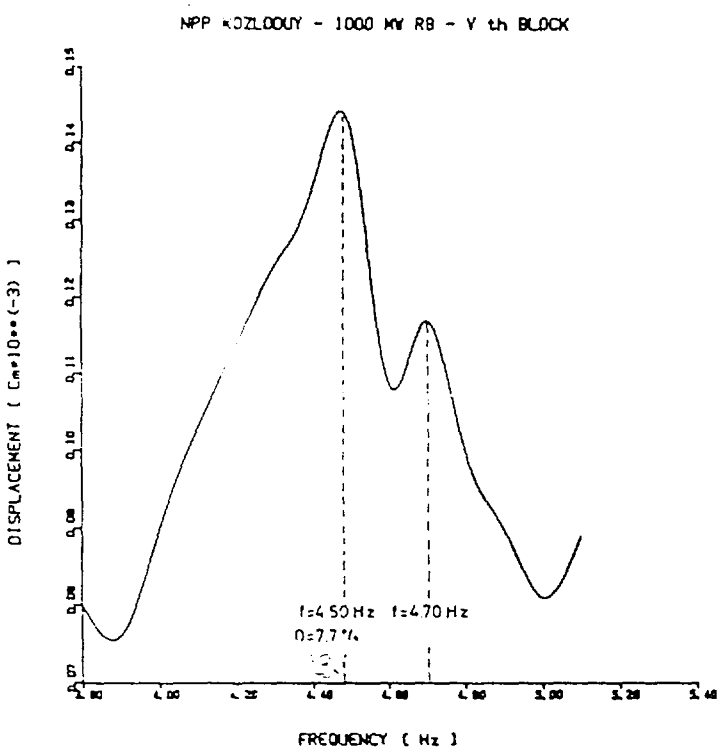

Fig. 13.d *Frequency Response Curves for Torsion Recorded at Point 3 (level 61.00) on the Reactor Building*

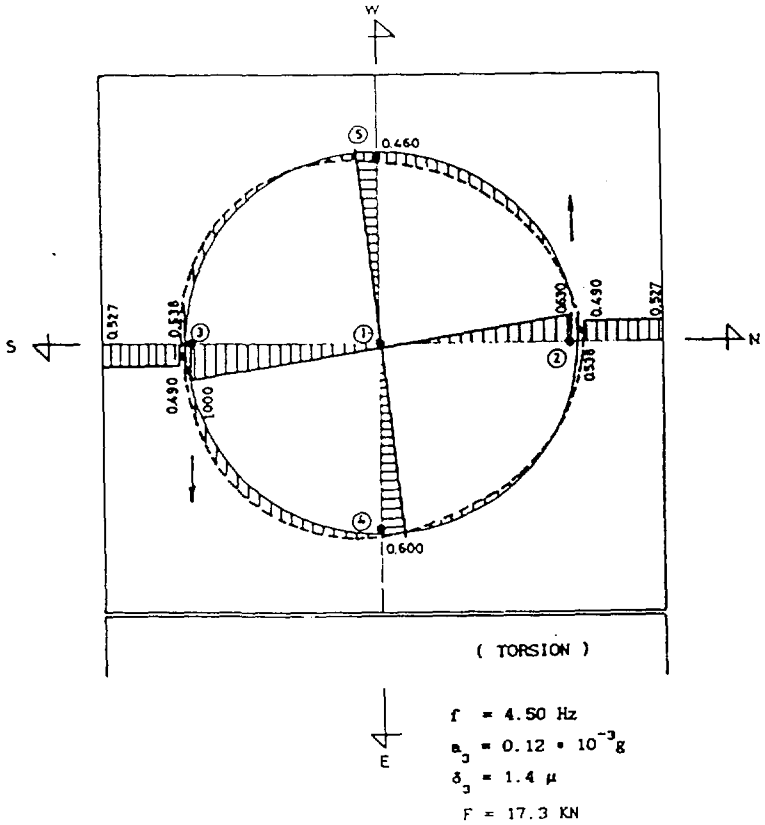

Fig. 14 *Horizontal Mode Shapes for Torsion Obtained at Level 61.00 and 45.60, f = 4.50 Hz*

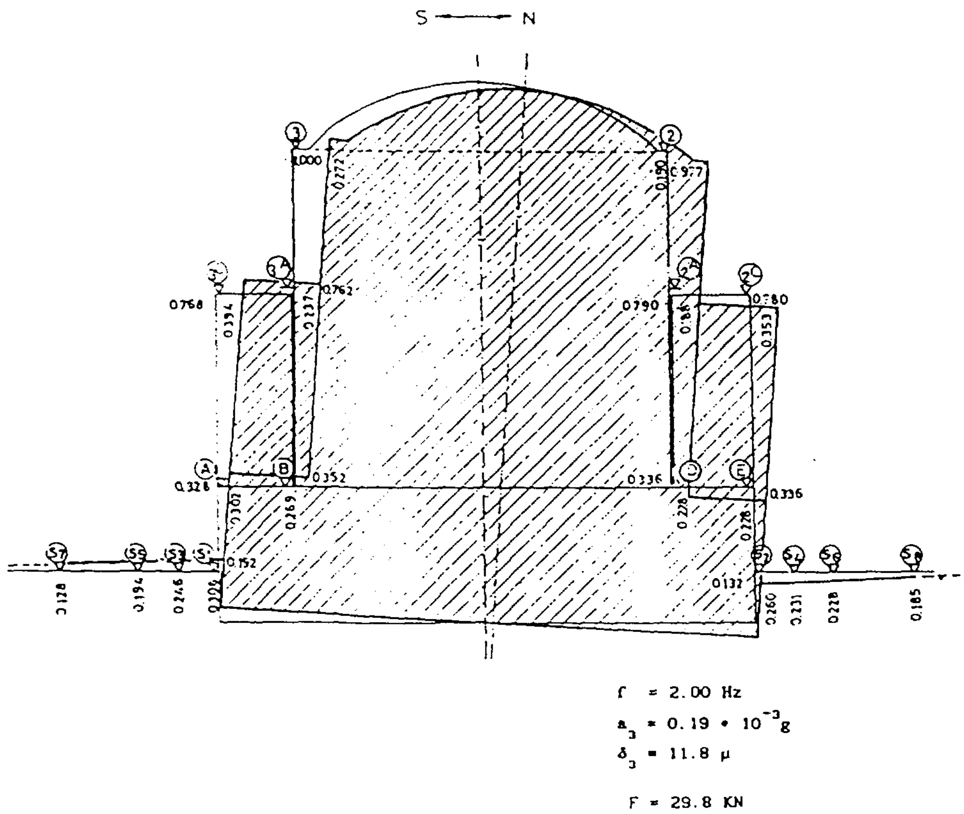

Fig. 15 *Vertical Mode Shapes in N-S Direction, f = 2.00 Hz*

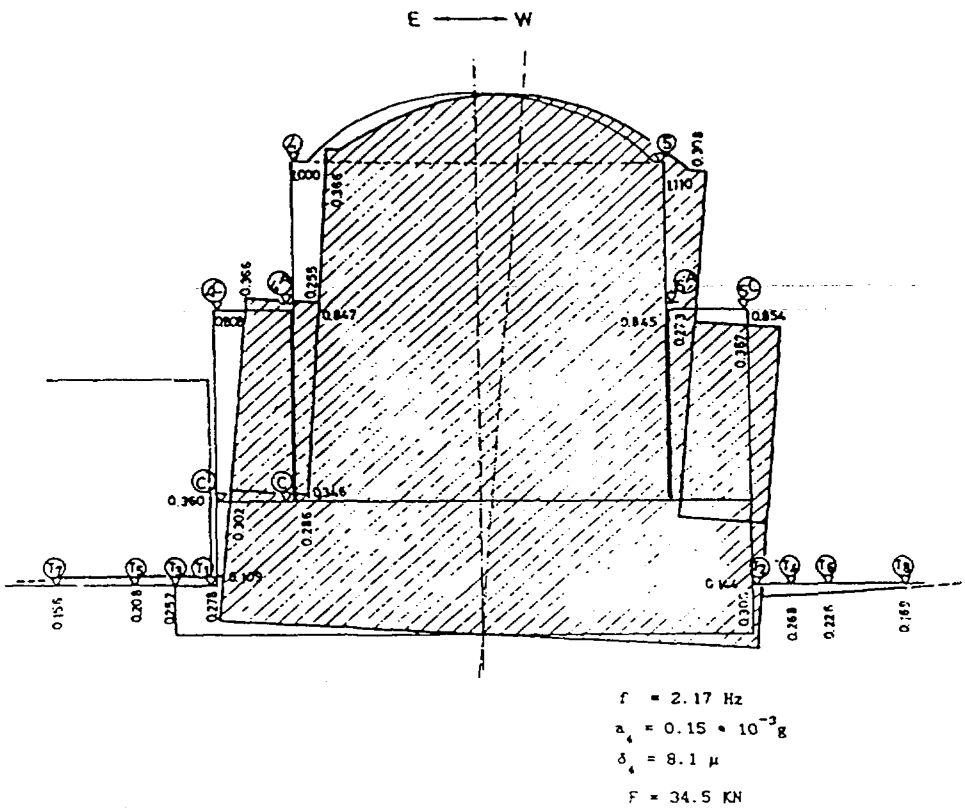

Fig. 16 *Vertical Mode Shapes in E-W Direction, f = 2.17 Hz*

С - Ю, напречен разрез

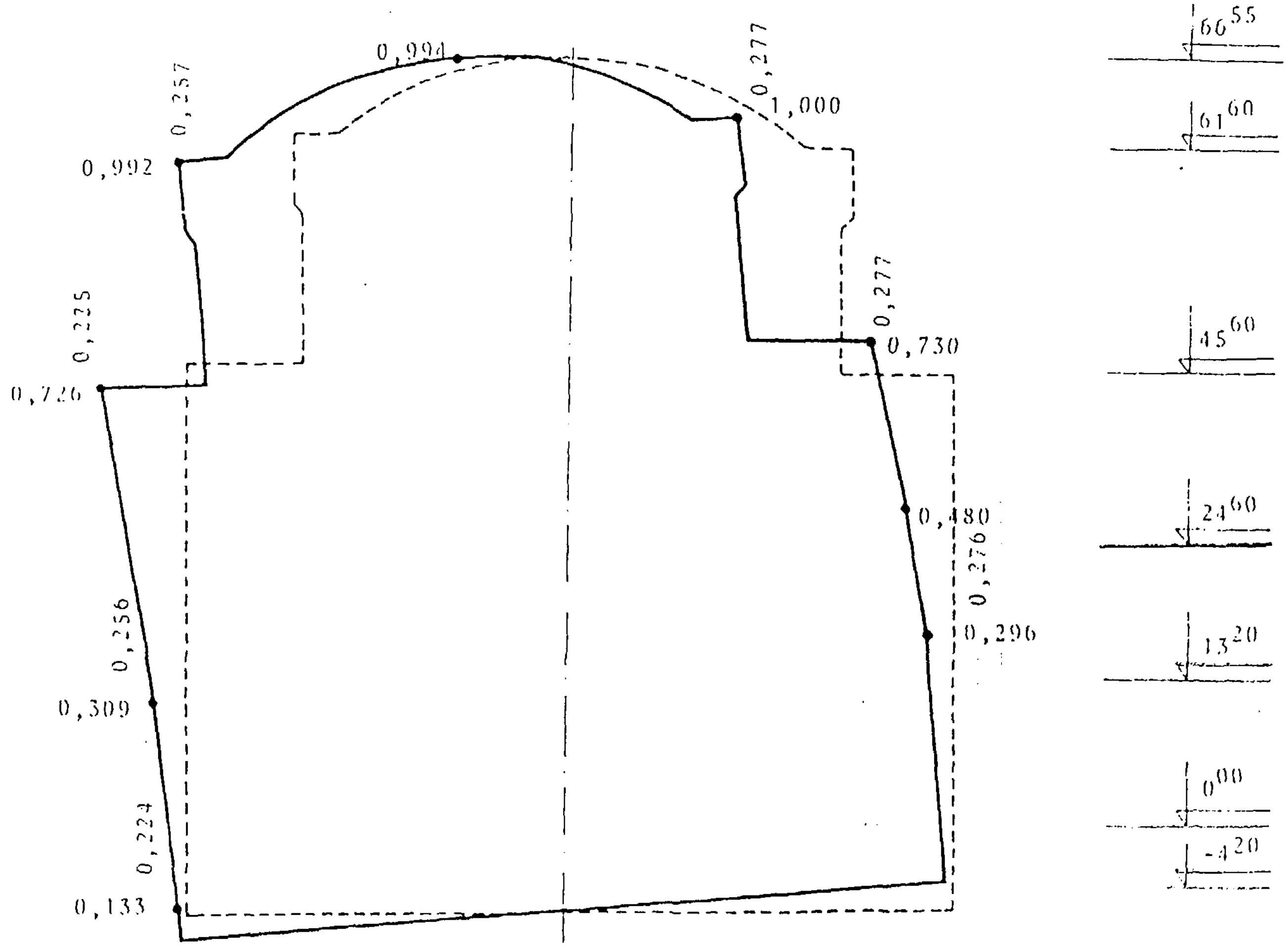

Fig. 17

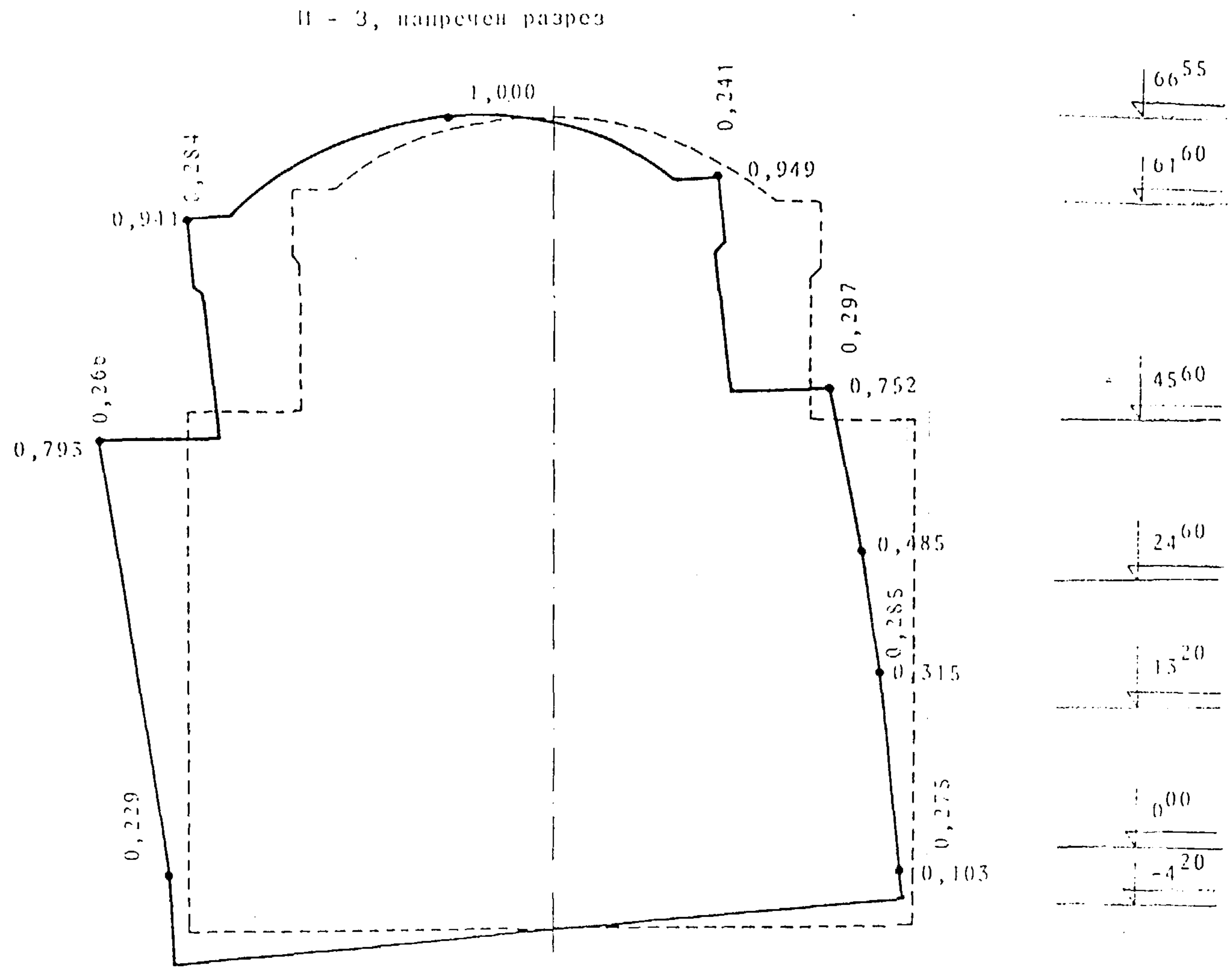
II - 3, напречен разрез
1,000
0,241
0,949
0,284
0,941
0,297
0,752
0,266
0,793
0,485
0,285
0,315
0,229
0,275
0,103
66.55
61.60
45.60
24.60
13.20
0.00
-4.20

Fig. 18

SUMMARY REPORT

Research Contract No 7438/EN

EXPERIMENTAL INVESTIGATIONS AND SEISMIC ANALYSES FOR BENCHMARK STUDY OF 1000 MW WWER TYPE (WATER-COOLED AND MODERATED REACTOR) NUCLEAR POWER PLANT KOZLODUY

Part of coordinated programme :

Benchmark Study for Seismic Analysis and testing of WWER - type Nuclear Power Plants

Building Research Institute (NISI) Sofia, Bulgaria

Chief Scientific Investigator : Prof. Dr. S. Sachansky

15 June 1993 - 14 June 1994

1. Scientific background and scope of project

NPP Kozloduy 1000 MW reactors No 5 and 6 have been designed in Moskow (1980) for peak ground acceleration 0.1 g and have to be redesigned for twice higher seismic excitation.

From the experiments in laboratory and on the real buildings were indentified findings and possible weakness.

New experiments have to be performed for determination of characteristics, which were not determined in previous investigations (1986, 1991) and are necessary for Bencmark Program.

The response of 1000 MW unit N0 5 or 6 should be investigated by blasting in the ground modelling real earthquakes in respect to be investigated : floor response spectra; response of critical equipment from selected floors; soil-structure interaction; spring and dashpot characteristics of the soil as well as radiation and material damping; impendance matrix of the foundation soil.

The results from the experiments should be used for verification and improving of the mathematical models and the analytical results.

2. Experimental method

Testing of "AS BUILT" structures and investigation of ground "in situ" is the main principle used for determining of the specific characteristics and defining the weak places and components which should be upgraded for twice higher seismic excitation.

The experiments were started in 1986, immediately after Chernobyl NPP accident, when 1000 MW unit No 5 was not compleated. The reactor building and turbine hall were shaked by moving and stoping of the existing cranes.

In 1991 the experiments were repeated by shaking the containment with two actuators (resonance method) on the roof. The results were the same like in 1986.

Benchmark program need data for verification and improving of the mathematical models and analytical results, for investigation the response of structures and equipment during simulated and real earthquakes.

3. Obtained results

Because of different soil conditions under unit 5 and 6, two geologigal profiles for each unit should be used for mathematical modelling. Another geological profile for "free field" should be used for deconvolution of the design accelerograms to selected levels . The following data should be used :

* Data for natural ground periods could be used for verification and improvement of mathematical models;

* Data for shear moduli ratio G|Gmax and for damping should beused in the analysis;

* Data for experimentaly determined natural periods of reactor building and turbine hall could be used for verification and improvement of structural math. models;
From laboratory testing and analysis of the reactor containment tendors were established some weakness places.

4. Conclusions

4.1.Proposals for establishing three soil geological profiles should be used for establishing respective soil mathematical models and their verification and improvement by the data for soil natural periods given in table 1.

4.2. For Benchmark program the establishing, verification and improvement of the structural mathematical models and analytical results is necessary to be performed full scale testing by explosions in the ground modelling real earthquakes for :

* registration of floor time history and response spectra, as well as response of critical equipment;

* soil-structure interaction effects for determination of spring characteristics, radiational damping, impendance matrix etc.

4.3. From laboratory, in situ testing and observations the following finding and weaknesses were established :

* destorsion of some of the containment tendor during prestressing at 60-80% of the designed force;

* the strenght and deformation characteristics of the tendor steel wires are reduced from several factors, and this have to be taken into consideration;

* replacement of the destroyed tendors with new ones do not increase the safety, because the technology for prestressing is not improved;

* the data from previous stress-strain analises should.be reinterpreated.

4.4.The vertical vibrations of the turbine hall roof were very large in unit 2 during the experiments, as well as during 1977 earthquake.

4.5. There are many weaknesses in the auxilary buildings (electrical, diesel generator etc). Their investigations in Benchmark program should be discussed.

4.6. Work plan for testing and investigation of 1000 MW unit 5 and 6 is proposed.