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Benchmark study for the seismic analysis and testing of WWER type NPPs

Final report of a co-ordinated research project

INTERNATIONAL ATOMIC ENERGY AGENCY

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FOREWORD

This TECDOC presents the final results of a five-year IAEA Co-ordinated Research Project (CRP), launched in 1992, “Benchmark Study for the Seismic Analysis and Testing of WWER Type NPPs”.

The main target of the CRP was the harmonization of criteria and methods used in Member States in seismic reassessment and upgrading of existing nuclear power plants (NPPs). To this aim, most of the activities have been focused on a benchmarking (blind prediction) exercise related to a mixed numerical and experimental dynamic analysis carried out on two reference units of WWER reactors (WWER-1000 and WWER-440/213): Kozloduy NPP Units 5/6 and Paks NPP.

Twenty-four institutions from thirteen countries participated in the CRP. Two other institutions (both from Japan) contributed to the CRP informally and on a voluntary basis.

The co-ordination of the research conducted by these institutions was ensured by the IAEA project officer and through annual research co-ordination meetings (RCMs).

Technical details, procedure description and extensive output from the RCMs are recoverable in the source reports from the participants, available with the project officer, and collected in Background Documents (5 volumes).

The objective of this TECDOC is to provide a consistent and comprehensive summary of the results of the work performed in the CRP through the preparation of a “self-standing” report with the general conclusion of the programme: a great deal of information from the Background Documents has been included in this TECDOC with a set of recommendations for future work in this field.

The IAEA is grateful to the participants for their valuable contribution and to the utilities in Paks (Hungary) and Kozloduy (Bulgaria) for making their plants available for the benchmark tests.

The work of all contributors to the drafting and review of this TECDOC is greatly appreciated. In particular, the contributions of R.D. Campbell (EQE Int.) and R. Masopust (S&A), who drafted the report, are acknowledged. The IAEA officers responsible for this publication were A. Guerpinar and P. Contri of the Division of Nuclear Installation Safety.

CONTENTS

Chapter 1

INTRODUCTION

BACKGROUND

In August 1991, following the eleventh Conference on Structural Mechanics in Reactor Technology (SMiRT-11) in Tokyo, a Technical Committee Meeting (TCM) was held on the Seismic Safety Issues Relating to Existing NPPs. One of the main recommendations of this TCM called for the harmonization of criteria and methods used in Member States in seismic reassessment and upgrading of existing NPPs.

With this objective in mind, a consultants meeting was convened in Vienna in April 1992 to produce a general outline of an IAEA Co-ordinated Research Project (CRP) which would assist in the realization of this recommendation. This meeting was attended by twenty specialists from eastern Europe, western Europe, the USA and Japan. It was decided that the CRP would concentrate on WWER type NPPs and that the focal point would be a benchmarking (blind prediction) exercise.

The CRP was named Benchmark Study for the Seismic Analysis and Testing of WWER Type NPPs with two types of WWER reactors (WWER-1000 and WWER-440/213) selected for benchmarking: Units 5/6 of the Kozloduy NPP and the Paks NPP.

The main objective of the CRP was therefore the meeting among utilities, safety authorities, engineering companies and suppliers involved in seismic re-evaluation programmes for WWER type plants. The scientific framework aimed at a harmonization of the methodologies to be used in such programmes and to their validation through dedicated exercises and in general through the experience that many Member States were accumulating in actuality. The proceedings of the research co-ordination meetings (RCMs) were compiled in Background Documents. (Vols 1–5).

Consistent with the recommendations of the TCM and the working paper prepared by the subsequent Consultants’ Meeting, the focal activity of the CRP was the benchmarking exercises. A similar methodology was followed both for Paks NPP and Kozloduy NPP Unit 5. Firstly, the NPP (mainly the reactor building) was tested using a blast loading generated by a series of artificially generated ground explosions. The participants had to make a blind prediction of the structural response and their analytical results were then compared with the results from the test.

Twenty-four institutions from thirteen countries participated in the CRP through either a research contract or a research agreement. Two other institutions (both from Japan) contributed to the CRP informally and on a voluntary basis. The list of participating institutions and the names of the chief scientific investigators are given in the Annex.

A general, independent confirmation of the high scientific value of the whole project has been given by the international scientific community. Some 50 scientific papers directly related to the research carried out in this CRP have been published in international journals and proceedings.

CONDUCT OF THE CRP

The co-ordination of the research was provided by the IAEA project officer and through annual research co-ordination meetings (RCMs).

During the RCMs, presentations were made by each participant summarizing the work done during the previous year and the workplan for the upcoming period.

Technical visits to a facility relevant for the project were also arranged in conjunction with every meeting: they provided new information or insight to topics related to the CRP. During the first two RCMs (which were held at the Paks NPP and Kozloduy NPP respectively), these technical visits comprised plant walkdowns. The main product of each RCM was an updated joint work plan comprising a list of tasks with an indication of the participating institutions in the tasks as well as their completion status. A comprehensive list of the reports issued by participants is shown in the Annex.

In fact, the initial list of tasks prepared during the planning meeting in Vienna in April 1992 was expanded from year to year after evaluation of the proposals of the participants. Therefore, over time, the task list of the CRP grew considerably. It collected many generic studies on codes and standards used in WWER design, studies on the comparison with current international practice, experience data on equipment qualification, research studies on seismic input definition oriented towards a re-evaluation activity, and new seismological evidence in the areas where WWER plants are currently located.

This enlargement of the initial target of the CRP, still very focused on the seismic analysis of WWER plants, formed a very good basis for new re-evaluation activities, spanning all the related topics, from input definition, to standard selection, to component qualification. Such an “open list” was very much influenced by the re-evaluation activities running at the plants in the same years: the seismic upgrading in most of the WWER plants in fact was the driving force behind the CRP activities, pushing the potential suppliers to show themselves up and to use the CRP as a scientific hosting occasion where they could exhibit their capabilities. This mechanism was one of the keys of the success of the CRP in terms of completeness, scientific repercussions and participation.

A comprehensive global list of the tasks is shown in Table I.1, with the symbol of the contributing organization and the pointer to the chapter of this TECDOC where the most relevant results were collected.

The benchmarking tasks had a peculiar sequence. The Paks and Kozloduy reactor buildings were tested using a blast loading generated by a series of explosions from buried TNT charges. Readings from this test were obtained at several free field locations (both downhole and surface), at the foundation mat, at various elevations of structures as well as at some tanks and the stack. Then the benchmark participants were provided with structural drawings, soil data and the free field record of the blast experiment. Their task was to make a blind prediction of the response at pre-selected locations. The analytical obtained results from these participants were then compared with the results from the test.

TABLE I.1 TASK LIST AND ACTIVITY SHARING (TASK CO-ORDINATOR, IF ANY, IN BOLD)

Task	Title	Participants	Tecdoc Chapter	WM volume
1	Safety shutdown systems identification/classification	**WESE** PNPP KNPP	3	1
2	Design regulations, acceptance criteria, loading combinations	**AEP** S&A-US	2, 3	2, 1
3	Seismic input, soil conditions	**PNPP** **KNPP** ISMES SIEMENS EP	3	1
4	Standards, criteria — Comparative studies	**S&A-CZ** MD CKTI WESE	2	2
5	Walkdown of reference plants (Paks and Kozloduy Unit 5)	ALL	only in WM	2
6a	Dynamic analysis of Kozloduy NPP Unit 5 RB for seismic input	**SIEMENS** EQE-BG EQE-US CL KNPP BRI EP AEP	5	3
6b	Dynamic analysis of Paks NPP RB for seismic input	**SIEMENS** ISMES MD	4	4
7	Dynamic analysis of Paks NPP structures (benchmarking with results of Task 8)	**ISMES**	6	3, 4
7a	Reactor building	**SIEMENS** ISMES CL MD EQE-US IVO	6	3, 4
7b	Stack	IZIIS SAGE	6	3, 4
7c	Worm tank	**PNPP** ANL/AES NIED/IHI S&A-CZ	4	4

TABLE I. (cont.)

Task	Title	Participants	Tecdoc Chapter	WM volume
8a	Full scale blast testing of Paks NPP	**ISMES** PNPP	6	3, 4
8b	Full scale blast testing of Kozloduy NPP Unit 5	**ISMES** KNPP	6	3, 4
9	Shaking table experiment for selected components	**PNPP** **KNPP** IZIIS	4, 5	4, 3
10	On-site testing of equipment at Paks and Kozloduy NPPs	**PNPP** **KNPP** VNIIAM	5, 7	3, 5
11	Preliminary component test data	**S&A-RO** AEP VNIIAM IZIIS CKTI	7	5
12	Experience data from Vrancea and Armenia earthquakes	**EQE-US** S&A-RO	7	5
13	Experience data from US earthquakes	**EQE-US**	7	5
14	Special Topic 1 — Assessment of containment dome pre-stressing for Kozloduy NPP	**S&P** EQE-BG KNPP BRI	5	3
15	Special Topic 2 — Assessment of containment dome/cylindrical part for different loading combinations	**S&P** EQE-BG KNPP BRI	5	3
16	Special Topic 3 — Stress analysis of safety related piping for Kozloduy NPP	**S&P** SIEMENS BRI WO	5	3
17	Special Topic 4 — Dynamic analysis of selected structures of Kozloduy NPP	**S&P** BRI	5	3
18	Paks NPP feedwater line analysis to be compared with testing which was already performed	PNPP CKTI SA WESE	not ended	/
19	Analysis of buried pipelines for Kozloduy NPP (between DG and spray pools)	EQE SIEMENS S&A-CZ	5	3
20	Analysis of buried pipelines for Paks NPP	EQE-US SIEMENS S&A-CZ	4	4
21	Comparison of beam vs. 3D models for Kozloduy NPP and Paks NPP structures	MD EQE-BG	6	3, 4

TABLE I. (cont.)

Task	Title	Participants	Tecdoc Chapter	WM volume
22	Experience database (WWER SQUG) initiation	S&A-US S&A-CZ S&A-RO EQE-US PNPP KNPP	7	5
23	Consolidation of results and reports	ISMES S&A-CZ EQE-US	/	/
24	Dynamic analysis of Kozloduy NPP Unit 5 structures (Benchmarking with results of Task 8)	SIEMENS ISMES CL MD EQE-US IVO	6	3, 4
25	Comparison of blast and vibrator tests for Kozloduy NPP	ISMES IZIIS	6	3, 4
26	Evaluation of potential hazard of WWER400 reactor operating control and drive system	CKTI	4, 5	4, 3
27	Influence of rotation seismic input on structural seismic response	SAS	2	2
28	Vrancea hazard	EQE-US S&A-RO	7	5

This scientific work highlighted the reliability of the available numerical tools, the need for further research, a general judgement on the best compromise between experimental and numerical tools in the seismic re-evaluation processes.

The reports from the CRP participants have been compiled in Background Documents, grouped under the following broad categories:

- Volume 1: Data related to sites and plants (Paks NPP and Kozloduy NPP Units 5/6)
- Volume 2: Generic studies (codes, standards, criteria) (Subvolumes: A, B)
- Volume 3: Kozloduy NPP Units 5/6 analysis/testing (Subvolumes: A, B, C, D, E, F, G, H, I)
- Volume 4: Paks NPP analysis/testing (Subvolumes: A, B, C, D, E, F, G, H, I)
- Volume 5: Experience data (Subvolumes: A, B, C).

The “Background Documents” constitute a comprehensive and unedited documentation of the CRP: the volumes are available on request from the IAEA Secretariat (i.e., the Project Officer).

As an additional result of the experiments, studies and research activities, a large number of scientific papers have been issued by the participants, both in the Post-SMiRT

Seminars dedicated to the re-evaluation of WWER plants, and in scientific journals. A comprehensive list of these offshoot activities is shown in the references to each chapter.

Adherence to a predefined grid compelled **the working group** to condense a substantial amount of information — **the working group** focused primarily on the applicability of the results, as evidenced by the six points below:

- Task objective: this is a short identification of the objectives, where the consistency with the general CRP targets is highlighted.
- Summary of work done: work assumptions and procedures are summarised.
- Results: in this chapter the main scientific and technical results are summarized; all the details necessary for an evaluation of the work done are provided.
- Applicability of results: a specific evaluation on the applicability to other plants of the task results.
- Lessons learned: a specific evaluation on the main engineering output from the task, as a basis for the establishment of general procedures for seismic re-evaluation of WWER plants.
- Conclusions and recommendations: a task evaluation aimed at identifying open issues, the need for further research (if any), connections with other tasks and specific recommendations for the analysed plant (when applicable).
- References: divided in "Post SMiRT Seminar papers" and "Scientific papers", for a quick recovery of the full reports and papers.

In the following chapters, the scientific material is presented task by task according to this grid.

OBJECTIVE

The objective of the present technical document is to provide a consistent and comprehensive summary of the results of the work performed by the participants of the CRP within the framework of this programme and preliminarily collected in the Background Documents.

The target of the authors was the preparation of a 'self standing' document containing the general conclusions of the programme. To this aim, much information from the basic reports has been recovered, rearranged and included in the present TECDOC. Therefore, many technical details, procedure descriptions and ancillary data are still recoverable, but only in the source reports, available from the project officer in the form of "Background Documents".

There are also numerous publications which have resulted from the CRP either in conference proceedings or in international scientific journals. Some important conclusions can be recovered also from these sources. Another objective of this TECDOC is to sort out a large number of publications, which are referenced in the relevant chapters for easy access.

SCOPE

Although the benchmarking exercises constituted the focus of the CRP, many other interesting problems related to the seismic safety of WWER type NPPs were addressed by the participants. These involved generic studies, i.e. codes and standards used in original WWER designs and their comparison with current international practice; seismic analysis related to different structures or systems of Paks NPP and Kozloduy NPP Units 5/6 and experience data for WWER type NPPs (previous laboratory results and earthquake experience).

This TECDOC summarizes the main results of the benchmark and other valuable results that might be extremely useful in the light of the general objectives.

STRUCTURE

The main chapters of this TECDOC present the summaries of the work performed in relation to the identified tasks. These summaries include the title and objective of the tasks, participants involved, summary of the work done and results obtained, applicability of the results to other NPPs, lessons learned and recommendations for future work.

The structure of the TECDOC loosely follows the subject areas set out in the Background Documents as follows:

- Chapter 2: standards, seismic input: here many contributions deal with the comparison between WWER design standards and current international practice.

- Chapter 3: description of sites and plants: this is a description of the two “reference” sites and plants, selected respectively in Paks (Hungary) and Kozloduy (Bulgaria) for their easy accessibility, for their representativeness of the WWER unified design and their site conditions.

- Chapter 4: analysis and testing at the Paks NPP: this is a collection of basic studies on structures, components and equipment which provide a framework for the interpretation of the specific results from the benchmark.

- Chapter 5: analysis and testing at the Kozloduy NPP: as above.

- Chapter 6: benchmarking exercises at the Paks and Kozloduy NPPs: here the results of the benchmark are collected, with a summary of the main assumptions taken by the participant organizations, a synthesis of the results and interpretation of their scattering.

- Chapter 7: experience data: a summary of relevant activities in the field of equipment qualification both by test and experience data (oriented databases) and siting procedures.

The final chapter of this TECDOC comprises the recommendations for future work identified during the final RCM in San Francisco. This is the main conceptual outcome of the RCM, which outlines the suggested trend, based on other scientific initiatives and IAEA programmes.

Chapter 2

GENERIC RESEARCH

TABLE II.1.

Task	Title	Participants	Tecdoc Chapter	WM Volume
2	Design regulations, acceptance criteria, loading combinations	**AEP** S&A-US	2, 3	2, 1
4	Standards, criteria — comparative studies	**S&A-CZ** MD CKTI WESE	2	2
27	Influence of rotation seismic input on structural seismic response	SAS	2	2

2.1. DESIGN REGULATIONS, ACCEPTANCE CRITERIA, LOADING COMBINATIONS (TASK 2) AND STANDARDS, CRITERIA – COMPARATIVE STUDIES (TASK 4)

Objectives

The objective of these two tasks was to prepare a detailed summary of design regulations, acceptance criteria, and loading combinations which were originally used for the design of both reference NPPs and their comparison with current international practice used for seismic design and evaluation of existing NPPs.

Summary of work done

These tasks were performed jointly and they can be divided into three sections:

- comparative study in which the original Soviet and Russian design regulations, acceptance criteria and loading combinations are compared with the internationally recognized practice for seismic design and seismic evaluation of existing NPPs;
- proposed general criteria for seismic evaluation and potential design fixes for WWER type NPPs, the development of a graded approach for natural phenomena hazard design of WWER NPPs, the proposed guidelines for safety related equipment typically used in WWER type NPPs, and the proposed expert system GIP WWER for verification of seismic adequacy for WWER equipment;
- detailed recommendations and experience in relation to the functionality of WWER electrical and I&C components, in relation to using of high viscous pipework dampers and in relation to evaluation of the seismic adequacy of some types of electrical devices.

Results

The results obtained can be summarized as follows:

(a) Differences between the Soviet/Russian standards and regulations which relate to seismic design and qualification of NPPs and the corresponding internationally recognized practice are significant and they are identified in the references to this TECDOC. It is impossible to conclude that these differences imply more or less conservatism in seismic designs and qualifications performed in accordance with the Soviet/Russian standards and regulations when compared to those performed in accordance with current international practice. Experience is such that the greatest seismic vulnerabilities of the WWER type NPPs are rather caused by the absence or negligence of the corresponding seismic standards and regulations as well as errors in construction and detailing. Figure 2.1 shows the historical development of original Soviet and current Russian standards and regulations related to the seismic design and qualification of NPPs.

(b) Particularly, when comparing the pipe stress criteria as given in the Soviet/Russian standard PiNAE to the corresponding ASME BPVC, it was recognized that the Soviet/Russian criteria are generally more conservative than those given in ASME BPVC.

(c) It should also be concluded that the well known methodologies seismic margin assessment (SMA) and generic implementation procedure (GIP) are very useful when properly modified to take into account specific conditions of WWER type NPPs. The objective of these methodologies is not to design or redesign the plant, but to determine the realistic seismic resistance of as-built structures, components and systems when subjected to the postulated earthquake and modify only those which are required to provide at least a minimum level of seismic resistance. A general definition of seismic margin is expressed in terms of the earthquake peak ground acceleration (pga) that is established with high confidence that there is a low probability of failure (HCLPF).

(d) A great deal of effort has been spent over the past several years to develop design and review procedures associated with the seismic adequacy of the safety related systems of WWER type NPPs. However, there are also other systems associated with gaseous, liquid and solid radioactive waste processing and storage and spent fuel storage facilities at WWER sites for which the seismic evaluation criteria developed for the reactor and other safety related systems may not be appropriate. In addition, other natural phenomena hazards such as extreme wind and flooding have still not received sufficient attention.

(e) Practical aspects of the evaluation of seismic functionality of electrical and I&C components are systematically summarized in the references to this TECDOC, including the relay analysis process. This pragmatic approach which is described in the detailed flow chart of functional evaluation of electrical and I&C components presented in the Background Documents can be recommended for evaluation of the seismic adequacy of such components installed in all other WWER NPPs.

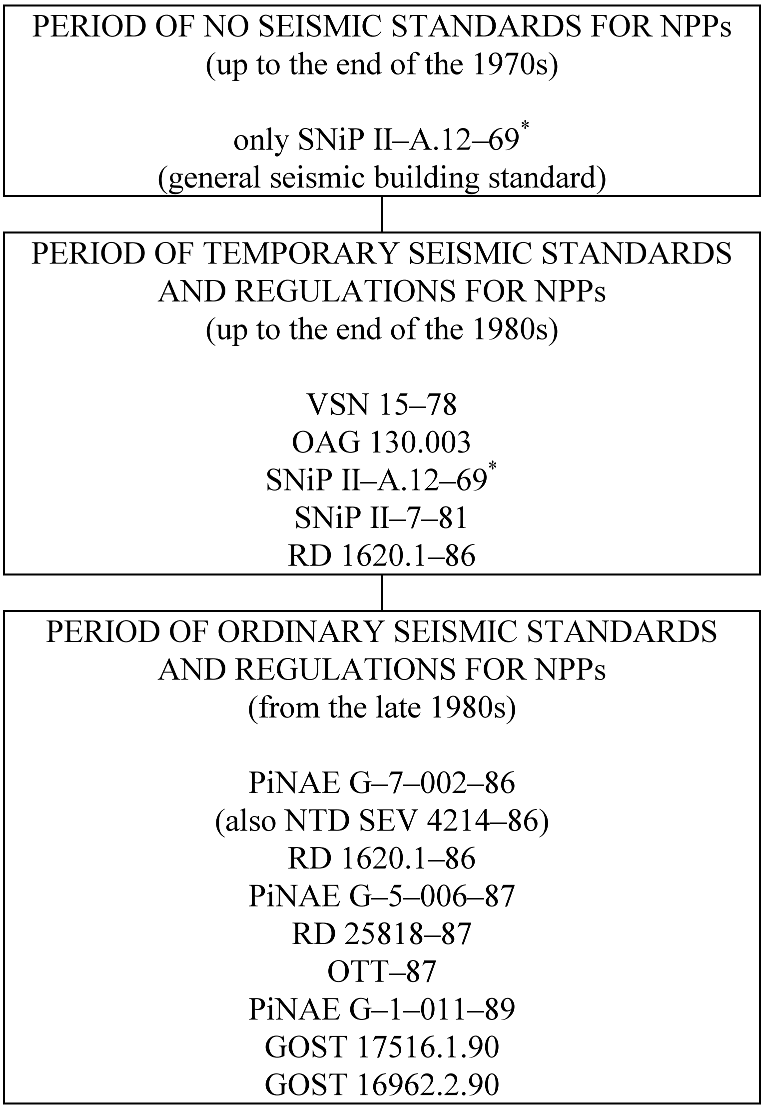

FIG. 2.1. Historical development of the initial Soviet and current Russian standards and regulations related to the seismic design and qualification of NPPs.

Notes:

(1) There were and still are many coherent Soviet standards and regulations related to the general safety issues of NPPs, to the siting of NPPs, the design and construction of their building structures, the design and manufacturing of mechanical and electrical equipment, quality assurance etc.

(2) NTD SEV standards issued by the Interatomenergo in association with several institutions from the former socialist countries for atomic energy.

(3) RTM 108.020.37–81 was only a recommended document.

Applicability of results

The results obtained within the scope of these tasks are generally applicable to the seismic evaluation of many other WWER plants.

Lessons learned

In relation to the original Soviet/Russian seismic standards and regulations, the main problem is perhaps if and how these documents have been used, in particular in relation to seismic design and qualification. There are still many WWER type NPPs (particularly in the Russian Federation and Ukraine) with no or almost no seismic design and still without any seismic evaluations and upgrades.

Generally, the well known and internationally recognized seismic evaluation procedures such as SMA and GIP, when properly modified as proposed for example in the references relating to this task may be applicable to seismic evaluation of these NPPs, i.e. their building structures, equipment components and systems.

Conclusions and recommendations

The following can be recommended in relation to these two tasks:

- the technical guidelines for seismic evaluation of WWER type NPPs, based on the prepared documents within the scope of this task, should be issued as an IAEA technical document,

- future activities should take into account external hazards other than seismic, systems associated with radioactive waste processing and storage as well as spent fuel storage facilities at WWER sites.

2.2. INFLUENCE OF ROTATION SEISMIC INPUT ON STRUCTURAL SEISMIC RESPONSE (TASK 27)

Objectives

The objective of this task is the application to a case study, the vent stack on the EBOV2 NPP in Slovakia, of the theory of the rotational seismic input in order to assess the structural effects and, possibly, the need for a specific updating of current seismic design procedures.

Summary of work done

A very detailed theoretical analysis is carried out in the reference reports, showing how true seismic input waves can generate rotational input on top of translational input. This effect is connected to the nature of seismic waves, to some delay effects between P and S waves, to different damping, but especially to a sort of “size” effects typical of large and tall structures, sensitive to travelling waves and therefore interacting with the wave length.

This effect has been recently included in Eurocode 8 for structural design.

A 3D model of the vent stack of Bohunice NPP Units V2 has been generated, with solid elements for foundation modelling. The special input has been applied at the foundation with different time histories on each node to represent the wave passage, according to the theory.

The comparison of the responses (with and without rotational degrees of freedom) have been carried out starting from the free field recorded motion from the blast experiment in Paks.

Similar comparisons have been carried out on the seismic structural response of the Paks NPP reactor building.

Results

The comparison of displacement and stress fields provides some evidence of the effects of the special input in the order of a few percentage points, as compared with the usual “translation” input.

A theoretical discussion shows that the effect cannot be completely modelled with additional equivalent eccentricity in seismic input application, due to a significant difference in frequency content between translation and rotation spectra.

Lessons learned

The torsional waves could have structural effects especially for tall buildings, coupling rotation and translation doffs. The effect could be even larger than observed if the study is extended to the influence of rotation input on dynamic soil properties.

However, little evidence still supports the present theory for a wider use by the designers who have to deal, in general, with much larger sources of uncertainties.

Conclusions and recommendations

The effect of rotation degree of freedom should be evaluated by the designers for tall and large foundation structures.

It is recommended that further studies quantify the expected effect on structural design, eventually providing easy procedures for such analysis as an alternative to the equivalent eccentricity suggested by Eurocode 8 standards.

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Chapter 3

DESCRIPTION OF SITES AND PLANTS

TABLE III.1.

Task	Title	Participants	Tecdoc Chapter	WM Volume
1	Safety shutdown systems identification/classification	**WESE** PNPP KNPP	3	1
2	Design regulations, acceptance criteria, loading combinations	**AEP** S&A-US	2, 3	2, 1
3	Seismic input, soil conditions	**PNPP** **KNPP** ISMES SIEMENS EP	3	1

3.1. SAFE SHUTDOWN SYSTEM IDENTIFICATION/CLASSIFICATION (TASK 1), DESIGN REGULATIONS, ACCEPTANCE CRITERIA, LOADING COMBINATIONS (TASK 2), SEISMIC INPUT, SOIL CONDITIONS (TASK 3)

Objectives

The objective was to recover the original design parameters of the plant so that they could be used by benchmark participants in their detailed analytical and experimental tasks.

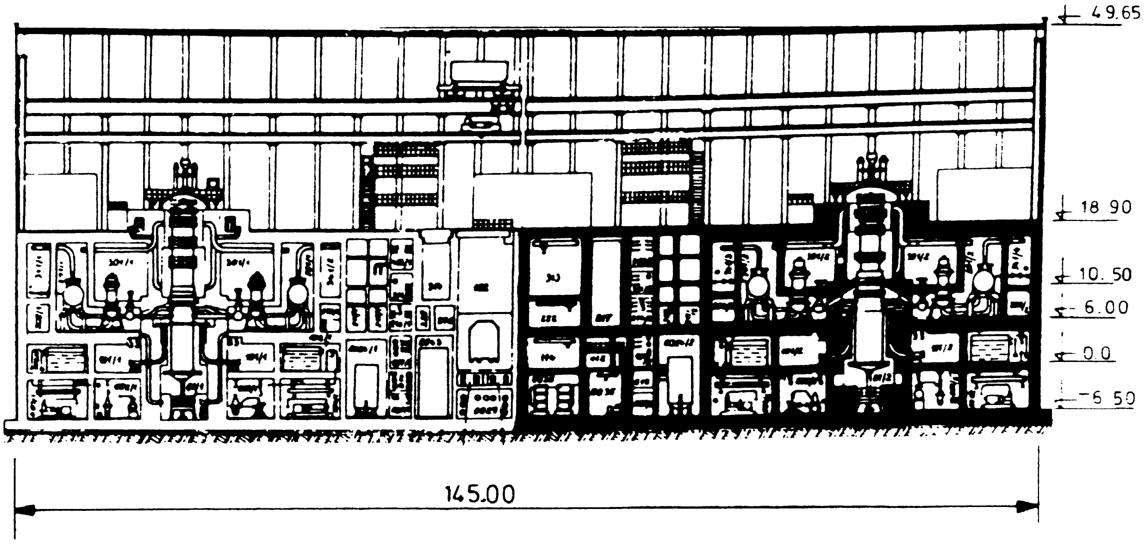
Summary and results

Both sites are “soft soil sites” thus requiring special care in the modelling of the interaction between soil and structure when subjected to earthquake input motion. The buildings and the foundations are quite different between the two plants and therefore the structural modelling had to be specific for each plant.

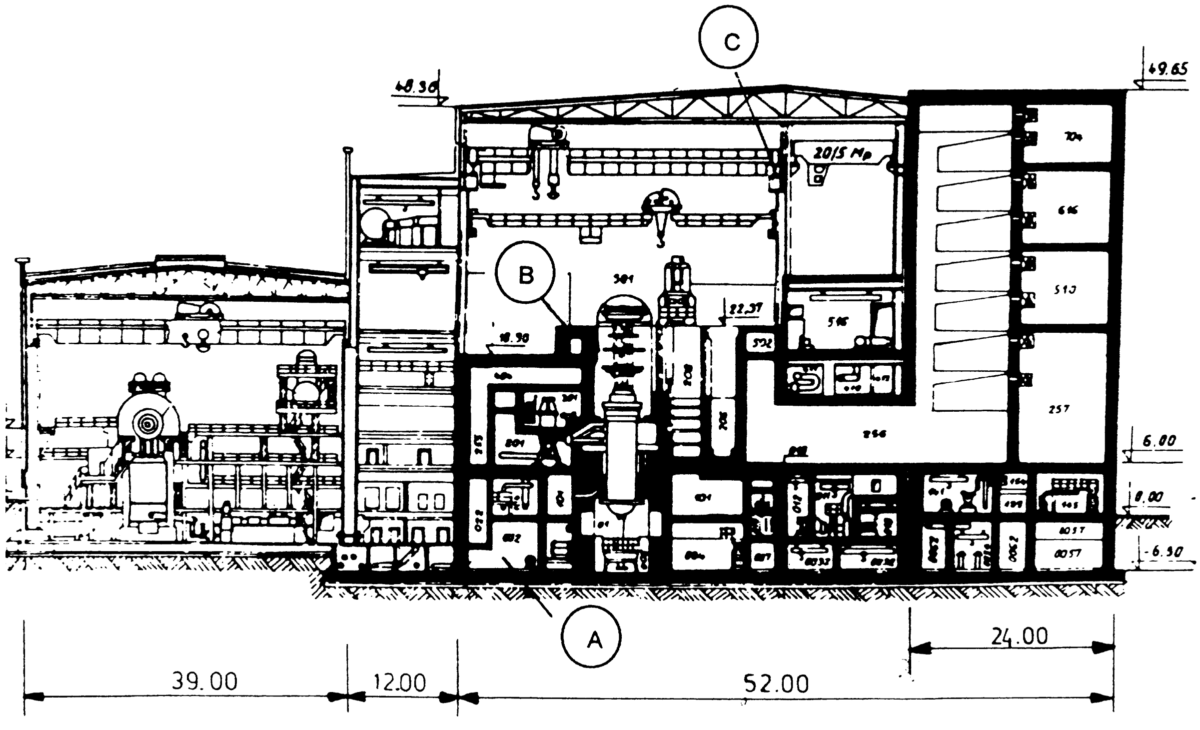
The configuration of the Paks NPP reflects the WWER/440-213 unified design and therefore does not have any containment structure. It has a reinforced concrete confinement and a reinforced concrete bubble condensing tower to mitigate and confine the effects of a loss of coolant accident. The attached structures of the electrical halls, ventilation building and turbine building are primarily steel frame constructions. The foundations of the electrical halls and the turbine building are independent strip footings as opposed to the large reinforced concrete base mat for the reactor building and bubble condensing tower.

Figure 3.1 shows two sections of the main building complex of the NPP consisting of the reactor building, bubble condensing towers, electrical galleries and turbine building.

The 1000 MW design at Kozloduy has a conventional post tension concrete containment. The integral safety related auxiliary building containing the safety related electrical and mechanical equipment is primarily of reinforced concrete. The containment sits



Longitudinal Cross Section (N - S Direction)



Perpendicular Cross Section (E - W Direction)

FIG. 3.1. Construction concept of a main sections of a WWER–440/213.

on top of a portion of the auxiliary building. A single reinforced concrete basemat supports the entire reactor/auxiliary building complex.

Figures 3.2 and 3.3 show two sections of the reactor/auxiliary building complex.

Volume 1 of the Background Documents contains the input from the CRP participants regarding the plant layouts, the safety systems, the geological conditions and seismic qualification and evaluation programs.

The material presented in the following sections is broken down into the following categories:

- plant layout
- description of the safety systems
- geological conditions and seismic input
- seismic safety programme
- analytical and experimental evaluations prior to the CRP.

Paks NPP

Plant layout

Chapter 1 of Volume 1 of the Background Documents contains plan and isometric drawings of the plant layout from elevations between 6.5 m and 14.1 m for the reinforced concrete reactor building and bubble condensing towers of Units 3 and 4. Chapter 2 contains plan views of the transverse and longitudinal electrical buildings of Units 3 and 4 from elevations between 3.6 m and 24 m. In Chapter 6, Experimental and Analytical Investigations of Paks NPP, a description is provided for the concrete portion of the main building structure. The base mat is 2 m thick and the concrete floor and wall thicknesses vary from 0.6 m to 1.5 m with the thicker walls being associated with the confinement boundary. Site layouts identifying other essential building structures are not provided.

Description of the safety systems

Information on the plant safety systems is contained in Chapters 5 and 7 of Volume 1 of the Background Documents. Chapter 5 describes the safe shutdown scenario in the event of an earthquake and the modifications to be made to the systems to accomplish the safe shutdown. The fundamental functions stated are:

- shutdown of the reactor
- boration
- heat removal.

Reactor shutdown is achieved by the reactor protection system. There is a seismic monitoring system that provides alarms in the event that shaking exceeds a certain level but the system is not connected directly to the reactor protection system to provide an automatic scram. The reactor protection system causes the turbine to trip, the control rods to be inserted and the emergency diesels to start. The load sequencing of the diesel generator supplied power is also controlled by the reactor protection system.

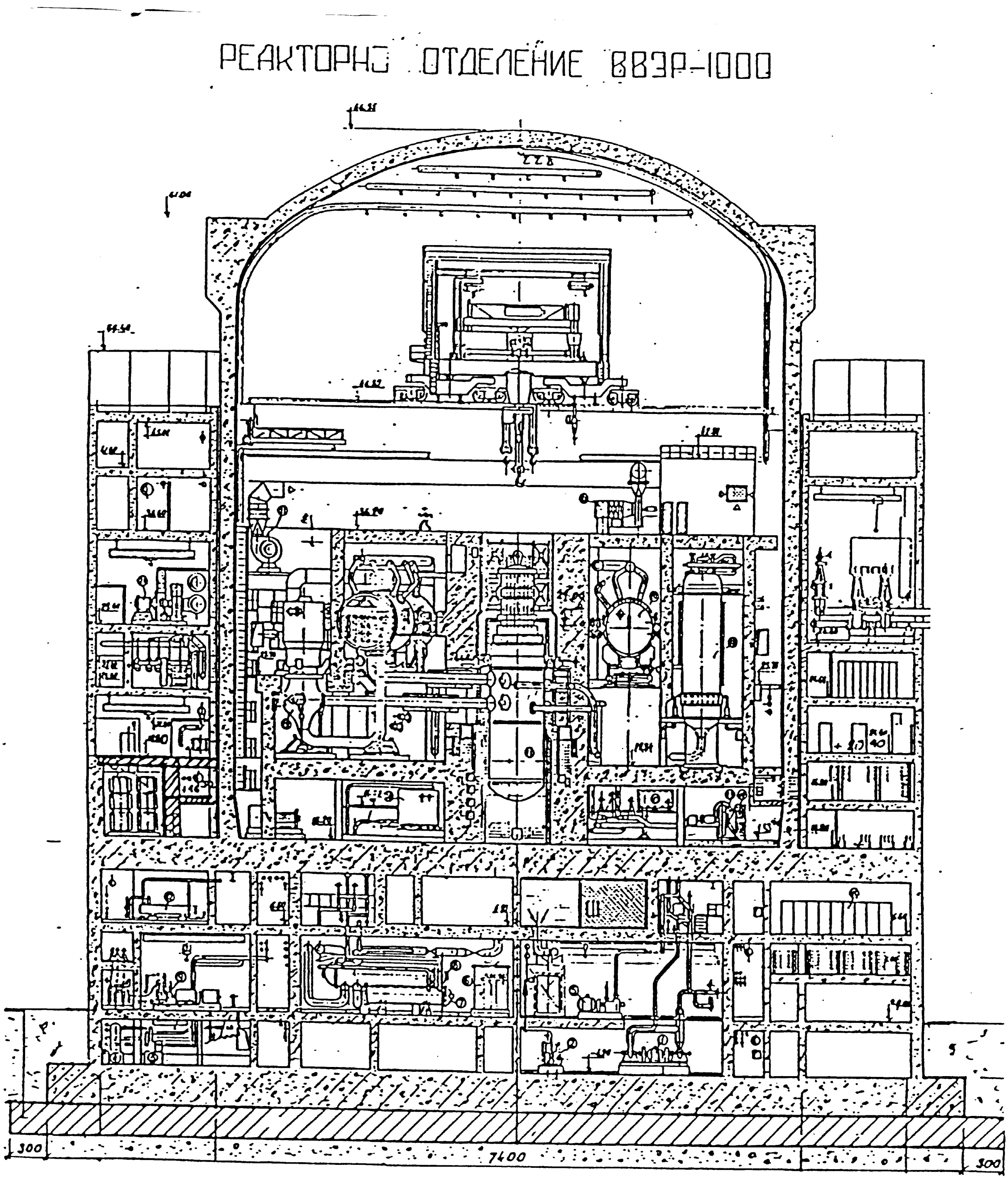


FIG. 3.2. Cross section of a WWER-1000 MW reactor building.

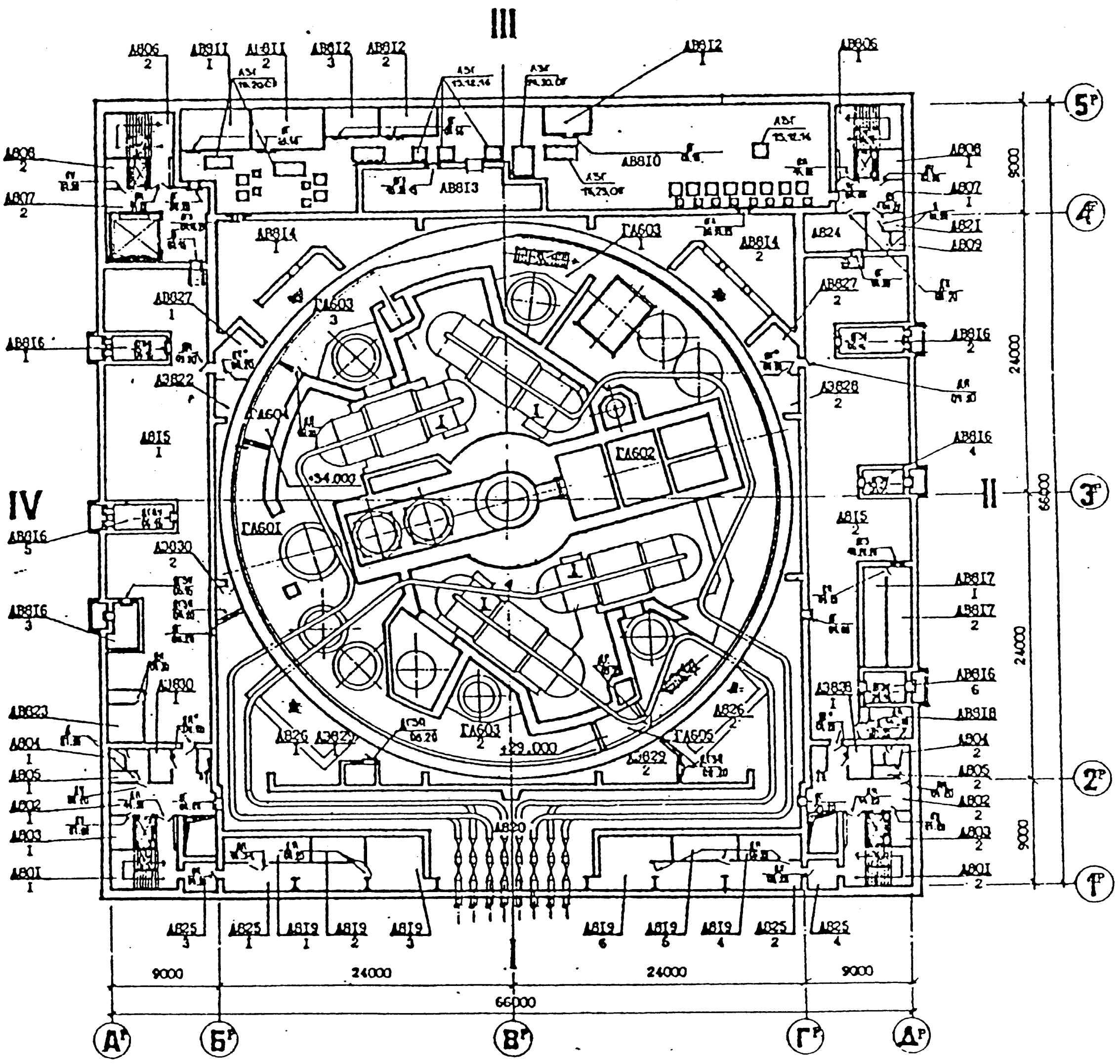


FIG. 3.3. Plan view of a WWER-1000 MW reactor building.

The first stage of the reactor cooldown to 130°C is accomplished by the steam and feedwater system. Steam is released to the atmosphere by means of the power operated safety valves. Makeup water to the steam generators is supplied by the emergency feedwater system. The pressure is decreased in the primary system through release of steam from the pressurizer to the bubble condensing tower by means of the pressurizer power operated relief valves. Makeup water to the primary system to compensate for shrinkage and depletion of inventory by the pressurizer steam release is supplied by the high pressure emergency core cooling (ECC) pumps. These pumps supply borated water to increase the boron concentration during cooldown.

After reaching 130°C, cooling is accomplished by means of a future modification of the low pressure ECC system to provide a closed loop decay heat removal system. The water in the primary system is circulated through the ECC heat exchangers and cooled down to a cold shutdown condition of 60 to 70°C.

In addition to the systems mentioned above, instrumentation, control systems and support systems are required. Also, it is important to maintain the confinement integrity, thus all isolation systems, their power supplies and controls are also required.

Chapter 5 focuses on the programme to qualify the safe shutdown and confinement isolation systems described.

In Chapter 7, virtually the same description of the safe shutdown and confinement isolation systems is given. Chapter 7 elaborates in more detail the plans for qualification of the essential systems and components by analysis, test and use of seismic experience.

Geological conditions and seismic input

Chapter 4 of Volume 1 of the Background Documents provides a historical summary of the seismotectonic evaluation of the Paks NPP site.

Based upon historical earthquake data and isoseismic maps at the time of the site selection, the area was declared to be of low seismicity. In 1978 the Geophysical Institute in the USSR estimated the intensity at the site as 8 on the MSK-64 scale. The Hungarian official position was intensity 5 and the plant was designed accordingly. Later, in 1986 the Geophysical Institute lowered their estimate to intensity 7. All efforts were made to show that there were no faults in the site vicinity. Before the beginning of the most recent research work it was postulated that there were two transcurrent fault zones perpendicular to each other that intersected just south of Paks in the area of the NPP. Hungarian scientists estimated the peak horizontal ground acceleration to be about 0.28g.

A later study (described by its authors to be preliminary and conservative) in 1992 by an British consultant company using both deterministic and probabilistic methods determined that the 84th percentile pga for the SL2 earthquake was 0.35g.

In Chapter 3 of Volume 1 of the Background Documents, an independent evaluation is made of the material produced for the seismic input of the Paks NPP. The report describes the source of the data, the criteria followed in the evaluation, the opinions on the content of the data set and conclusions and suggestions. The criteria used in the evaluation were those of IAEA Safety Guide 50-SG-S1, Rev. 1. Point by point recommendations of the guide were used to evaluate the data and methodology used in the seismic evaluations of the site. The following general conclusions were reached in the study (21–23 November 1995):

(1) It did not appear that a QA programme was implemented during previous investigations.

(2) It was recommended to organize the geological and seismological data into an integrated database.

(3) Data from a single three-component micro-earthquake station at Paks since 1985 and any future micro-earthquake data from new stations should be incorporated into the seismotectonic model.

(4) Intensity maps should be digitized and stored in a uniform computer format.

(5) Different experts have proposed different interpretations of the seismotectonic model. Further effort should be conducted to reach a unique seismotectonic zoning, perhaps by combining the judgment of several experts. More attention should be paid to large scale gravimetry, geodesy, heatflow, aeromagnetic investigations and satellite imagery.

(6) Seismic surveys do not allow at present to observe the first 100 m of the subsoil. Therefore, it is not possible to determine if the proposed faults are continuing towards the surface (capable faults). Reinterpretation of the profiles is strongly recommended.

(7) More trenches should be excavated if further investigations are carried out at the site.

(8) Historical data could have been used more extensively.

(9) A value of 0.35 g pga seems too high for the region.

A new study was therefore conducted in 1995 and the current estimate for the SL2 event is 0.25g.

Seismic safety programme

Since Paks did not have an initial explicit seismic design, the NPP has laid out an extensive programme to qualify the essential structures, systems and components for the defined seismicity. Chapters 5 and 7 of Volume 1 of the Background Documents provide similar data on the seismic safety programme at Paks. Chapter 5 discusses the current requirements for seismic safety, principles of seismic safety and the structure of the seismic safety programme for Paks. The structure of the seismic safety programme consists of the following steps:

- examination of the seismic hazard
- development of the seismic safety concept
- assessment of the seismic resistance of buildings
- evaluation of the seismic resistance of the technology equipment.

A summary of the tasks performed for the buildings and the equipment is provided.

In Chapter 7 details are provided on the work that has been conducted to date for the analysis and testing of the main building, essential buildings and other buildings which might interact with essential buildings and systems. Chapter 7 also covers the testing of relays and other active components.

Analytical and experimental investigations

Chapters 5, 6 and 7 of Volume 1 of the Background Documents describe the analytical and testing programme that has been carried out on the main building at Paks. Three numerical models have been generated for the reactor and turbine building.

(1) Two dimensional models, one for each horizontal direction, were made consisting of beams and plates. This was the first modelling of the main building. Analyses for 0.15 g were carried out and it was determined that the structure was acceptable for this level of

excitation. Soil interface was added and calculations for 0.28 g indicated that steel members were overstressed.

(2) A three dimensional lumped mass beam model was later made and dynamic features and responses were determined for an earthquake acceleration of 0.28 g pga.

(3) A three dimensional finite element model consisting of beams and plates was constructed which included the electrical galleries around the reactor building and the turbine hall. All of the buildings are coupled together but are on separate foundations. This model was used to develop response spectra for a 0.35 g US Regulatory Guide 1.60 ground motion spectrum. It was also used in the blast experiment to compare measured vs. test response.

Chapter 6 of Volume 1 of the Background Documents describes the artificial input generated by the explosion and used in the numerical simulation.

The free field ground motion due to the blast contains an initial high frequency vibratory motion followed by a lower frequency harmonic response. The latter vibratory motion has a frequency content similar to the fundamental frequencies of the main building structures. Thus, the earlier portion of the blast free field motion were ignored for the benchmark purposes.

Kozloduy NPP

Plant layout

Chapter 12 of Volume 1 of the Background Documents contains plan views of the room layout of the Units 5 and 6 of the Kozloduy NPP from elevations 4.2 m and 41.4 m. A site layout showing other essential structures is not given.

Description of the safety systems

Chapter 8 of Volume 1 of the Background Documents describes the systems necessary for a safe shutdown of the plant during and after an earthquake. The safe shutdown concept follows the model of the US seismic margins methodology. Flow diagrams and a list of safety systems as defined in the original design are contained in Chapter 12. Also in Chapter 12 is a list of components which were modelled in the Kozloduy 5 seismic PSA.

Systems identified for safe shutdown and isolation of the primary coolant boundary are described in Chapter 8, Volume 1 of the Background Documents. The essential systems are:

- Main coolant pressure boundary including all auxiliary piping connecting to the main system (vents, drains, and instrument lines) through their isolation devices.
- Charging/Letdown system and seal injection and return system
- High pressure safety injection system
- Low pressure safety injection system
- Containment spray system

- Steam generator secondary side including connecting piping through their respective isolation devices.
- Main steam isolation valves
- Emergency feedwater
- Essential service water
- Intermediate cooling water
- High pressure sampling system
- High pressure instrument air
- Emergency diesel generator system
- Essential ventilation systems
- Containment isolation components
- Essential electrical systems (6.3 kv AC, 400 v AC, 220 v DC, cabling, motor generators, batteries, thyristors, etc.)
- Instrument and control system.

Marked up flow diagrams are provided to show the extent of the fluid systems required.

Geological condition and seismic input

This information is provided in Chapters 9 and 11, Volume 1 of the Background Documents, as provided by AEP/Moscow. Figure 3.4 shows the ground motion spectra used for standard design of WWER 1000 NPPs as a function of the specified earthquake intensity at the site.

The Kozloduy NPP was designed to withstand an intensity 7 earthquake and therefore the design pga value was 1.0 m/s^2. Fig. 3.5 shows standard floor response spectra for this ground motion input for the horizontal and vertical directions for 1, 2 and 3% damping for elevations between 24.6 m and 45.6 m.

Note that later studies of the site seismicity have resulted in a pga of 2.0 m/s^2 as being appropriate for the site in accordance with the IAEA Safety Guide 50-SG-S1, Rev. 1.

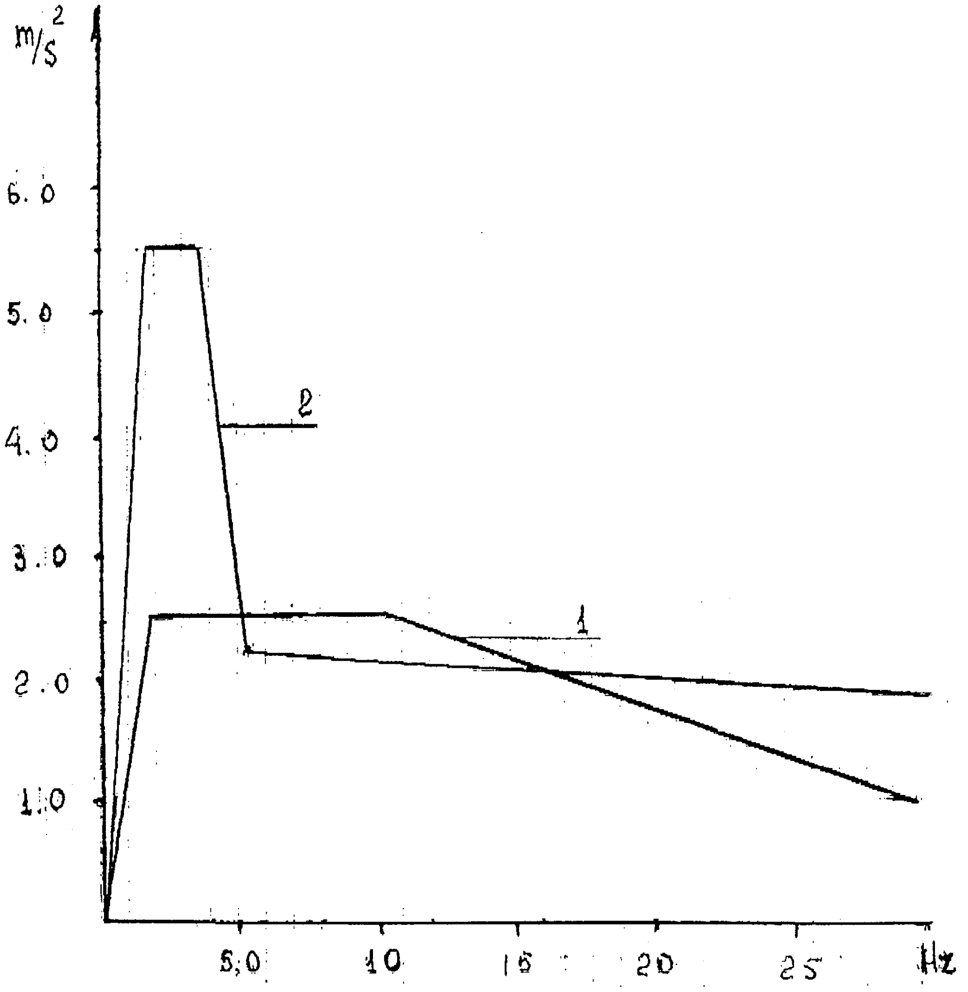
According to AEP, the following material properties for soil and concrete have been used in the original design of the Kozloduy NPP:

Shear wave velocity in soil = 600 m/s
Structure elasticity module = 3E7KN/m2
Structural damping = 5%

Chapter 11 contains a summary of the soil data from boreholes. The data include soil type, depth and thickness density, shear wave and P wave velocity for each soil layer and Poisson's ratio.

Seismic safety programme

Unlike Paks, Kozloduy Units 5 and 6 had originally been designed for seismic loading. No specific seismic re-evaluation programme was defined for these units.



1. Standard design spectrum for Unified NPP V-1000.
2. Original design spectrum for Kozloduy V-1000.

FIG. 3.4. Ground response spectrum for the Kozloduy NPP site.

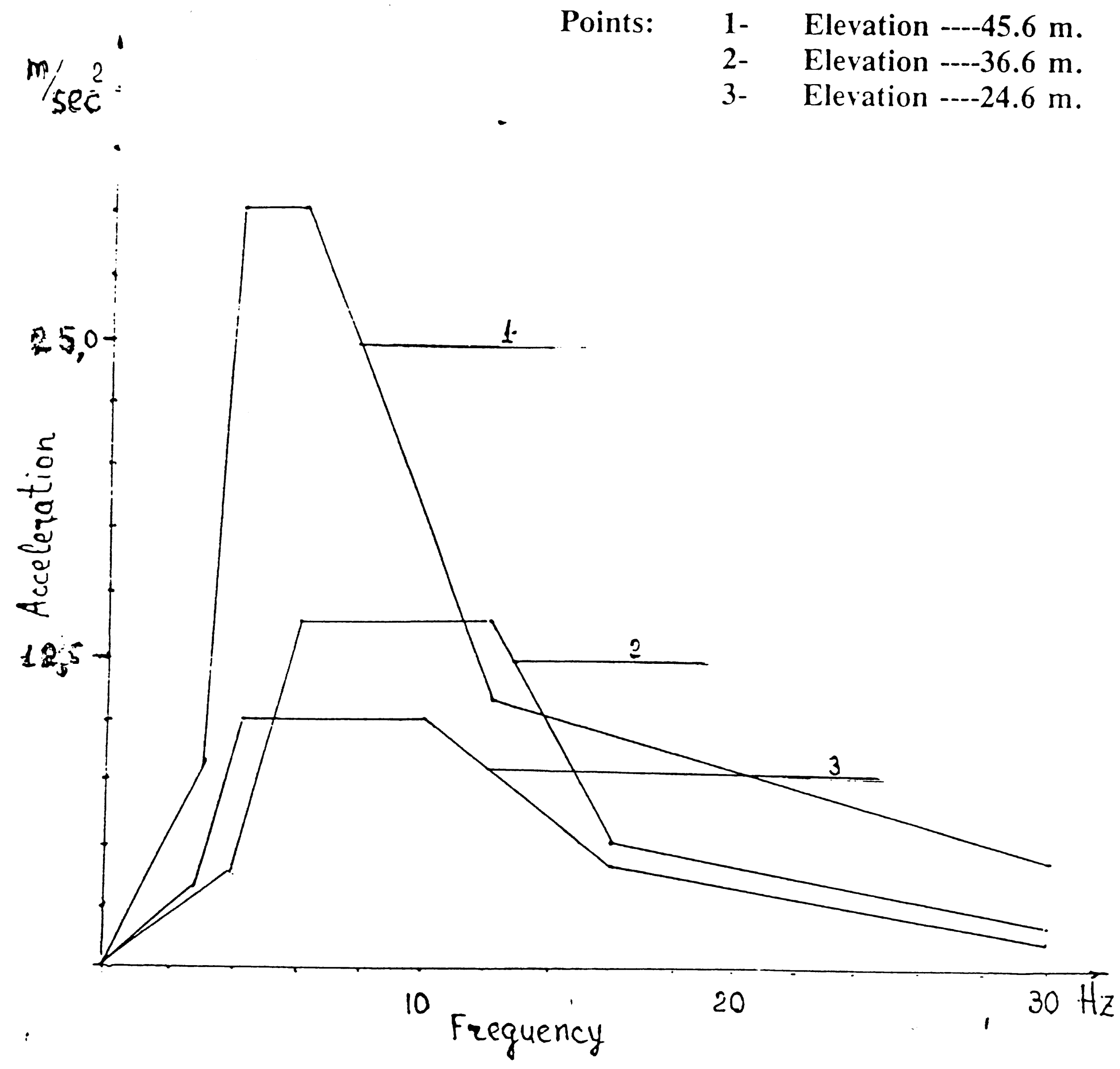


FIG. 3.5. Envelope design floor response spectrum for Unified NPP WWER-1000 (maximum acceleration 0,4, damping -2%) (horizontal direction).

Analytical and experimental evaluations

Chapter 10 provides a brief description of the results of full scale on site blast and vibration tests conducted in 1991 and 1992. For the reactor and turbine buildings, dynamic characteristics such as frequencies, mode shapes, damping and amplification factors were determined from blast and vibration tests. Instruments in bore holes were used to determine seismic wave velocities in the soil.

Applicability of results

Most of the structural data are valid for the same plants built using the same unified design criteria.

The sites for each unit, though are quite different, are in a stiffness/damping range where soil structure interaction effects play a crucial role.

Lessons learned

The review process applied to the seismic input of Paks which generated deep modifications in the design values, points out the need for reliable seismic hazard studies.

The technology has changed considerably over the past 20 years and therefore this review also highlighted the improvements in siting methodologies which have taken place during this period.

Conclusions and recommendations

Most of the material provided by the contributors was a collection of historical design data that showed that the original designs did not account for the currently accepted seismic hazard for the sites.

More updated seismic hazard studies have been conducted recently, the results of which have been reviewed by the IAEA.

The management of Paks has presented a complete programme for the evaluation of the safety related structures and components by analysis and testing and to upgrade them if necessary.

No such programme has been outlined for the Kozloduy NPP, although it is known that the NPP has made seismic upgrades and has performed a seismic PSA.

A general seismic safety review on the adequacy of such interventions and their consistency with the updated seismic hazard is therefore strongly recommended.

Chapter 4

ANALYSIS AND TESTING — PAKS NPP

TABLE IV.1.

Task	Title	Participants	Tecdoc Chapter	WM Volume
6b	Dynamic analysis of Paks NPP RB for seismic input	**SIEMENS** ISMES MD	4	4
7c	Worm tank	**PNPP** ANL/AES NIED/IHI S&A-CZ	4	4
9	Shaking table experiment for selected components	**PNPP** **KNPP** IZIIS	4, 5	4, 3
10	On-site testing of equipment at Paks and Kozloduy NPPs	**PNPP** **KNPP** VNIIAM	5, 7	3, 5
20	Analysis of buried pipelines for Paks NPP	EQE-US SIEMENS S&A-CZ	4	4
26	Evaluation of potential hazard of WWER-400 reactor operating control and drive system	CKTI	4, 5	4, 3

4.1. DYNAMIC ANALYSIS OF PAKS NPP REACTOR BUILDING FOR SEISMIC INPUT (TASK 6b)

Objectives

Two parallel analyses of the reactor building (RB) of Paks NPP were performed. These studies were mainly focused on the development of the floor response spectra for a comparison between two numerical approaches.

A special sub-task was devoted to the calculation of the reliability of numerical models for the seismic re-evaluation of existing plants.

Summary of work done

Three-dimensional models of the main building, turbine hall and galleries were developed. Seismic response was obtained using the modal integration method for different soil properties in order to capture the effects of their uncertainties.

Floor response spectra were calculated and broadened for an easier comparison with component and equipment testing spectra.

As free field input motion, the following values were assumed:

- PGA (hor) = 0.35g,
- PGA (vert) = 0.23g,
- NUREG 0098 spectrum for competent soils was applied.

These assumptions are not consistent with the input provided for the benchmark, but they allow a comparison of the responses of the two models which is valid in general.

The structural reliability analysis was carried out using a simplified stick model provided by Siemens and subsequently validated with the more refined 3D model presented below.

Geometry description

MODEL 1 – MD

- 6450 degrees of freedom.
- Walls from pre-cast panels were not considered due to their minor contribution to the global stiffness, but their weights were considered in the model as additional masses.
- Soil–structure interaction (SSI) was modelled using equivalent springs the values of which were determined by the half space method (for the soil condition G_{ave} only).

A general view of Model 1 is shown in Fig. 4.1.

MODEL 2–SIEMENS

- 9930 degrees of freedom.
- Walls from pre-cast panels were modelled considering a reduced thickness for the related elements, due to their reduced bending stiffness.
- SSI was represented by discrete spring and dampers acting in all nodes of the idealized foundation slab.
- A parametric study, taking into account uncertainties related to the soil properties, was performed, considering three soil conditions G_{max}, G_{ave} and G_{min}.

The total weight of the model consists of the weight of the structure itself, the weight of major heavy components, the weight of all other mechanical, electrical and I&C components and systems and all non-deadweights and amounts, approximately 2200 MN.

A general view of Model 2 is shown in Fig. 4.2.

Evaluation of equivalent soil elastic properties

Both models used the soil representation given in Table IV.2.

For Model 1 the frequency-independent stiffnesses (see Table IV.3) were obtained using the formulas of the halfspace method.

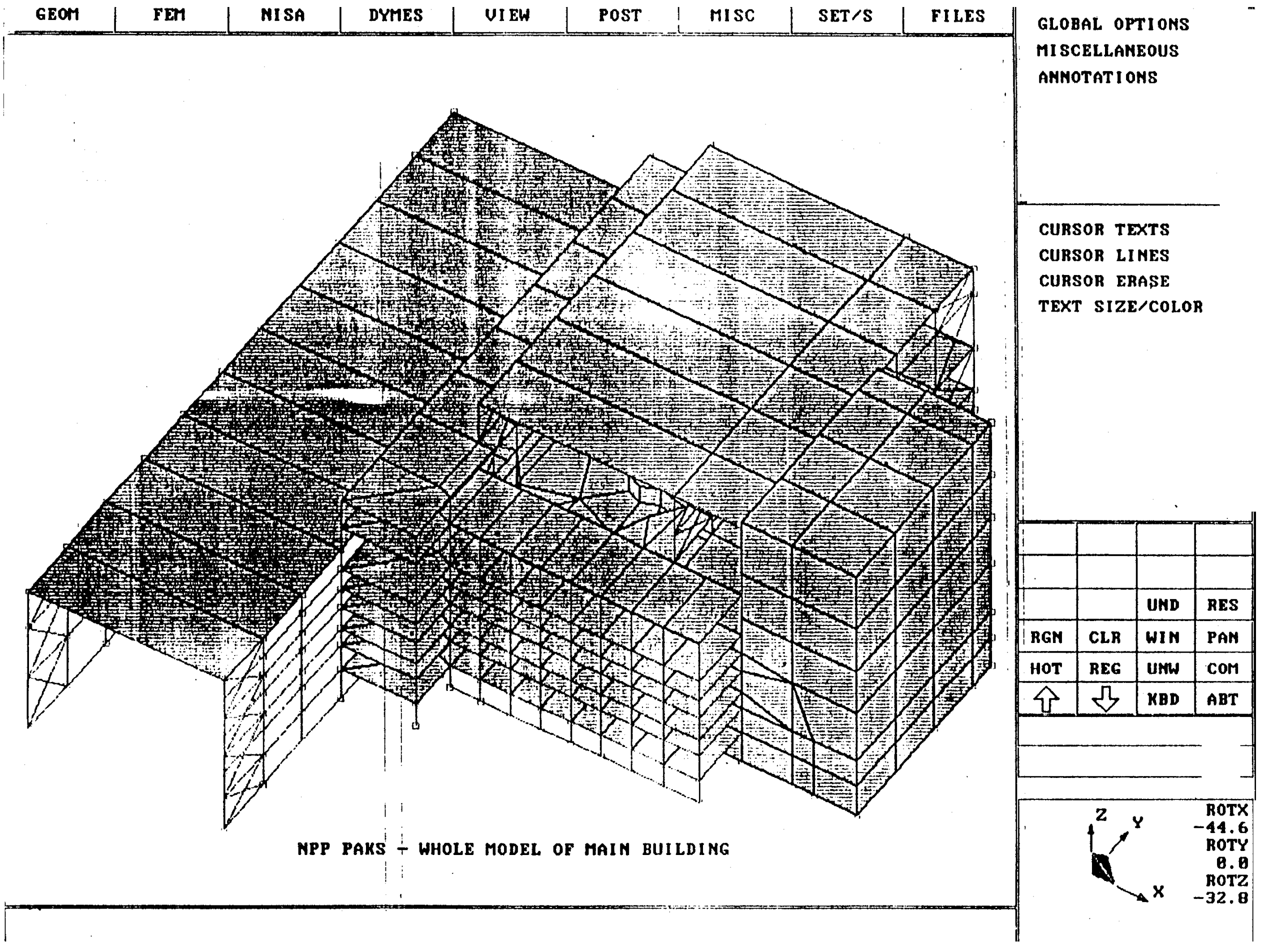


FIG. 4.1. Model 1 (MD) – Global view.

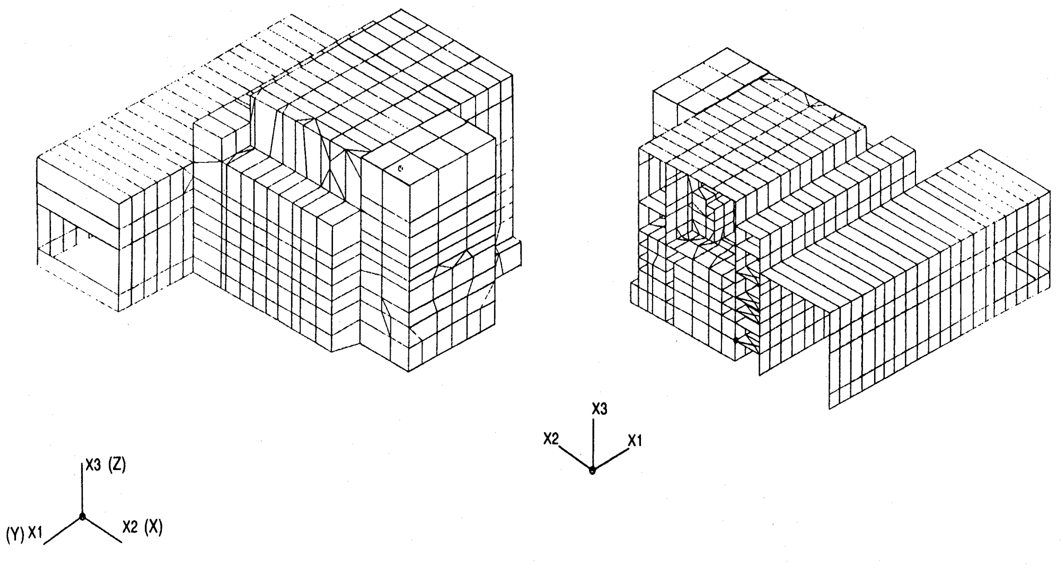


FIG. 4.2. Model 2 (Siemens) – global view.

TABLE IV.2. SOIL REPRESENTATION

		Shear modulus	Density	Void index	Damping ζ
Depth	Soil	G_o MN/m^2	ζ t/m^3	v –	D_o %
0.0 -9.5	Sand loose to dense	50	2.0	0.49	1
-20.0	Sand Gravel	120	2.0	0.49	1
-27.0	dense to very dense	250	2.0	0.49	1
-100.0	Marl Sand with clay Sandstone	500 1.000	2.2	0.45	1
-500.0		1.000	2.2	0.45	1

TABLE IV.3. FREQUENCY INDEPENDENT STIFFNESS AND DAMPING

Direction	Stiffness (Mpa/m)	Damping (% of critical)
X1	3.68	15
X2	3.68	15
X3	10.52	30

For Model 2, the compatible shear moduli of the soil were computed, taking into account the defined free field motion and therefore the induced strain field in the soil, using the SHAKE computer code, for each soil layer.

For Model 2 only, the calculated soil profile was taken as G_{ave} and the following variations of the soil properties were used:

G_{ave}
$G_{min} = 0.5\ G_{ave}$
$G_{max} = G_0$ (shear moduli at zero strain).

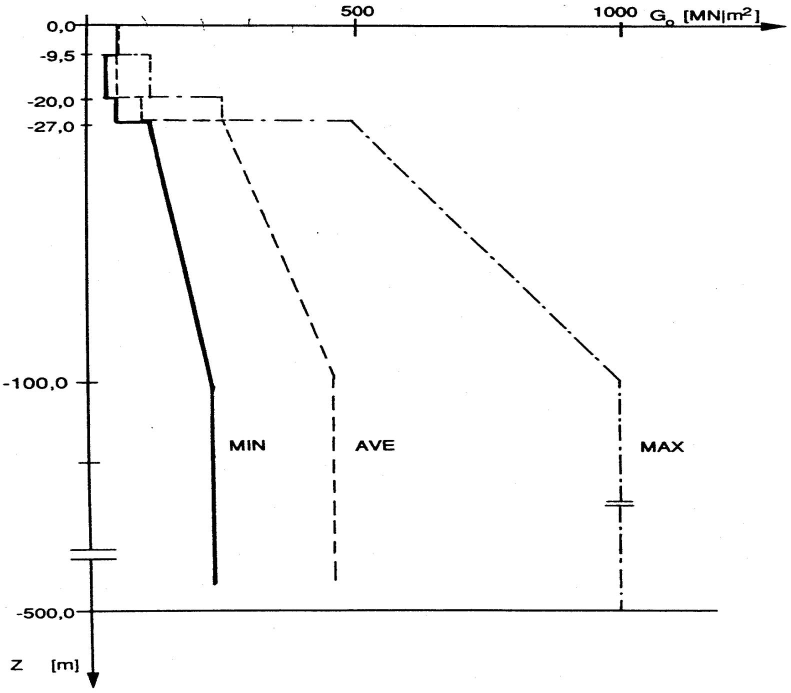


FIG. 4.3. Shear modulus profiles at the Paks NPP site.

The resulting shear modulus profile is shown in Fig. 4.3.

The impedance functions (see Figs 4.4 and 4.5) for the foundation of the coupled vibrating buildings, taking into account the soil layering, soil properties and representation of the foundation, were calculated using the CLASSI software, in the frequency domain.

The global frequency-independent soil stiffness and damping (see Table IV.4) under the RB were then derived from the impedance function for the corresponding G-values by matching these with the fundamental frequencies of the coupled soil-structure system.

The stiffness for the turbine hall and galleries (see Table IV.5) were determined in the same manner.

The stiffnesses were lumped at each individual node representing the foundation slab under the assumption of a uniform distribution of the bearing pressure.

Modal characteristics

The main modal characteristics were obtained using the NISA (Model 1) and STRUDYN (Model 2) softwares. Comparison of the modal characteristics relating to the particular model was performed only for the soil condition G_{ave}.

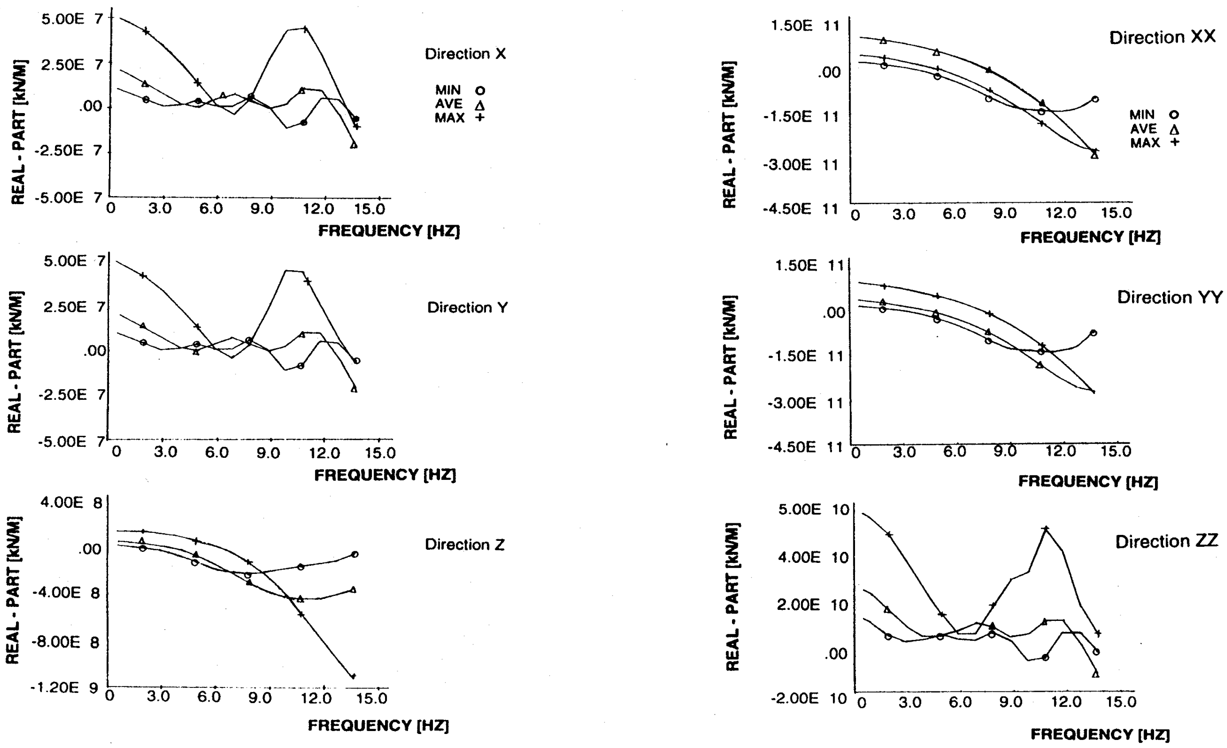


FIG. 4.4. Impedance functions — real parts— for translation and rotation movements.

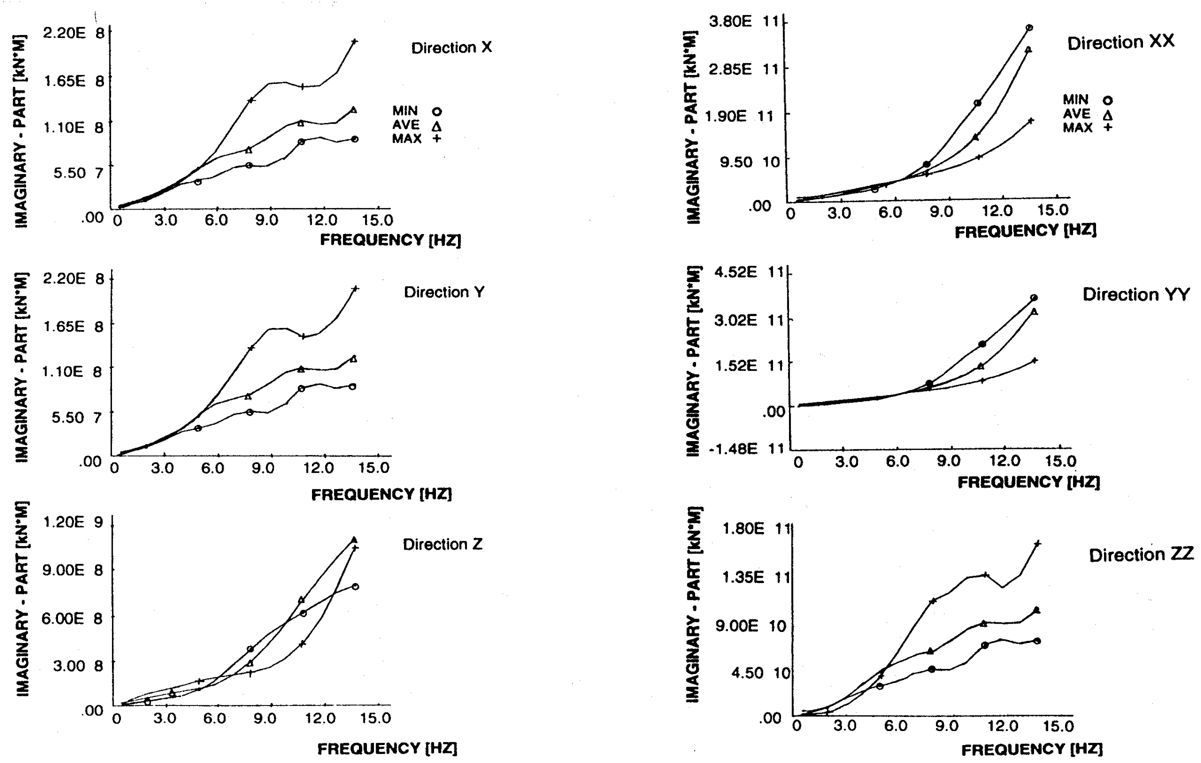


FIG. 4.5. Impedance functions — imaginary parts — for translation and rotation movements.

TABLE IV.4. FREQUENCY INDEPENDENT EQUIVALENT SOIL SPRINGS AND DAMPERS

GN MIN						
DIR	X	Y	Z	XX	YY	ZZ
Ko[kN,m]	10 E6	10 E6	35 E6	21 E9	21 E9	12 E9
FRQ[Hz]	0.92	0.92	1.38	0.92	0.92	0.92
K[kN,m]	8 E6	8 E6	23 E6	19 E9	19 E9	10 E9
D[%]	27	27	49	13	13	15

GA AVE						
DIR	X	Y	Z	XX	YY	ZZ
Ko[kN,m]	21 E6	21 E6	72 E6	44 E9	42 E9	25 E9
FRQ[Hz]	1.35	1.35	2.00	1.35	1.35	1.35
K[kN,m]	17 E6	17 E6	50 E6	38 E9	37 E9	20 E9
D[%]	28	28	50	13	13	16

GX MAX						
DIR	X	Y	Z	XX	YY	ZZ
Ko[kN,m]	50 E6	50 E6	157 E6	106 E9	102 E9	59 E9
FRQ[Hz]	2.0	2.0	3.27	2.0	2.0	2.0
K[kN,m]	41 E6	41 E6	122 E6	92 E9	90 E9	47 E9
D[%]	17	17	49	5	5	5

TABLE IV.5. EQUIVALENT SOIL STIFFNESSES FOR SEPARATED FOUNDATIONS

G	MAX	AVE	MIN
X	3.7×10^6	1.5×10^6	0.9×10^6
Y	3.7×10^6	1.5×10^6	0.9×10^6
Z	11.0×10^6	4.6×10^6	2.1×10^6
XX	8.0×10^7	3.4×10^7	1.9×10^7
YY	5.6×10^7	2.6×10^7	1.3×10^7
ZZ	3.4×10^7	1.5×10^7	0.9×10^7

The first six modes, in both cases, have significant contribution to the global response because the modal mass corresponding to these modes is equal to 0.98% of the total mass.

The first natural frequency of the main building concrete block, for horizontal and vertical direction, is equal to 1.40 and 2.38 Hz, respectively (1.17 and 1.27 Hz for the whole structure).

The modal integration method was used to obtain the response.

The modal damping values in Model 1 were assumed as follows:

- of critical damping for modes with modal mass greater than 40% of the effective mass: for the case of translation rigid body motion on the soil;
- of critical damping for modes with modal mass between 20 and 40% of the effective mass: for the case of rocking rigid body motion on the soil;
- of critical damping for all other modes.

In Model 2, the averaged modal dampings were applied, with cut-off values according to KTA rules as follows:

- 0.15 for the horizontal direction
- 0.3 for the vertical direction.

Seismic loading

The artificial time histories corresponding to the NUREG 0098 free field response spectra were deconvoluted to the foundation level (-7.00 m), in order to take into account the effect of the embedment, using the SHAKE computer codes. The comparison of free field spectrum with response spectrum for embedment level is shown in Fig. 4.6.

Additional input for the reliability model

The structural model used in the reliability analysis was loaded with stochastic variables respectively for:

- soil shear modulus (each layer)
- soil hysteretic damping (each layer)
- structural damping
- soil radiation damping

All the variables were assumed to be stochastically distributed, with Beta distributions covering the range deterministically calculated in the Siemens model and identified as “min”, “ave” and “max” soil properties.

A full probabilistic analysis was carried out with algebraic combination of the continuous distributions (Form and Sorm algorithms), with the final evaluation of the probability distribution of two global structural variables: acceleration at the top of the structure and bending moment at the basemat.

Results

The dynamic response of the main building complex was calculated for all locations of every floor on which safety related components and systems are located. The response spectra were derived for damping values of 2%, 5%, 7% and 10% and different soil conditions.

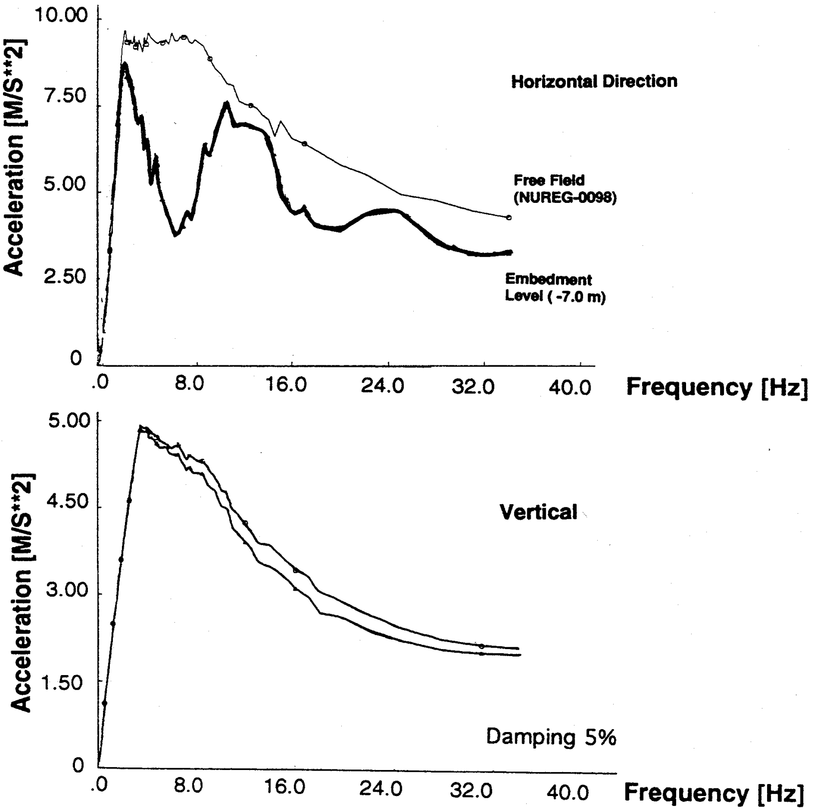


FIG. 4.6. Comparison of seismic response spectra: free field to foundation level.

In order to evaluate the effects of different model concepts and soil representation on the response assuming the same soil properties but different modal damping, the corresponding response spectra were plotted in the same graphs (see Figs. 4.7–4.12).

From these figures it is evident that due to the different modal dampings used for analysis, the response in some frequency ranges is slightly different.

To obtain benchmark design response spectra for the soil condition G_{ave} the enveloping was performed of the spectra obtained from the analysis of modes 1 and 2.

The results of the reliability analysis are shown in Fig. 4.13, in terms of acceleration at the top and global bending moment at the basemat.

The scattering in input data induce high uncertainties in the results, as it is shown in the probabilistic distribution of shear force and bending moment affected by a high standard deviation.

A numerical representation of such phenomenon is provided by evaluating the mathematical derivatives of these statistical distributions (typically structural results like stresses or displacements) against the statistical parameters of the distributions of the variables (e.g.: mean value and standard deviation of a geotechnical parameter).

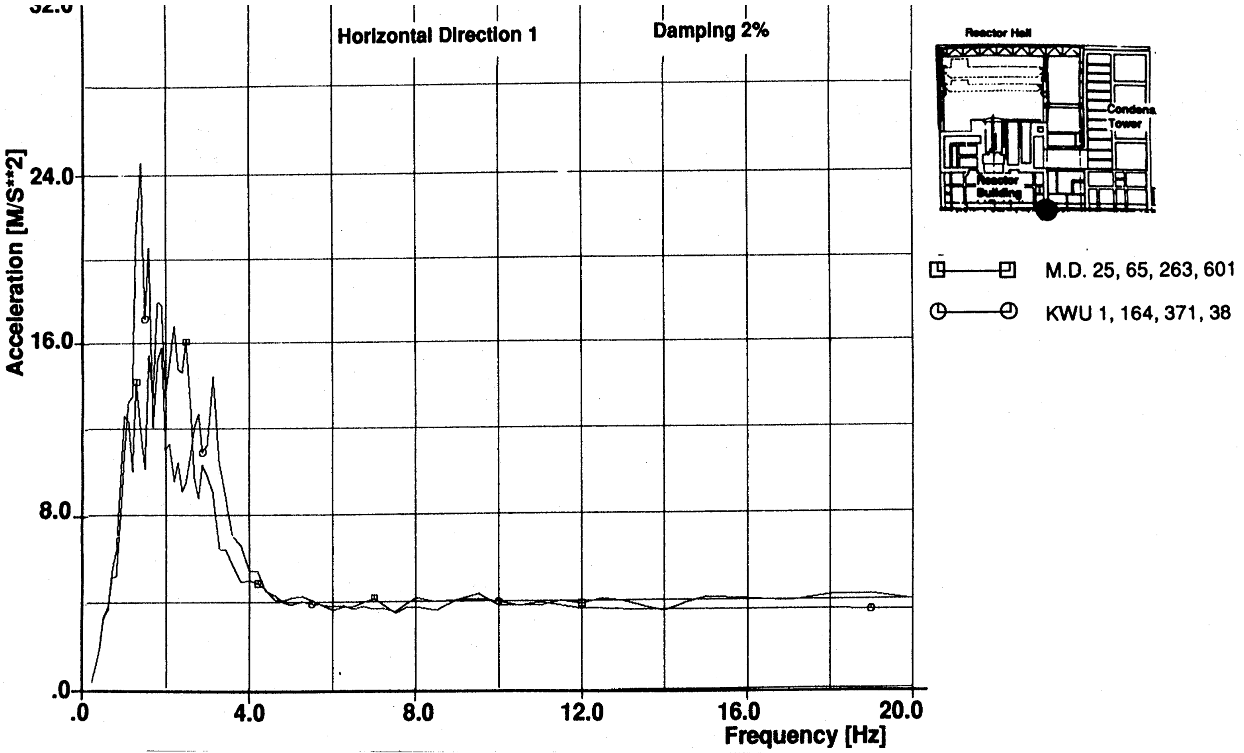


FIG. 4.7. Comparison of seismic response spectra calculated by MD and Siemens (foundation level, horizontal direction 1, damping 2%).

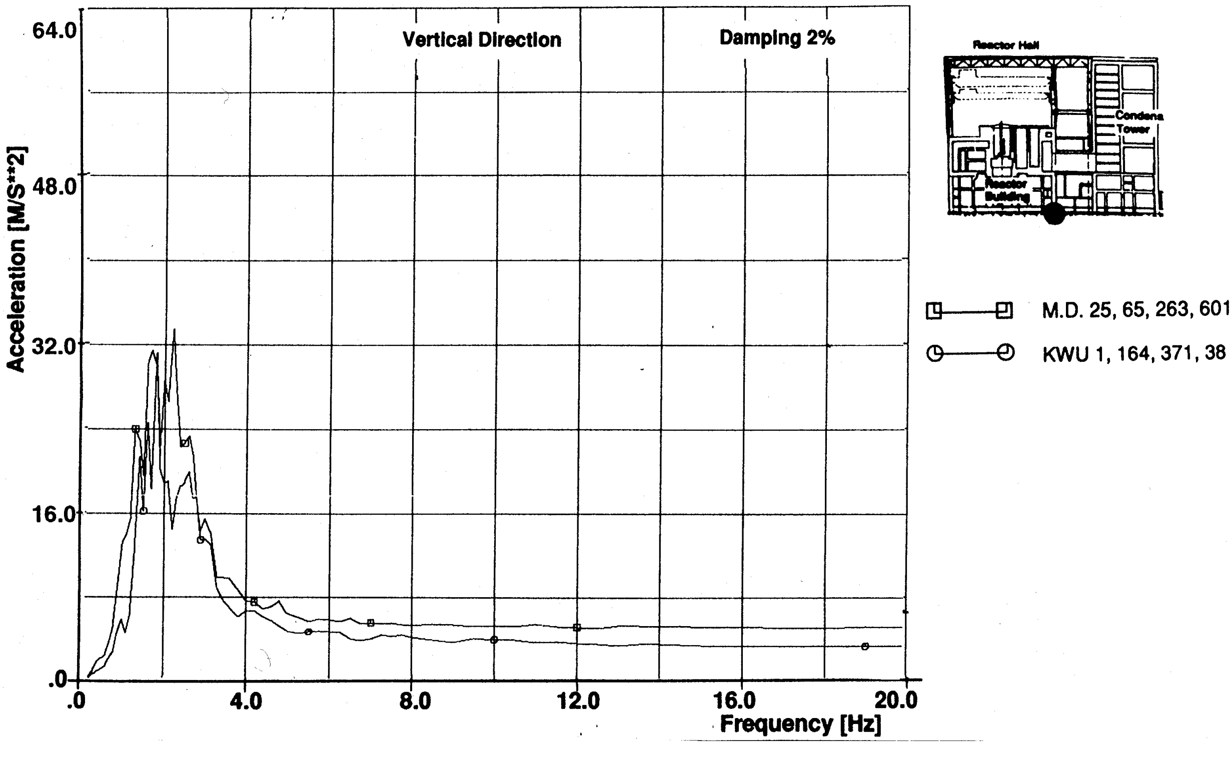


FIG. 4.8. Comparison of seismic response spectra calculated by MD and Siemens (foundation level, vertical direction, damping 2%).

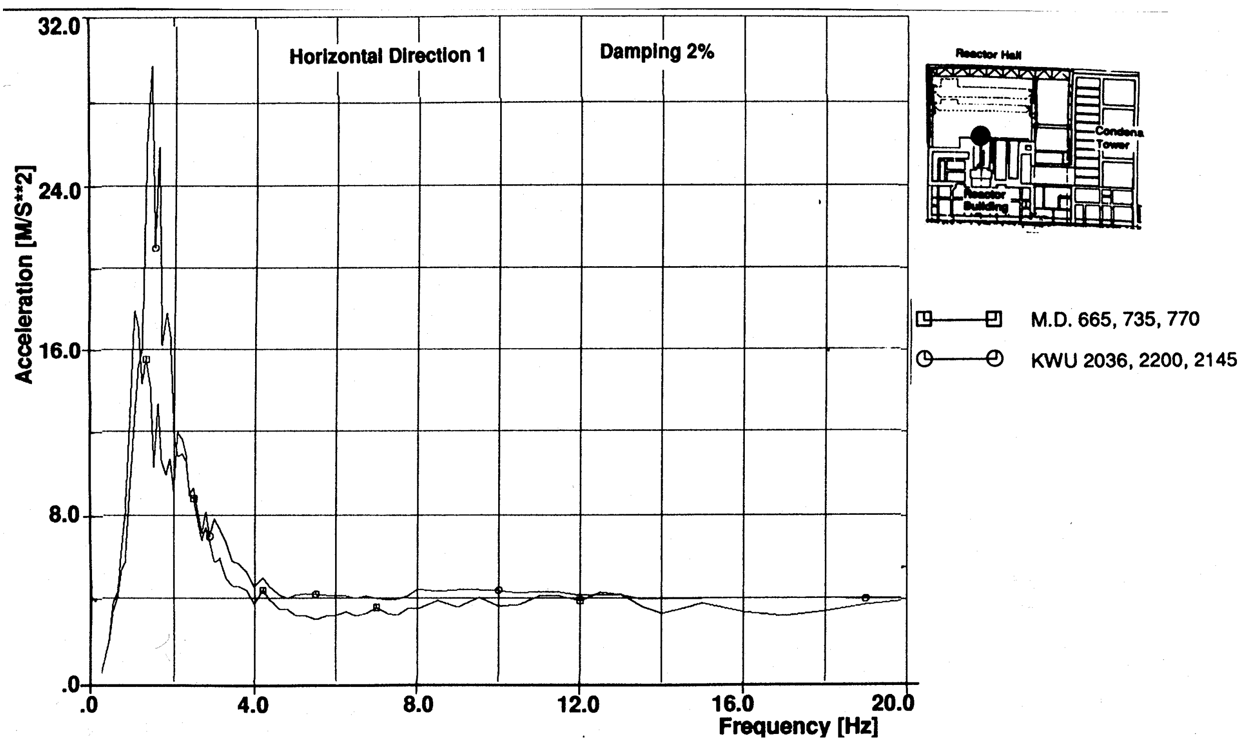


FIG. 4.9. Comparison of seismic response spectra calculated by MD and Siemens (reactor hall, horizontal direction 1, damping 2%).

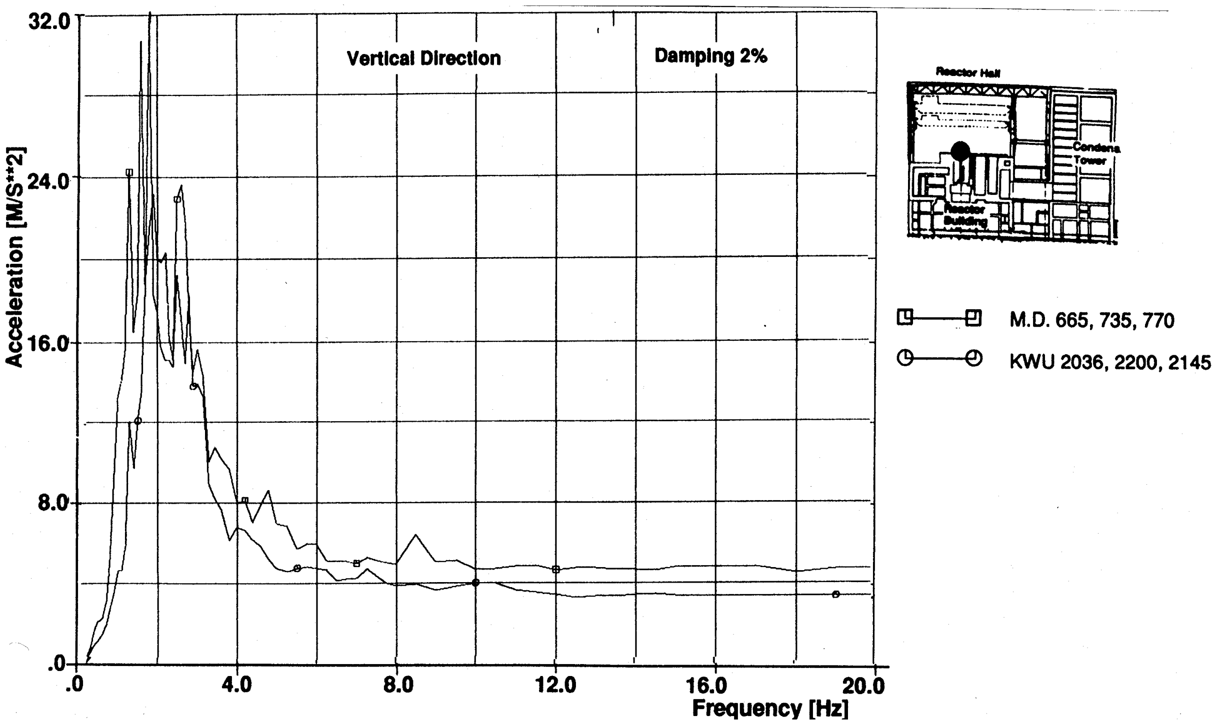


FIG. 4.10. Comparison of seismic response spectra calculated by MD and Siemens (reactor hall, vertical direction , damping 2%).

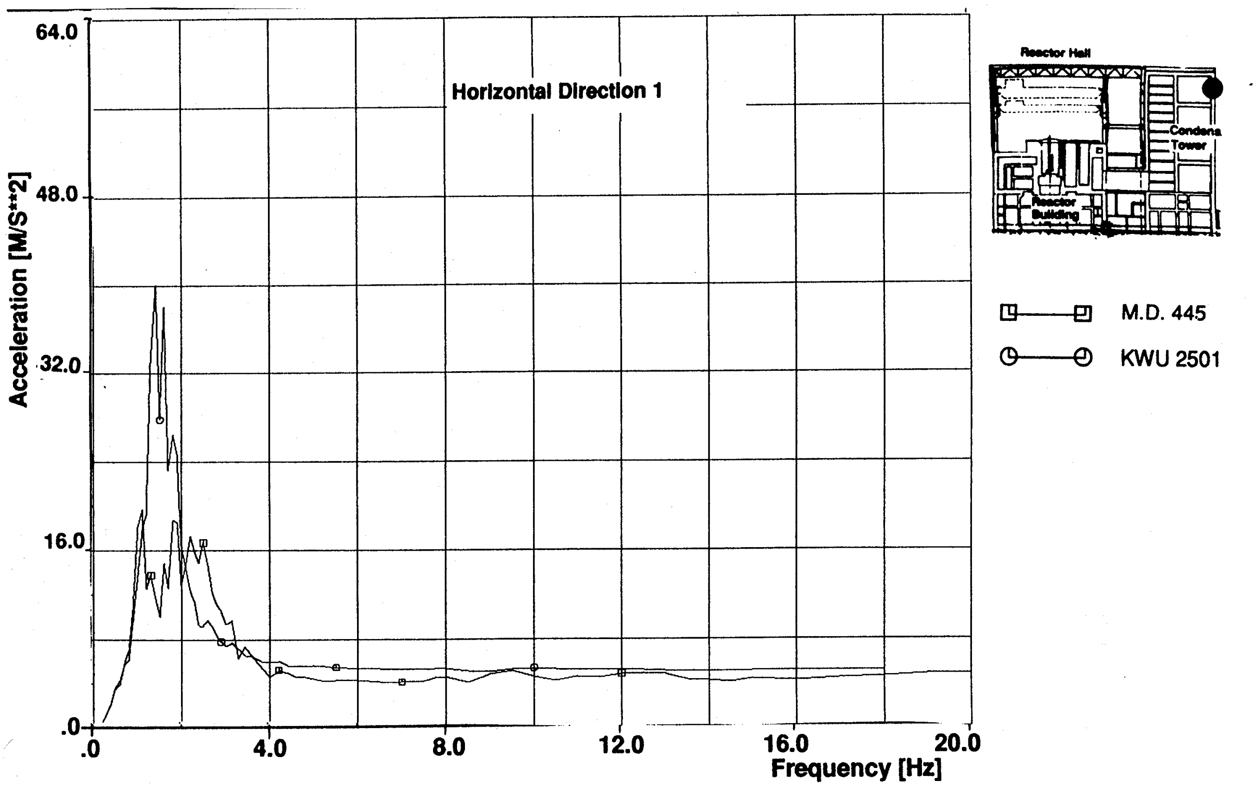


FIG. 4.11. Comparison of seismic response spectra calculated by MD and Siemens (top of the condensing tower, horizontal direction 1, damping 2%).

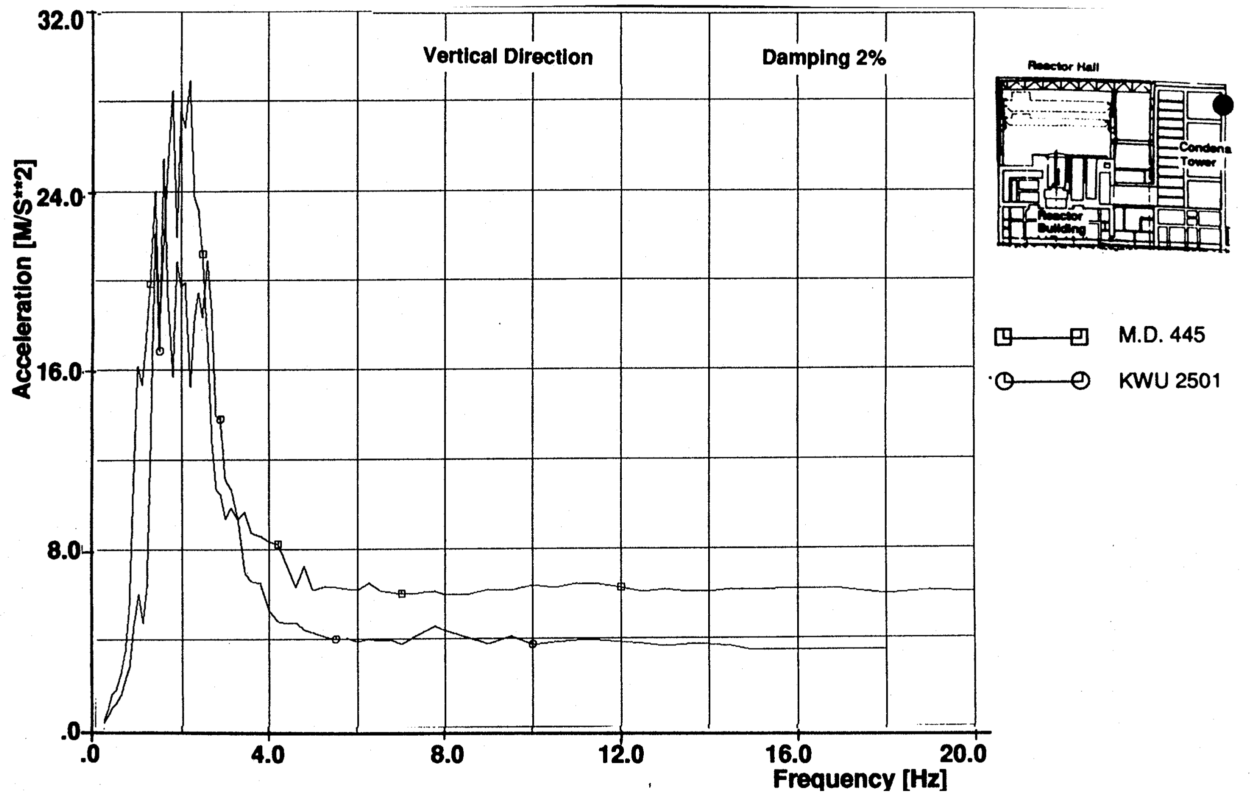
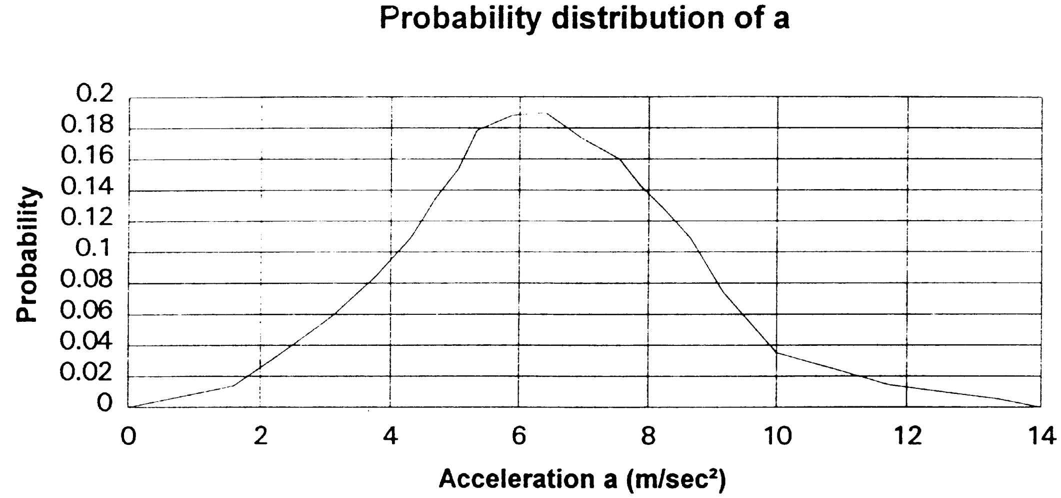


FIG. 4.12. Comparison of seismic response spectra calculated by MD and Siemens (top of the condensing tower, vertical direction, damping 2%).



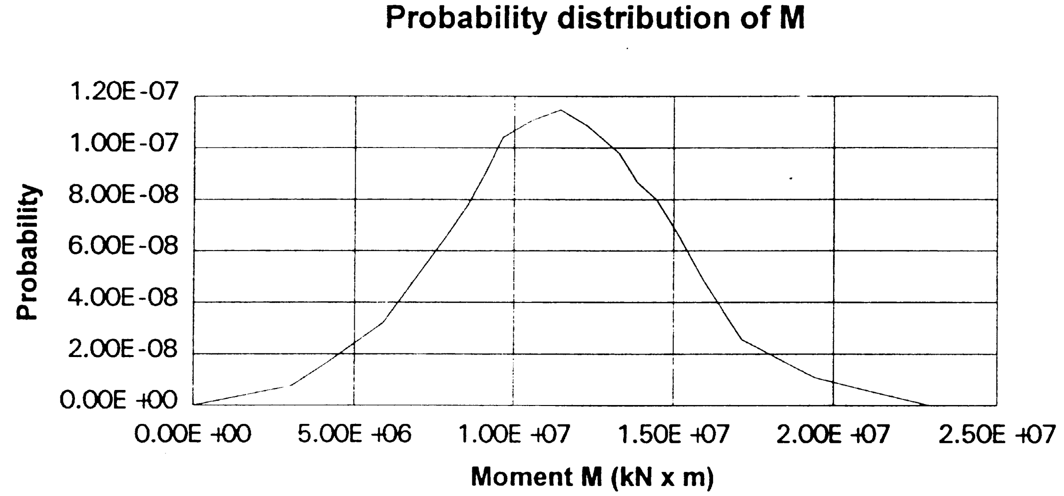


FIG. 4.13. Probabilistic distribution of acceleration and bending moment.

A high value of these derivatives can in fact tell the engineers that the scattering of the result is very sensitive to a scattering in the variable.

This information can be used in the planning phase of the re-evaluation process and identify the most critical source of uncertainty affecting the results: the engineers can therefore decide either to reduce the uncertainty in the variable (e.g. with more testing) or leave it as it is and manage the uncertainties in the results at the end of the process.

The tool is very powerful, as it provides a quantitative evaluation of the benefit, in terms of reduction of the scattering in the result, related to an extension of the usually expensive campaigns for data collection (typically geotechnics and geophysics), and in this sense is useful not only to the designers, but also to those who manage the whole re-evaluation process.

Lessons learned

The Paks plant is founded on relatively very soft soil layers. Therefore, the soil-structure interaction phenomena play a very important role in the seismic response of such a building: the seismic floor response spectra cannot be correctly determined without proper consideration of these phenomena.

The definition of proper input variables is very critical for the reliability of the final results and therefore a sensitivity analysis on the effects of the input variation should always be carried out.

Conclusions and recommendations

The comparison of the results obtained using Models 1 and 2 shows generally good agreement. Some differences may be explained by more realistic representation of the soil properties in the case of Model 2 under the concrete block foundation as well as under other coupled vibrations of the building structures.

4.2. DYNAMIC ANALYSIS OF PAKS NPP STRUCTURES — WORM TANK (TASK 7C)

Objectives

The objective of this task was to perform analytical and experimental investigations to obtain an adequate background for the correct estimation of seismic response and resistance of this kind of tanks, which are typical for all WWER-440 type NPPs and in particular for the Paks NPP.

It should be noted that the worm tank (low-pressure emergency core cooling system tank) is a specific vertical multi-cylindrical (four connected cylinders) flat bottom tank made of stainless steel and resting free (no anchorage) by means of a special intermediate steel grid on the concrete floor (Fig. 4.14).


'97 2 19

FIG. 4.14. Typical arrangement of the bottom part of multi-cylindrical vertical liquid storage tanks as installed on WWER-440/213 NPPs.

Summary of work done

(a) Work performed by a team of investigators from Japan

Several models (1/14, 1/5 and 1/3 scale) were investigated and tested at the National Research Institute for Earth Sciences and Disaster Prevention (NIED), Science and Technology Agency (STA) of Japan in co-operation with the Ishikawajima-Harima Heavy Industries (IHI) under the supervision of Mr. Heki Shibata of Yokohama National University and with the logistical support of the Paks NPP. These tasks have been described in two papers presented at the ASME PVP Conferences in 1996 and 1997 and published by the ASME. References are [4.3] and [4.4].

These activities focused on the investigation of the dynamic response of the worm tank under seismic excitation. The plastic model (1/5 scale) (Fig. 4.15) was used for the first stage of this investigation while the steel model (1/3 scale) was used for the second stage. The following phenomena were investigated:

1. Study of fluid-structure interaction effects

   – natural frequencies and mode shapes of the fluid-structure system,
   – distribution of the fluid pressure inside the tank,
   – seismic response of the tank,
   – overturning of the tank,
   – sliding of the tank,
   – effect of absence of any anchors,
   – effect of tie rods in intersection of tank cylinders.

2. Study of sloshing effects

   – sloshing frequencies and sloshing modes,
   – damping,
   – sloshing response of the tank including impact effects of liquid to the interior portion of the tank.

Details of the applied seismic excitations used for the corresponding floor at the Paks NPP and the location of accelerometers are described in the corresponding documents. Numerical analyses of the tank-liquid system were performed with the aid of the Finite Element Method (FEM) ANSYS 5.0 software, with special analytical procedures for the liquid elements: the results of these analyses are compared to those obtained in the above tests.

(b) Works performed during the blast test at the Paks NPP

On site measurement and data analysis were performed during the full-scale blast test at the Paks NPP by NPP technicians. The tank was filled with water during these tests. The signals measured at points 3 and 6 characterize the base excitation. These activities are described in Paks NPP documents.

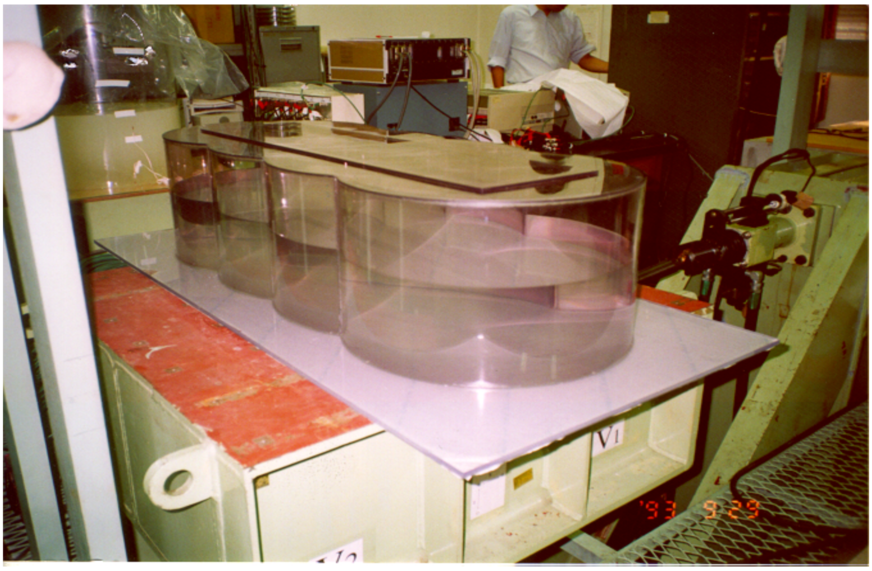


FIG. 4.15. A plastic model of a worm tank.

(c) Theoretical investigation performed by the Argonne National Laboratory (AES/ANL)

The interpretation of Japanese tests is given and completed by several theoretical investigations in documents presented by the Argonne National Laboratory in the USA. The first document is devoted mostly to the sloshing problems and interpretation of results obtained from the test performed using the 1/14 and 1/5 scale. The second document is devoted to the interpretation of results obtained during the last test of the 1/3 scaled tank model.

(d) Simplified analysis performed by S&A-CZ

A simplified analysis of the worm tank was also performed by S&A-CZ. This analysis was performed with the computer program TANKV–M which was developed to estimate approximately both the seismic response and seismic capacity of multi-cylindrical vertical flat bottom liquid-storage tanks in accordance with the Seismic Margin Assessment (SMA) methodology. Unfortunately, very little theoretical background is available in relation to seismic response and seismic capacity analysis of such multi-cylindrical vertical flat bottom tanks. Therefore, to determine the seismic response of such a complicated structure, the multi-cylindrical tank is replaced by an equivalently shaped tank which has a rectangular plane form and internal tie rods.

Results

(a) Works performed by Japanese investigators and by the Argonne National Laboratory

Natural frequencies and mode shapes of the fluid-structure system

Comparison of natural frequencies, mode shapes and corresponding participation factors shows relatively good agreement between the results obtained from the test and results of the Finite Element Method (FEM) analysis.

Seismic response of the tank-fluid system

The test and analytical results show that the horizontal seismic excitation applied in a lateral direction on the short side (perpendicular to the axis) is the most critical for such a tank connecting tank cylinders. Response accelerations measured in the lateral direction are up to ten times larger than those measured in the longitudinal direction.

Buckling of the tank wall

The worm tank buckled during the seismic test in a local area just close to the connection of tank cylinders. It is considered that this was caused by the residual stresses due to the welding and by residual strains during manufacturing, which is typical for thin-walled tanks.

No anchorage of the tank

Overturning was not observed under 0.30 g of horizontal seismic excitation. Also no sliding of the worm tank was observed up to the 0.40 g peak horizontal acceleration, even though the measured static friction coefficient was only 0.27.

Sloshing effects

It was clearly demonstrated that sloshing frequencies of liquid in such a multi-cylindrical tank can be easily and correctly determined using the approximate formulas as developed for rectangular tanks. The relevant references also discuss how to replace the real worm tank values by equivalent rectangular tank values to calculate the sloshing effects correctly.

(b) Work performed during the blast test at the Paks NPP

The dominant natural frequency and corresponding mode shape were determined for the tank-fluid system from the results of the full-scale blast test. They both agree well with the results obtained by Japanese tests and by analysis. Fig. 4.16 illustrates the response spectra calculated on the basis of the response acceleration time histories measured during the blast test at six different points on the tank wall.

(c) Simplified analysis performed by S&A-CZ

The stainless worm tank analysed stands on a special steel grid made of I-shapes. It is typical also for many similar tanks installed in WWER type NPPs. This steel grid rests on the floor liner and there are no tank-to-grid on grid-to-floor connections. It means that one of the most important questions is how these tanks can resist horizontal sliding forces. It was recognized that friction forces between the tank and the grid and also between the grid and the floor liner below the grid must be much higher than the conventionally assumed 25 to 30% of the corresponding vertical effective gravity forces (clamping forces) due to the following phenomena:

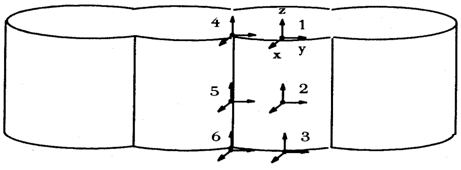


Figure 1. Location of the acceleration sensors on the worm-tank.

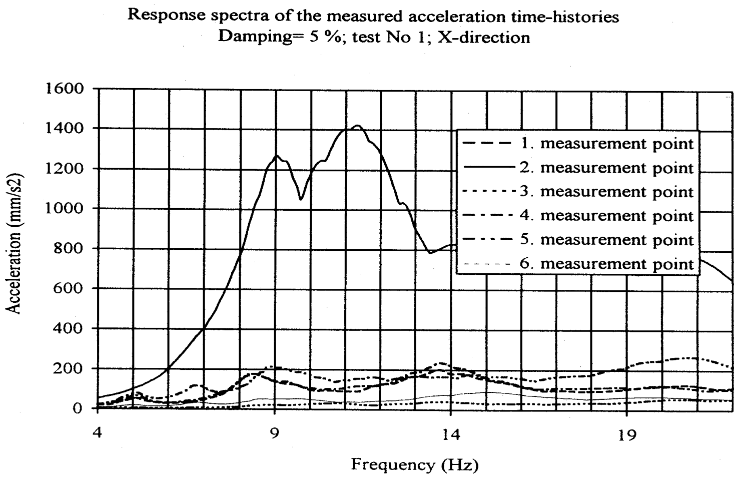


FIG. 4.16. Response spectra calculated at selected points of the tank based on the acceleration time histories measured during the blast test (5% damping, transverse direction).

- the tank bottom and the liner are slightly deflected in the contact to grid beams and both sliding planes are not plane: the grid beams are slightly pressed into the flexible tank bottom and into the relatively soft steel liner, which is grouted only by a plain and poor concrete,

- the mechanism of sliding under the fast and reversible peak seismic shear forces is such that the equivalent friction coefficient (equivalent to the shock friction effect) should be at least 1.3 times the conventional static friction coefficient.

Therefore, in this case the reasonable value of the friction coefficient for both sliding planes (tank-to-grid and grid-to-liner) can be at least 0.35. These considerations are supported by the results of seismic tests of the worm tank described above.

Results of simplified seismic evaluation of the worm tank TJ30B001 (Paks NPP):

- the fundamental horizontal natural frequency of the tank-liquid system is 10.80 Hz (lateral direction, relatively acceptable agreement with measured and calculated by FEM values which vary from 7 to 11 Hz);
- the fundamental vertical natural frequency of the tank-liquid system is 22.25 Hz (no comparison available);

- the fundamental sloshing frequencies are 0.38 Hz in lateral and 0.19 Hz in longitudinal direction respectively (good agreement);
- HCLPF seismic margin capacities were calculated as follows

– overturning moment capacity	1.106 g,
– sliding shear capacity	0.503 g,
– internal tie-rod capacity	0.331 g,
– liquid pressure capacity	>> 0.25 g ($\mathrm{PGA}_{\mathrm{SSE}}$).

Applicability of results

The results obtained within the scope of this task are very important and can be used to evaluate the seismic response and also seismic capacity not only for the investigated worm tank, but also for other similar tanks which are quite common on all WWER type NPPs.

Lessons learned

The tests and analyses performed within the scope of this task provide a good understanding of the dynamic characteristics, seismic response and seismic capacity of the worm tank.

The seismic capacity of such tanks is governed by the overturning moment or shear capacities at their base. The capacity primarily depends on the axial compressive buckling capacity of the tank shell, the tensile hold-down capacity of anchor bolts including their anchorage into the bases lab and attachment to the tank wall, and the hold-down capacity of liquid pressure acting on the tank base plate. Shear capacity may play an important role when the friction coefficient between the tank bottom and the tank foundation is relatively low.

The supporting grid has a great influence on free standing tanks. The tests performed showed that the friction coefficient between tank and grid and between grid and floor conventionally taken as 0.25 or 0.3 is probably higher. This is based on the following phenomena:

- the tank bottom and the liner are slightly deflected in the contact areas, which means that the sliding surfaces are not plane;
- the mechanism of sliding under the quick reversible peak seismic shear forces is such that the equivalent friction coefficient should be taken as at least 1.3 times the conventional static friction coefficient due to its dependence on velocity.

Conclusions and recommendations

Overturning and sliding of the investigated worm tank does not occur when subjected to the seismic induced motion currently determined for the floor on which this tank is located inside the main reactor building of Paks NPP.

Further theoretical and even the experimental investigations of seismic response and seismic capacity of this kind of multi-cylindrical vertical flat bottom liquid storage tanks are highly recommended for the other tanks present in the NPP, due to the difficulty in generalizing the above results.

4.3. ANALYSIS OF BURIED PIPELINES FOR PAKS NPP (TASK 20)

Objectives

The objectives of this task were:

(a) to prepare a theoretical background for seismic evaluation of buried pipes in general, based on the current state of the art, and therefore to evaluate the applicability of available computer codes;
(b) to analyse seismic response and seismic capacity, if possible, of the most important buried pipelines at the Paks NPP.

The objectives are very wide in scope and extend beyond the Paks NPP. Therefore in the following discussion, reference is made to analogous studies carried out for the Kozloduy NPP, which can also contribute towards a better understanding of the problem.

Summary of work done

(a) Work performed by EQE

This work is based on the following basic assumptions:

- dynamic inertia amplification does not play any important role,
- only the response of buried pipes due to wave passage is important,
- slippage between the pipeline and soil should be considered,
- only selected pipe segments can be analysed.

The EQE analysis procedure consists of the following steps:

- from wave field develop soil strain and displacement fields,
- develop non-linear soil springs,
- model pipeline segment in one-half of the dominant wave length using non-linear pipe elements (straight elements, elbows etc.),
- applying displacement field, perform non-linear analysis to calculate global response.

The EQE study was concentrated on one of the typical buried pipes (diameter 1220 mm, wall thickness 8 mm, material – carbon steel) connecting the cooling pools with the WWER-1000 units of the Kozloduy NPP (Fig. 4.17). Rayleigh waves and site specific shear wave velocity profile were assumed to evaluate the soil-strain field (Fig. 4.18). Non-linear soil spring characteristics were approximated by bi-linear curves and calculated using the well known references (O'Rourke and Elhmadhi, Guidelines for the Seismic Design of Oil and Gas Pipeline Systems). The last step — non-linear static analysis — was then performed with the aid of the ANSYS 5.3 software.

(b) Work performed by Siemens

This analysis only takes into account only seismic inertia effects and differential motions between the soil surrounding the pipe and the building structure into which the buried pipe is attached (Fig. 4.19). No wave propagation effects are considered. Accessorily, the cold water supply intake pipelines which extend between the pumping station and the turbine building of the Paks NPP are analyzed using the SASSI/S software. The correct model of non-linear soil behaviour is also reviewed.

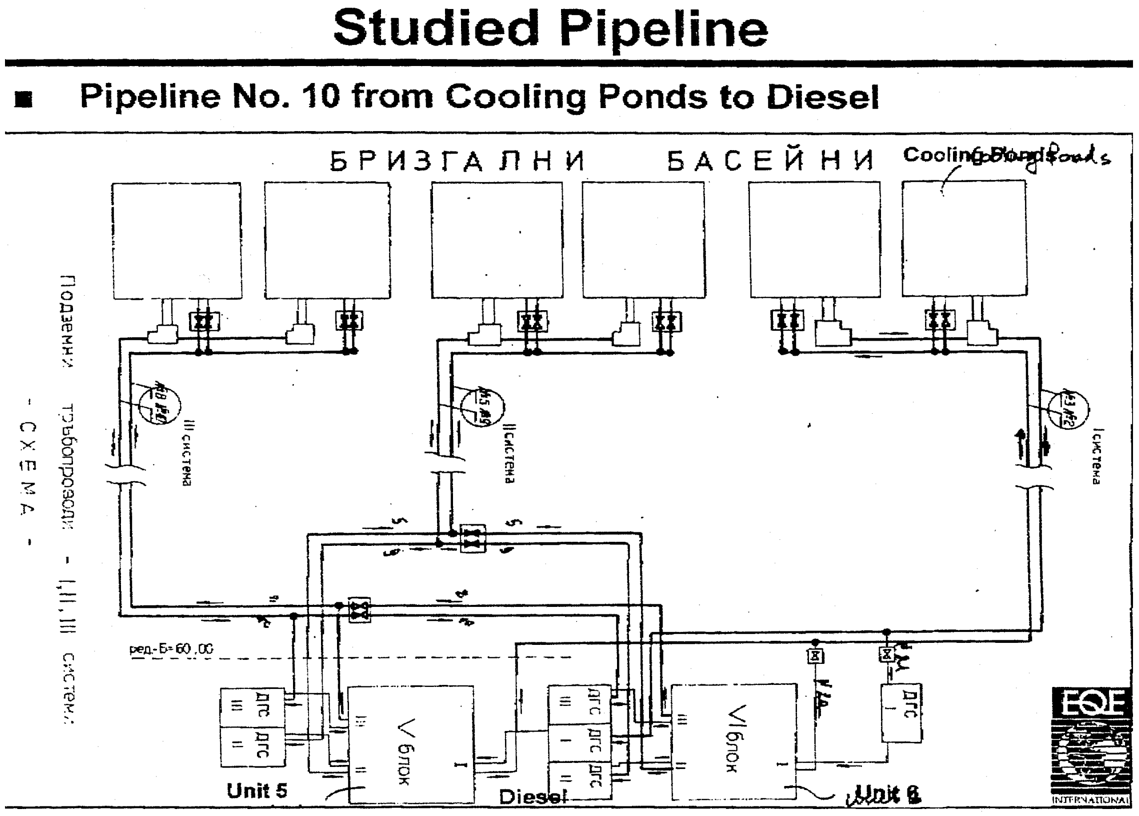
(c) Work performed by S&A-CZ

The simplified analysis based on the procedures recommended in the ASCE standard for seismic analysis of safety related nuclear structures (draft of August 1995) and other relevant documents was performed and is presented in this work.

Two important failure modes are considered:

- failure of long straight pipe segments remote from supports, sharp elbows, or intersections due to axial strain and curvature of the surrounding soil caused by propagating seismic waves,
- failure of elbows caused by wave propagation in the vicinity of elbows.

The numerical calculations were performed for the most important buried cooling water supply pipes located at the Paks NPP.



Studied Pipeline

■ **Pipeline No. 10 from Cooling Ponds to Diesel**

FIG. 4.17. Buried pipeline at Kozloduy NPP investigated by EQE.

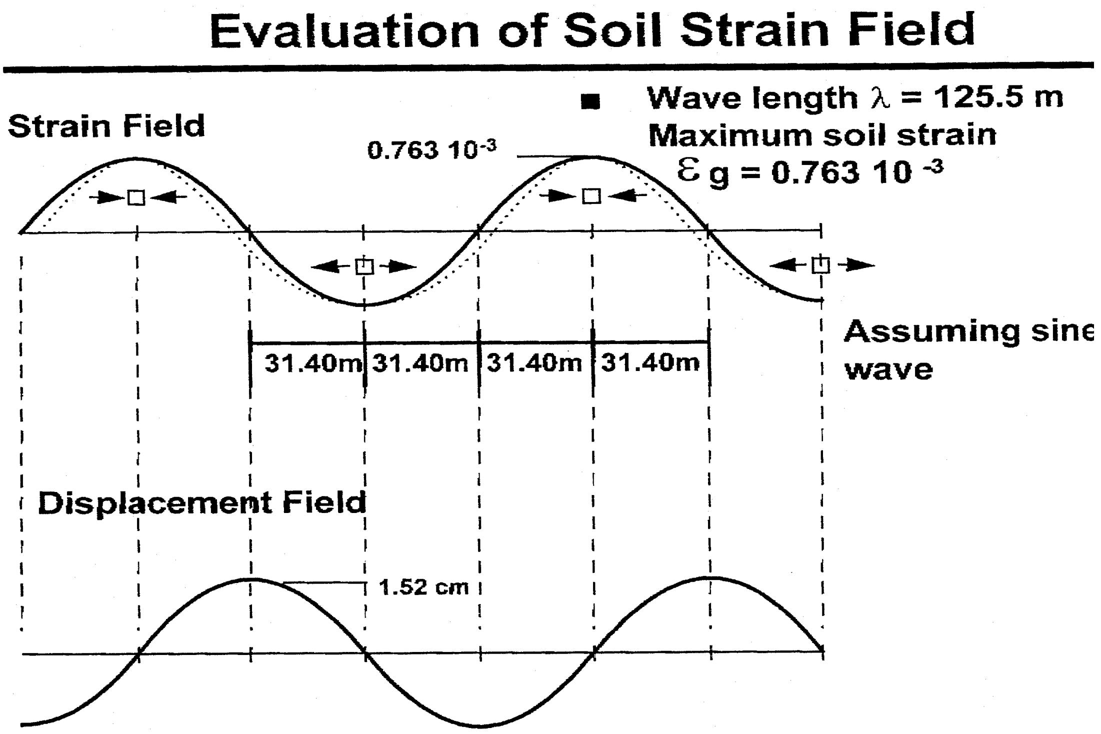


FIG. 4.18. Simplified approach to evaluation of soil-strain field.

Results

(a) Work performed by EQE

Results are presented not only for straight pipe segments, but also for bent segments and segments with elbows. Nevertheless, in relation to the buried pipes considered which are located at the Kozloduy NPP, it is currently only possible to render a final conclusion as to the straight buried pipe segments. Their seismic resistance is evidently satisfactory even if no slippage is conservatively assumed (i.e., the soil strain is equal to the pipe strain). Problems may occur when sharp elbows or bent elements are analysed due to the significant influence of local bending stresses. Investigation in this direction should be continued.

(b) Work performed by Siemens

Because the effect of propagating seismic waves is not taken into account, the results obtained by Siemens can be used only for study purposes. Consideration of how to correctly consider non-linear Behaviour of the soil around the pipe is very useful.

(c) Work performed by S&A-CZ

The main results of the work done by S&A-CZ are summarized in Table IV.6.

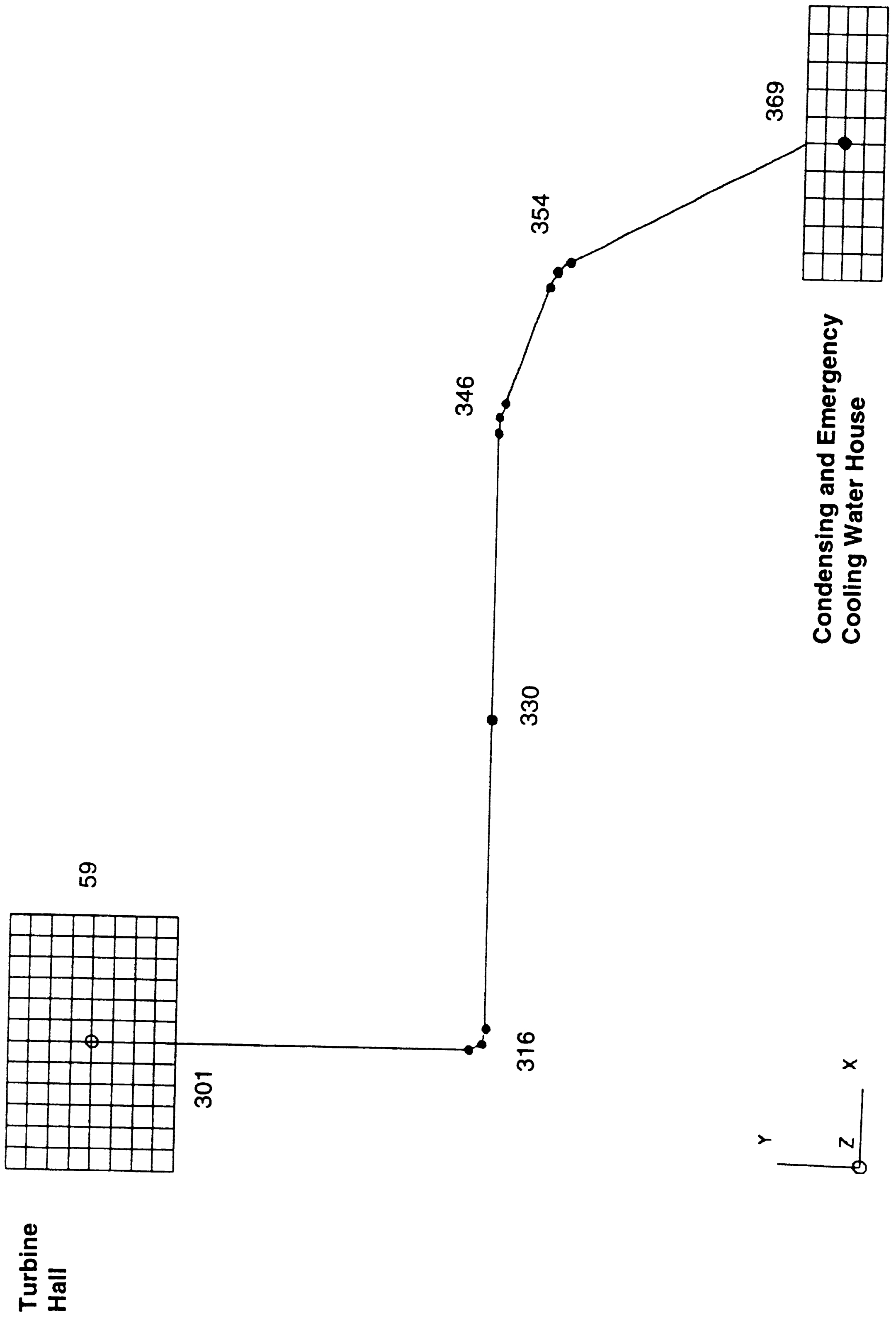


FIG. 4.19. Mathematical model.

TABLE IV.6. HCLPF SEISMIC MARGIN CAPACITIES CALCULATED FOR THE MAIN COOLING WATER SUPPLY BURIED PIPELINES AT PAKS NPP ($PGA_{SSE} = 0.25g$)

Pipeline System	Dimensions [mm]	HCLPF [g]
02VX,VY,VW11 (intake for two units)	720 ×10	0.31
02VX,VY,VW51 (outlet from two units)	1020 × 10, 720 × 10	0.28
30,40VX,VY,VW21 (cooling water for DG)	159 × 4.5	< 0.2

Note: The calculated HCLPF values are based on the following assumptions:

- estimated shear wave velocity Vs = 300 m/s for the surface sand layer;
- only the Rayleigh waves were considered, the effects of compression and shear waves were ignored (pipes are located near the surface and the site is located far from any possible earthquake epicentre);
- pipe materials are DX42 and A35K with the basic allowable stress (according to ASME BPVC Section III) $S_h = 112.\%$ and 92.5 MPa respectively;
- slight ductility considered (ductility factor 1.50);
- no lateral soil pressures and no anchor point where movement considered,
- friction coefficient between soil and piping was taken equal to 0.7.

Applicability of results

Results obtained by investigators within the scope of this task are starting an essential discussion on the most appropriate engineering methodology to be applied in the seismic evaluation of buried pipelines. Of course the problem is not only widely applicable, but it also deals with safety related crucial issues, like the water supply pipelines, which are very often buried.

Lessons learned

It should also be noted that generally there is also significant influence of large relative displacements caused by:

- faulting-induced movements (lateral spreading),
- liquefaction induced ground movements,
- landslides and slope failures,
- settlement and seismic-induced motions and deformations of the building structure to which the buried pipelines are attached.

These phenomena are, generally, excluded in both the Paks and Kozloduy NPPs.

Dynamic amplification does not play an important role in the response of buried pipelines. Stresses and strains due to amplification effects are less than those from small relative pipeline-soil relative displacement computed using maximum ground strain estimates. The static response of buried pipelines to the propagating seismic waves is only important when large relative displacements of the ground along the pipeline length cannot occur.

Conclusions and recommendations

The investigation of the buried piping showed that only the static part of the response provides a dominant contribution to the global response. Dynamic amplification does not play an important role. The slippage between soil and piping should be considered.

Future improvement to the proposed methodologies might include:

- A full simulation of the pipeline response at wave passage in linear and non-linear response
- Consideration of dynamic effects
- Consideration of slippage between pipeline and soil
- Development of non-linear soil springs
- Model pipeline using non-linear pipe elements.

For a realistic seismic resistance simulation of buried pipelines located at the Paks and Kozloduy NPPs, more detailed theoretical and analytical investigations are evidently necessary and strongly recommended.

4.4. EVALUATION OF POTENTIAL HAZARD OF WWER-440 AND WWER-1000 REACTOR OPERATING CONTROL ROD DRIVE SYSTEM (TASK 26)

Objectives

The objective of this task was the analytical and experimental investigation of the seismic response of the Control Rod Drive System (CRDS) of the WWER-440 and WWER-1000 reactors. As the problem has a common analysis, it was not split into separate task according to the two reactor configurations.

CRDS is used for operative control of the chain reaction in the active zone of the reactor and to control reactor reactivity in the following modes:

- initial fuel loading and fuel removing,
- reactor startup in the sub-critical mode,
- increase of the reactor power output,
- change and support the designated power level,
- reactor scram and reactor shutdown,
- control and support the reactor in the sub-critical mode.

In all these modes the reactor reactivity is changed by insertion or withdrawal of control rods using the related mechanical equipment. One of the most important requirements for CRDS is reliability of the insertion of control rods into the active zone of the reactor under any possible operation conditions including earthquake and other similar dynamic effects.

To assure nuclear safety, the following general requirements must be met:

- reliable movement of control rods in the direction of decreasing reactivity,
- limitation of the reactivity-increasing time,
- extremely low probability of throwing up of control rod from the active zone of the reactor,
- guarantee of the inserting speed of control rods,
- reliable releasing of the control rod assembly from the latches,
- Loss of Coolant Accident prevention,
- reliable cooling of the CRDS.

The acceptance criteria for seismic behaviour of CRDS were formulated on the basis of these general requirements. To be sure, they are different for different types of CRDS. For instance, in relation to the WWER-440-213 reactors, the control rods should fall down to the bottom of the active zone within 8.5 to 12.8 seconds after their release.

Summary of work done

(a) The methodology was prepared for the evaluation of a proper operation of the CRDS during an earthquake.

(b) The 1/4 scale model of WWER-440 CRDS was tested in the CKTI-VIBROSEISM laboratory in St. Petersburg.

(c) The FEM non-linear models of the CRDSs of the WWER-440 and WWER-1000 plants were performed and analysed.

The methodology of the experimental and analytical investigations are provided here below:

(a) Seismic testing of the CRDS for the WWER-440 reactor

The experimental investigation of the CRDS for the WWER-440 (1/4 scale model) was carried out on the CKTI-Vibroseism 1-D horizontal shaking table. The main goal of this investigation was to study the non-linear dynamic behaviour of the CRDS and to verify the analytical model and results of the numerical analysis. The principal chart of the testing system is shown in Fig. 4.20.

Horizontal excitations play the dominant role in seismic response of the CRDS. The most important is the insertion time of the rods into the active zone of the reactor, which is primarily affected by dynamic impacts by the rods to the housing pipes when subjected to horizontal seismic excitations. The influence of vertical seismic excitations was recognized as practically negligible. Thus, the general goal of these seismic tests was to determine the insertion time of rods into the active zone of the reactor under the given seismic excitation.

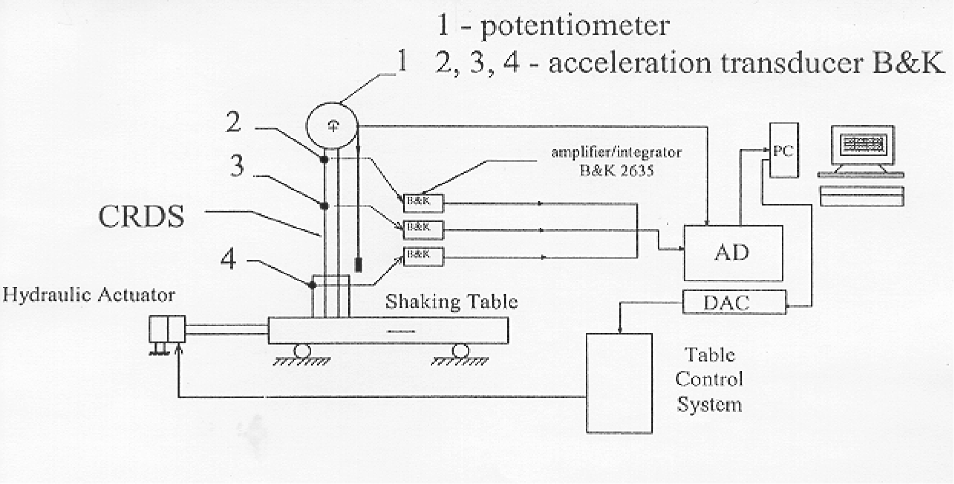


FIG. 4.20. Principal chart of measurement

(b) Numerical analysis of the CRDS for the WWER 440 reactor

To create the analytical model of the WWER-440 CRDS, the geometry and other properties of the experimental 1/4 scale model were used. The damping ratio was determined from the experimental results. The insertion time is influenced by a multitude of parameters including dry friction in the bearings of the drive mechanism and hydraulic resistance of all moving parts of the CRDS. These peculiarities are modelled by friction and viscous elements.

The complete analytical model for the WWER 440 CRDS is shown in Fig. 4.21. The seismic excitation was given by the corresponding response spectrum as calculated for the elevation of the upper block of the reactor in the Paks NPP (PGA = 0.25 g). The SEISM-2000 software developed for analysis of non-linear dynamic systems with parametrically varying characteristics (friction) was applied for the purpose of this analysis.

(c) Numerical analysis of the CRDS for the WWER-1000 reactor

The following assumptions were made to create the dynamic model of the WWER-1000 CRDS:

- all components of the WWER-1000 CRDS are modelled by beam finite elements with concentrated inertial parameters;
- the damping ratio is assumed to be 2% (based on test results);
- non-linear peculiarities of the structure are modelled by the so-called component elements;
- all assumptions are conservative in their nature and the influence of hydraulic damping is not taken into account,
- it is also assumed that, as they are inside the active zone of the reactor, the control rods are separated from the driver mechanism immediately when the electromagnetic system loses power,

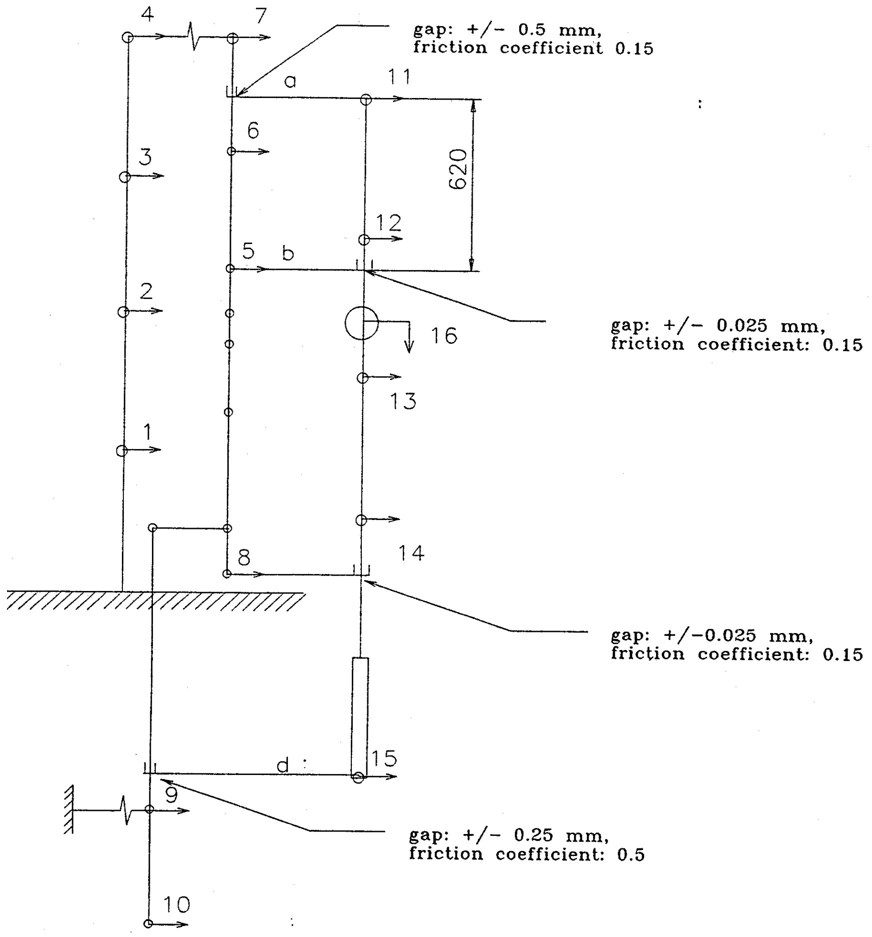


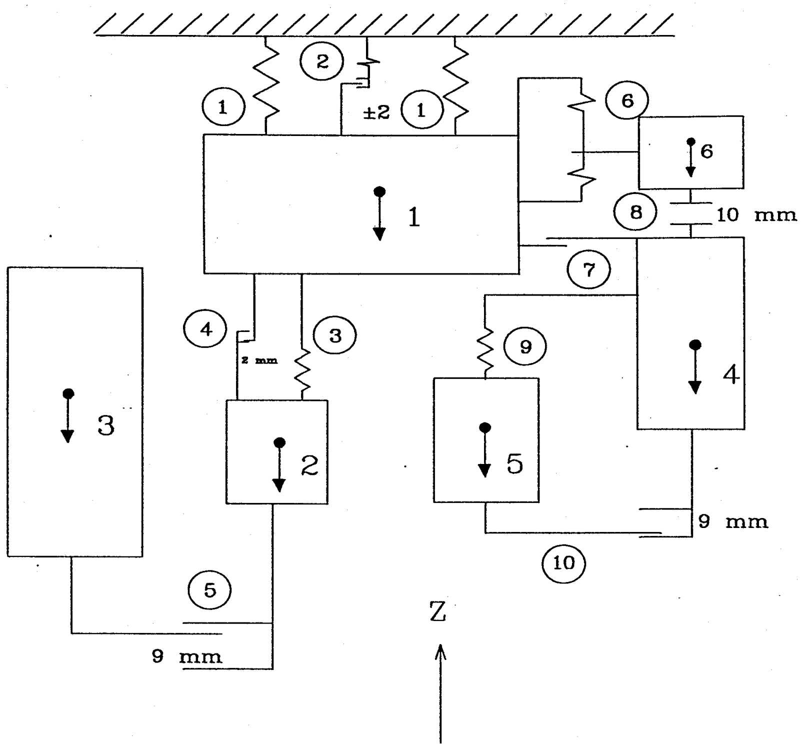
FIG. 4.21. Analysis model for the CRDS of the WWER 440 – 213.

- the seismic excitation was given by the corresponding response spectrum as calculated for the elevation of the upper block of the reactor in the Temelin NPP (PGA = 0.10g).

The same SEISM-2000 software was used for this analysis. Actually, two types of analysis were performed to check the main nuclear safety requirements:

- a one-component seismic analysis of CRDS to check the possibility of non-anticipated latching of control rods by the driver mechanism due to vertical seismic excitation (case 1, for the model see Fig. 4.22),
- a three-component seismic analysis of CRDS to define the control rod insertion time and to check strength problems of CRDS (case 2, for the model see Fig. 4.23).

Figure 4.24 demonstrates how the control rod insertion time depends on the level of seismic excitation. It is also possible to conclude that the control rod insertion time depends on the duration of seismic excitation.



1 - housing pipe of the driver mechanism;
2 - housing of the fixed latching mechanism (FLM);
3 - closing pipe of the FLM;
4 - pulling pipe of the moving latching mechanism (MLM);
5 - closing pipe of the MLM;
6 - bushing.

FIG. 4.22. Analysis model for the CRDS of the WWER-1000, case 1 (one-component seismic analysis — vertical).

Results

(a) Seismic testing of the WWER-440 CRDS

The initial stage of this experiment was to determine the first natural frequency and damping characteristics of the system:

$f = 4.6$ Hz and $k = 0.013$ (1.3%).

(b) Analysis of the WWER-440 CRDS

On the first stage of this investigations, the following analytical and experimental results were compared:

- free insertion without any external excitation,
- free vibrations of the supporting frame,
- dynamic behaviour of the system under the external seismic excitation (0.60g).

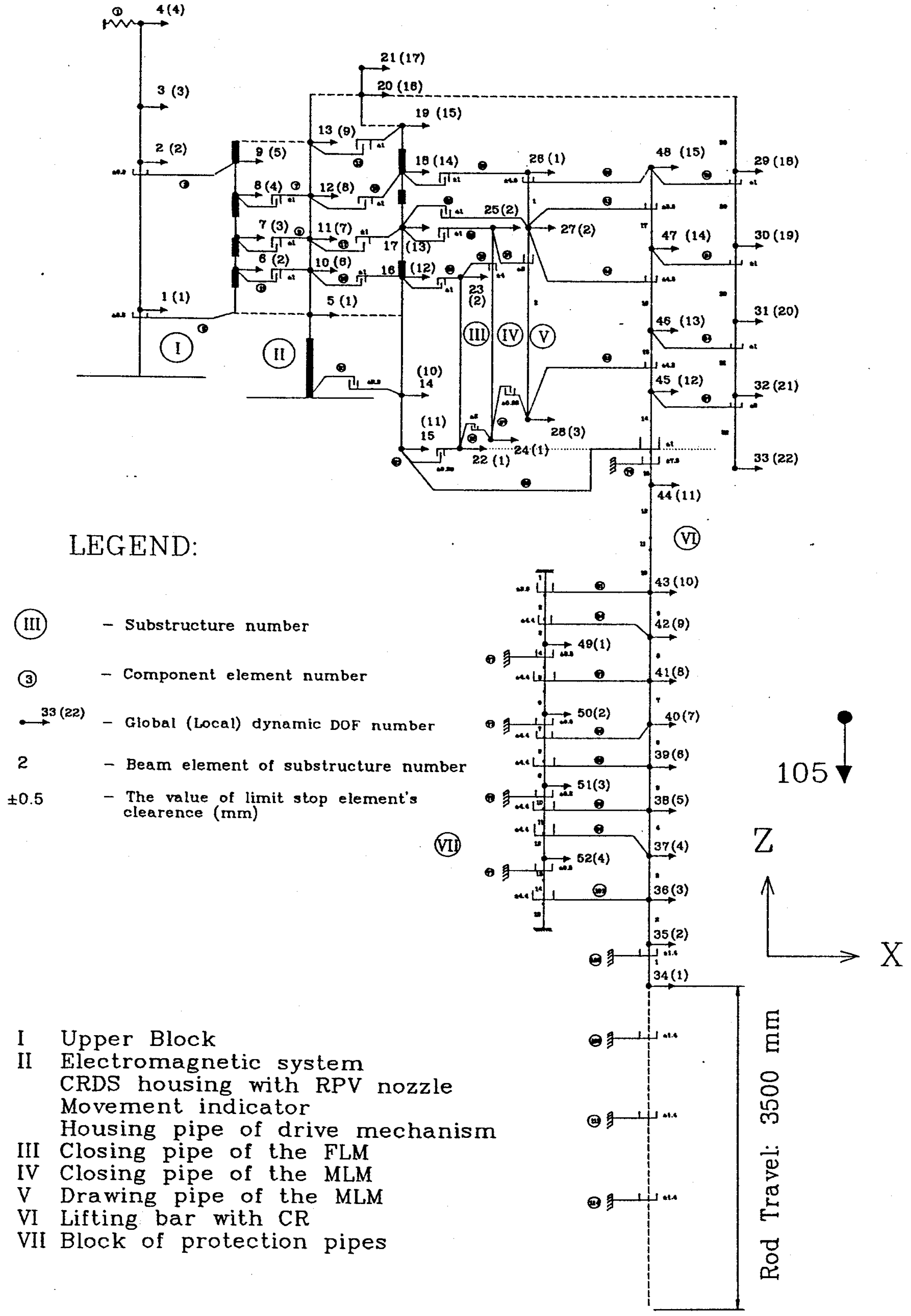


FIG. 4.23. CRDS (WWER 1000) – Analysis model for the CRDS of the WWER-1000, case 2 (three component seismic analysis).

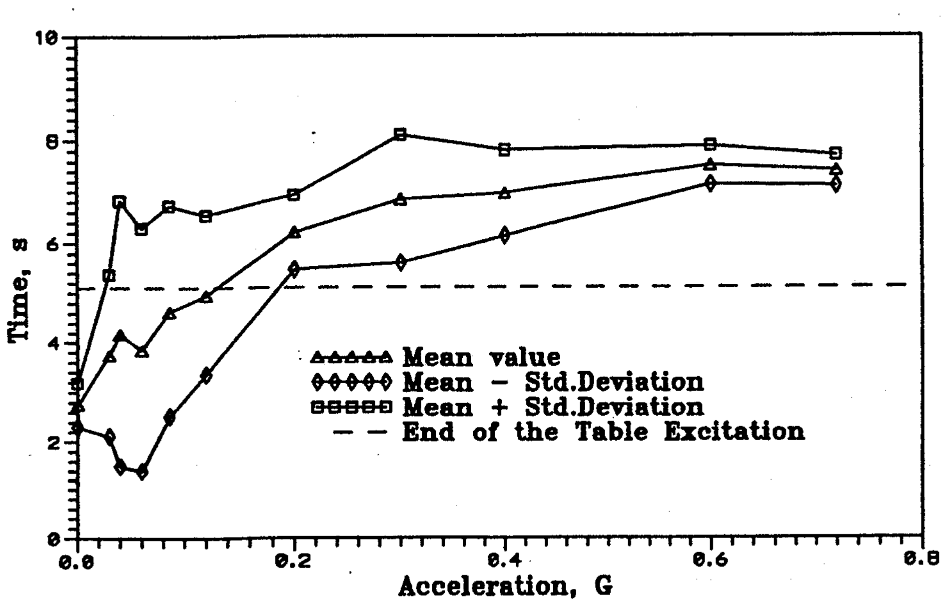


FIG. 4.24. Dependence of the WWER-440-213 control rod free insertion time on the level of seismic excitation.

(c) Analysis of the WWER-1000 CRDS

At the first stage of this analysis, the vertical model (case 1) was analysed. This was critical because there is some possibility that the CRDS lifting bar may latch due to vertical seismic excitation. The critical relative vertical displacement of the fixed latching mechanism (FLM) closing pipe along the FLM housing or corresponding

displacements of moving latching mechanism (MLM) closing pipe along the MLM pulling pipe should not exceed 5 mm. It was clearly shown in this investigation that the level of vertical displacements is below this limit in all cases.

The second investigation was devoted to the study of seismic response of CDRS and to determination of the control rod time insertion into the active zone of the reactor. Figure 4.26 illustrates the calculated control rod travel as to displacement-time for two cases: with and without the given seismic excitation. It is obvious that the difference between these two travels, which is the time delay due to earthquake excitation, is 1.35 seconds. It means that the control rod insertion time under the normal operation conditions is increased 1.54 times when an earthquake as given for this NPP will occur. It is clear that the PGA level can lead to serious downgrading of the CRDS seismic capacity.

Another important aim of this analysis was to check stresses in individual CRDS elements which showed values significantly below the allowable limits.

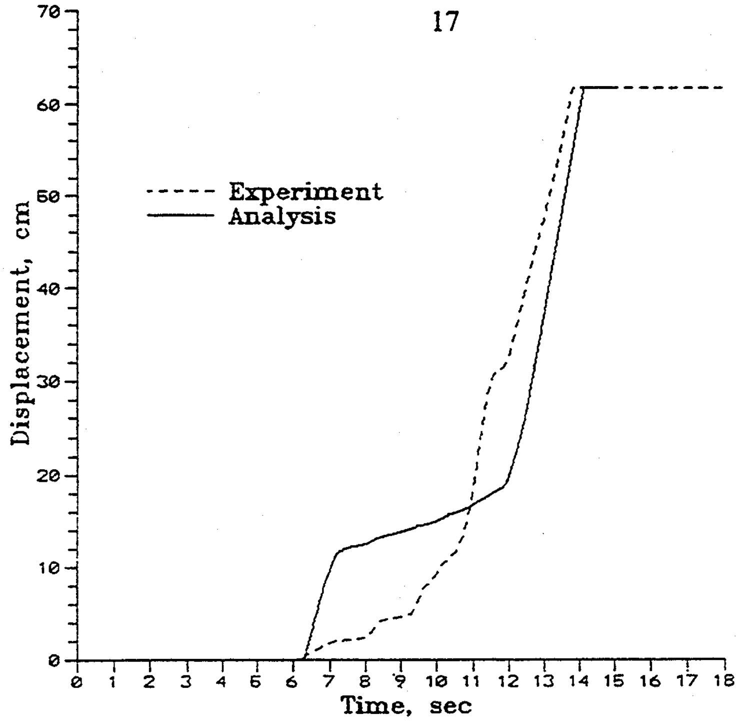


FIG. 4.25. Comparison of two time histories of the WWER 440-213 free control rod insertion into the active zone of the reactor (as obtained from the experiment and as calculated).

Applicability of results

Results obtained for this task are applicable to all NPPs with WWER-440 and WWER-1000 reactors. Actually, these results have already been used for the Paks and Temelin NPPs.

Lessons learned

In essence, there are two ways to obtain seismic response and to verify the seismic capacity of CRDS:

- experimental testing of the CRDS model on the shaking table to measure and record response parameters followed by a calculation of the CRDS seismic capacity on this basis,
- analysis of seismic behaviour of CRDS subjected to the given seismic motion.

Although the CRDS structure is complicated and its modelling presents difficulties due to non-linearities and parametrically changed characteristics, the second course of action seems to be preferable as it allows to vary some parameters to find the weak links of the structure and to define the reliable range of CRDS seismic capacity.

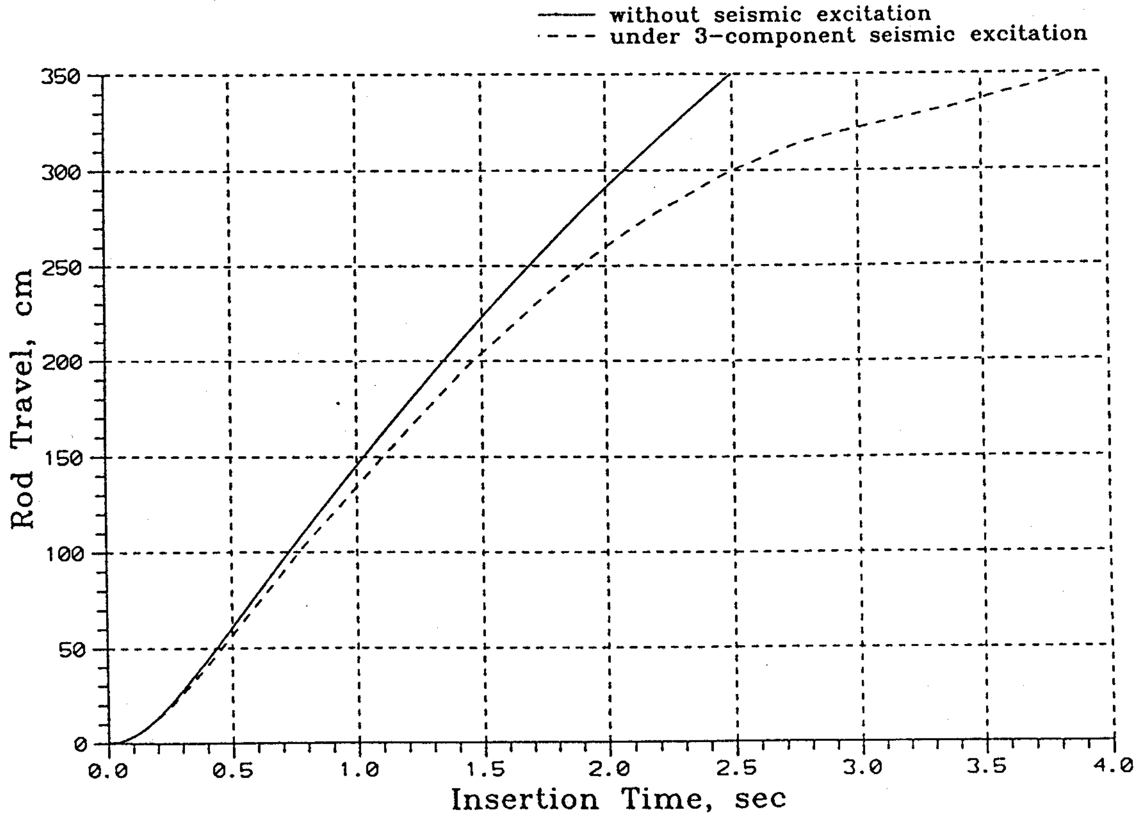


FIG. 4.26. Control rod (WWER 1000) free insertion time history (with and without seismic excitation as given for NPP Temelin).

Conclusions and recommendations

This investigation shows that seismic excitation significantly influences the safety of the plant due to the increased time insertion of CRDS into the active zone of the reactor.

Comparison should be carried out with other studies available in the literature in order to check the reliability of these conclusions for WWER type plants and to set up a well-assessed calculation methodology.

4.5. SHAKING TABLE EXPERIMENTS FOR SELECTED COMPONENTS (TASK 9) AND ON-SITE TESTING OF EQUIPMENT AT PAKS AND KOZLODUY NPPs (TASK 10)

See Chapter 4 (Kozloduy NPP) of Volume 1 of the Background Documents.

REFERENCES TO CHAPTER 4

A. *SMiRT papers*

[4.1] KATONA, T., “Analysis of the dynamic behaviour of the low-pressure emergency core cooling system tank at Paks NPP”, Proc. SMiRT 14 Post Conference Seminar 16, Vienna (1997).

[4.2] KOSTAREV, V. et al., “Experimental and computer analyses of control rod drive system seismic capacity”, Proc. SMiRT 13 Post Conference Seminar 16, Vienna (1995).

B. *Published papers*

[4.3] OGAWA, N. et al., “An experimental study of the sloshing behavior of the worm tank”, ASME PVP Conference, ASME Conference “Pressure Vessel and Piping Design, Analysis and Severe Accidents”, Montreal, Canada - Vol.331, ASME International, New York, Vol. 337 (1996).

[4.4] OGAWA, N. et al, “An experimental study of the fluid-structure interaction behavior of the worm tank”, ASME PVP Conference ASME Conference “Current Topics in the Design and Analysis of Pressure Vessels and Piping”, Orlando, Florida -Vol.354, ASME International, New York (1997).

Chapter 5

ANALYSIS AND TESTING — KOZLODUY NPP

TABLE V.1.

Task	Title	Participants	Tecdoc Chapter	WM volume
6a	Dynamic analysis of Kozloduy NPP Unit 5 RB for seismic input	**SIEMENS** EQE-BG EQE-US CL KNPP BRI EP AEP	5	3
9	Shaking table experiment for selected components	**PNPP** **KNPP** IZIIS	4, 5	4, 3
10	On site testing of equipment at Paks and Kozloduy NPPs	**PNPP** **KNPP** VNIIAM	5, 7	3, 5
14	Special Topic 1 — Assessment of containment dome pre-stressing for Kozloduy NPP	**S&P** EQE-BG KNPP BRI	5	3
15	Special Topic 2 — Assessment of containment dome/cylindrical part for different loading combinations	**S&P** EQE-BG KNPP BRI	5	3
16	Special Topic 3 — Stress analysis of safety related piping for Kozloduy NPP	**S&P** SIEMENS BRI WO	5	3
17	Special Topic 4 — Dynamic analysis of selected structures of Kozloduy NPP	**S&P** BRI	5	3
19	Analysis of buried pipelines for Kozloduy NPP (between DG and spray pools)	EQE SIEMENS S&A-CZ	5	3
26	Evaluation of potential hazard of WWER-400 reactor operating control and drive system	CKTI	4, 5	4, 3

5.1. DYNAMIC ANALYSIS OF UNIT 5 OF THE KOZLODUY NPP FOR SEISMIC INPUT (TASK 6A)

Objectives

The objective of this task was to perform an analysis of the reactor/auxiliary building structure of Unit 5 of the Kozloduy NPP for the currently specified 0.2g pga seismic input motion, using different approaches to soil-structure interaction and to compare the results. A specific subtask is devoted to soil liquefaction assessment.

Summary of work done

Siemens, EQE and the Central Laboratory performed the comparative analysis. The Kozloduy NPP and the Central Laboratory did a separate study on the response of the structure to local earthquakes (probabilistic) and AEP/Moscow made a comparison between AEP design spectra and spectra for hard and soft soil models developed by Siemens.

Previous experimental tests were performed at the Kozloduy NPP included: blast loads in the ground (1980), dynamic impact from the crane (1986) and forced excitation (1992). Natural periods were found around 0.46 s and 0.5 s in the two main directions, with structural damping around 6–8%.

Four numerical models were used for the comparison study, as described in Table V.2.

The probabilistic analysis carried out by the Central Laboratory with a 3D model (Fig. 5.1) studied the effects of seismic input variation and soil property uncertainties on structural floor response spectra.

The soil liquefaction analysis was carried out with three different methodologies, with the spray ponds in different conditions of emptiness, and a free field acceleration of 0.2g.

TABLE V.2. COMPARISON OF MODELS FOR UNIT OF THE KOZLODUY NPP

Participant	Structural Model	SSI Model
BG Central Laboratory, Model 1	3D finite element	Time domain, soil springs and dampers
EQE Bulgaria/US, Model 2	Lumped mass stick	Frequency domain, three different SSI codes, SUPELM, CLASSI, SASSI
Siemens, Model 3	Lumped mass stick	Time domain, soil springs and dampers
Siemens, Model 4	Lumped mass stick	Frequency domain, SASSI

Results

Comparisons were made between the results obtained using Models 1 and 3 on the one hand and Models 2 and 4 on the other. The outcome was further compared and it was concluded that the most realistic results were obtained from Models 2 and 4 which utilize frequency dependent soil stiffness and damping.

There was good agreement between the results of Models 2 and 4, even based upon completely different geometrical models and calculated with different SSI computer codes.

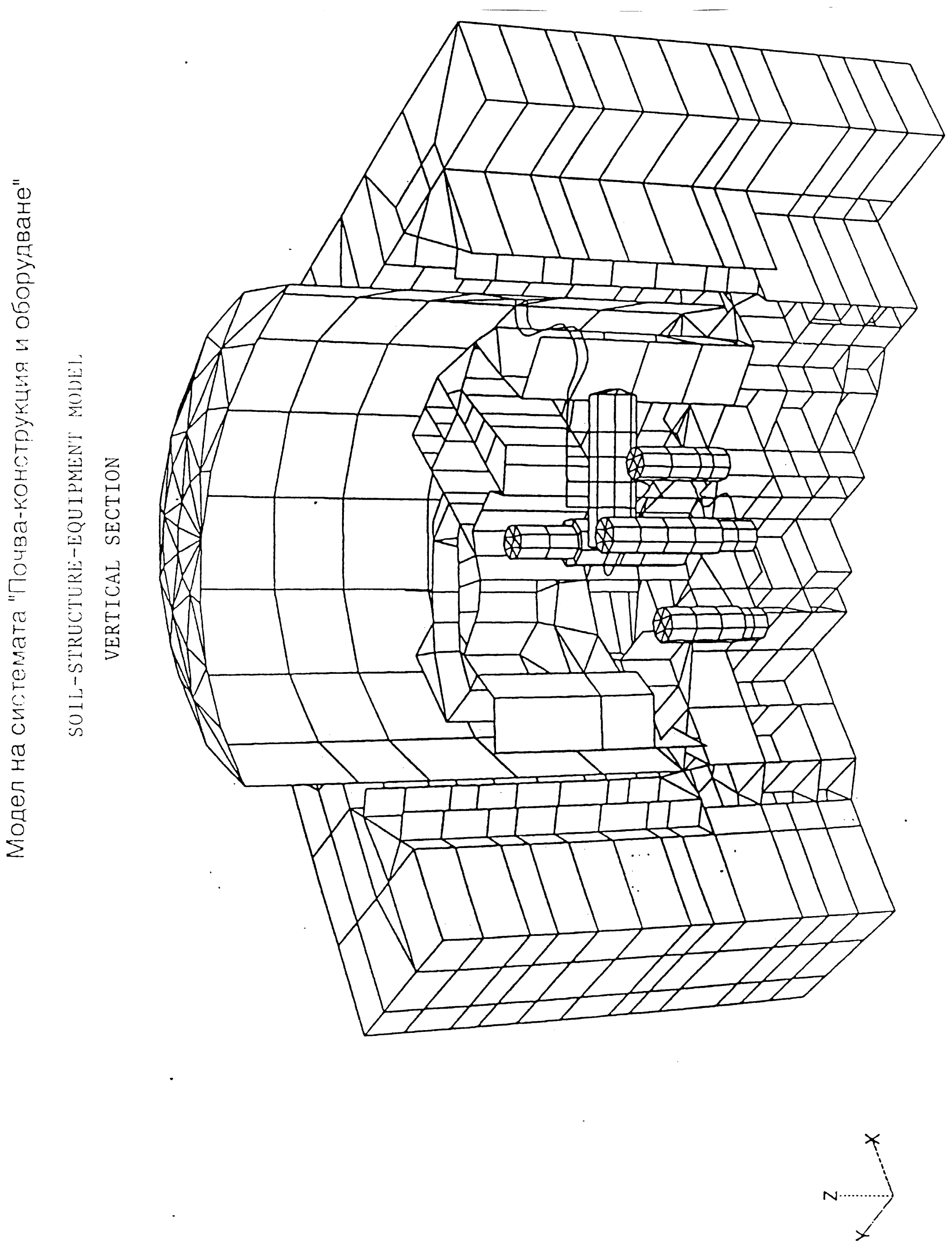


FIG. 5.1. Soil structure equipment model — vertical section.

The soil properties used in each of the models were slightly different and the differences in results can be partially attributed to this modelling difference.

The floor response spectra evaluated with deterministic and probabilistic input were compared and showed that no correlation is predictable between the results of the two approaches and therefore validating the double approach as a rule in structural design.

Soil liquefaction may be a problem in a sand layer at –5 m, when the spray pond is empty, for the re-evaluated level of the seismic excitation (0.2 g).

Applicability of results

Since good agreement was achieved between the two independent organizations using state-of-the-art frequency domain soil-structure interaction analysis software, the results should be directly applicable to the Kozloduy NPP for purposes of defining floor response spectra for evaluation and upgrading of systems and components.

Lessons learned

The application of the time domain integration method for soil structure interaction analysis yields in these cases more conservative results than frequency domain approaches. The comparison of the methodologies for liquefaction assessment has provided an evaluation of the reliability of the procedures (even between deterministic and probabilistic approaches), of their sensitivity to input data and to the specifications of boundary conditions (weight of water in the ponds, structures, etc.)

Conclusions and recommendations

Further analysis should be carried out for the generalization of the lessons learned to other soil-structure configurations.

A wider application of probabilistic methods, now affordable due to cheap hardware resources, should be encouraged as a basic tool for reliability evaluation in structural calculations.

Soil liquefaction hazard analysis should be refined and then finally assessed with the contribution of the coupled soil-structure interaction.

5.2. SHAKING TABLE EXPERIMENT FOR SELECTED COMPONENTS (TASK 9)

Objectives

The objective was to carry out tests of relays used in NPPs to determine their functionality during strong motion shaking. The tests should not be considered as fragility tests.

Summary of work done

Test were conducted on relays of the protective and auxiliary type for Unit 5 of Kozloduy NPP. Three samples of each relay were tested two new relays and one with prior usage. Two test response spectra were utilized.

A standard response spectrum test was carried out both in IEEE 501 and an envelope of the floor response spectra at node points 596 and 700 of the structural model no. 1 of Task 6a, corresponding to elevation 13.2 m (see Figs 3.2 and 3.3). The floor response spectrum had higher amplification in the lower frequency range than the standard test response spectrum. The ZPA of the envelope floor response spectrum was 0.25g.

Both tests were conducted on a bi-axial electro-hydraulic shaking table and conducted in each of two directions, i.e. (Horizontal +Vertical and Length +Vertical).

Test procedures conformed to IEEE 344, 1987. Tests were performed using the standard IEEE 501 response spectrum at levels of 0.5, 1.0, 1.5, 2.0 and 4.0 times the zpa of the floor response spectrum (4.0 × 0.25g = 1.0g ZPA max test level). Additional tests were performed using the envelope floor response spectrum factored by 0.5, 1.0 and 1.5 (1.5g × 0.25g = 0.375g maximum). Tests were performed for open and closed contacts. A total of 36 tests were conducted.

Results

All relays tested performed satisfactorily.

Applicability of results

Results for the relays tested can be used for application in all the NPPs where they are mounted.

Lessons learned

The test performed demonstrated the seismic adequacy of these relays for a cabinet amplification of 4.0. The use of an envelope floor response spectrum to assure low frequency input up to 1.5 times the floor response provides a factor of conservatism in the low frequency range.

Conclusions and recommendations

There are many more types of relays in the plant which should ultimately be tested to verify their performance for the currently specified 0.2 g SL2 earthquake, as any generalization about functionality is impossible for such kind of equipment.

5.3. ON-SITE TESTING OF EQUIPMENT AT PAKS AND KOZLODUY NPPs (TASK 10)

Objectives

The objective was to establish the dynamic characteristics of various items of equipment located in the NPPs with direct excitation and to set up reliable procedures for the assessment of their seismic capacity.

Summary of work done

Nine on site tests were carried out, five for the diesel generator system (heat exchanger, jalousie, axial ventilator in Paks) in 1997, three for the reactor coolant system in 1994 at Paks, and eight for the fire protection station and diesel generator station in 1995.

The tests were conducted by exciting the equipment with a shock.

Transducers mounted on the equipment measured the response.

Natural frequencies and damping were determined from the tests.

Subsequent numerical analyses were carried out to determine the seismic capacity, using the floor response spectra from numerical analyses at 0.35g for the Paks NPP and at 0.2g for the Kozloduy NPP. A large collection of data from testing on different WWER components (Kozloduy, Zaporozhskaya, Medsamor, Bohunice, Rostovskaya, Paks) (Fig. 5.2) has been organized and discussed, together with the capacity analysis and backfitting solution.

Results

Results are summarized in Table V.3.

Lessons learned

The testing and analysis results confirmed the seismic experience data. On site testing procedures have shown their particular importance for the proper evaluation of transfer functions from the base to the very sensitive electrical equipment.

TABLE V.3. RESULTS OF ON SITE SHOCK TESTS

Equipment item	Frequency, Hz	Damping %	Analysis results
DG Heat Exchanger (Paks)	x=7 (6 full) y=9.7 (8.2 full)		OK
DG Jalousie (Paks)	x=28.5 y=50		OK
Axial Ventilator (Paks)	x=11 y=10 z=24		OK
DG Cooling Water Tank	18	2.1	OK
DG Lubrication Oil Heat Exchanger	10	0.8	OK
DG Compressed Air Tank	12	2.9	OK
DG Oil Filter	x=6.2 y=9.1	x=1.7 y=5.8	OK
DG Reserve Oil Tank	16.9		OK
Reserve Water Tank	x=24 y=32	x=5.5 y=4.6	OK
Fire Pump	60	4.4	OK
Pump Slide Valve (Manual Valve)	30	5.3	OK
Pump Slide Valve (Motor Operator)	17.5	2.9	OK
(Valve Body)	50	5.5	OK

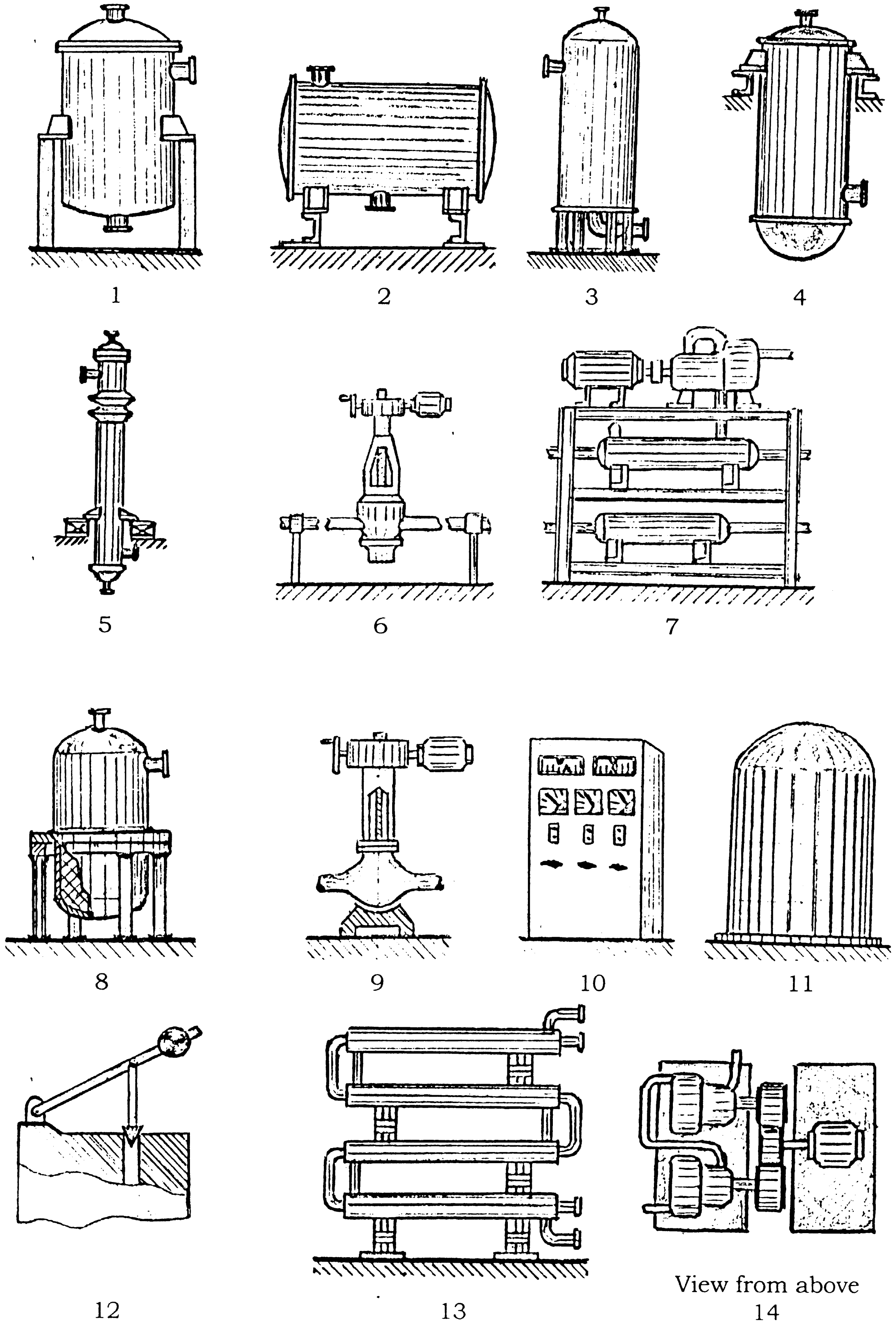


FIG. 5.2. Simplified forms of different types of seismically instable equipment.

Conclusions and recommendations

Proper methodologies should be developed for the evaluation of specific transfer functions from the excitation base to the electrical equipment of interest, and an attempt should be made to generalize the results of the experiments. In addition experimental data should be organized in accessible databases for further seismic capacity evaluations.

5.4. ASSESSMENT OF CONTAINMENT PRESTRESSING FOR DIFFERENT LOADING COMBINATIONS (TASKS 14 AND 15)

Objectives

To assess the structural effects of the degradation of tendons in the Kozloduy NPP containment.

Summary of work done

Management of the Kozloduy NPP co-ordinated a testing programme in order to assess the actual pre-stressing force inside the tendons and the actual maximum force which the tendon can withstand.

Tendons appear less tensioned than the nominal values (10 000 kN) and therefore the analysis had to clarify the consequences on the final capacity of the containment. The response of the containment has been evaluated by means of numerical models based upon the following properties.

Material properties

- Concrete M40: Rbn=29Mpa (compression), Rb=22Mpa (compression), Rbtn=2.1 Mpa (tension), Rbt=1.4 Mpa (tension).
- Steel (vertical and horizontal steel bars) class AIII: Rsn=410 Mpa, Rs=375Mpa, Es=210000 Mpa.
- Pre-stressing steel class BII (diam. 5 mm): Rsn=1360 Mpa, Rs=1100 Mpa.
- Bearing capacity of cables (450 diam. 5mm) Rsn=14000KN, Rs=10000 KN.
- Yield limit for cables R01=0.61 Rsn in installed cables.
- Yield limit for cables R02=0.7 Rsn in installed cables.

In the initial pre-stressing of the tendons, the design load of 10 000 kN could not be reached in some cases due to rupture of tendon wires and failure of threads in the anchor blocks.

Reference loads (according to IAEA SG–D15 and Bulgarian code)

- Crane dead load = 600 t.
- Crane live load = 700 t (comb. factor = 0.3, only vertical).
- Snow load = 0.7 KN/mq (comb. factor = 0.8).
- Wind load (ref. at 10m from ground) = 0.48 KN/mq (comb. factor = 0.3).
- Accident load, pressure = 50t/mq in 1 hour, temperature = 150°C internal for 10 hours (-30°C external).

- Prestressing load reduced according to Bulgarian standards for temperature, creep, shrinkage, relaxation effects.

EQE performed a detailed finite element analysis of the containment on a 3D shell model with degraded prestress (Fig. 5.3) (SAP90 code). A second 3D model coupled a stick for internals and a shell structure for the containment, aimed at the non-linear static and dynamic response evaluation (COSMOS code).

The numerical simulation clarified the effects of a lower prestressing force (8500–9000 KN per cable, instead of the nominal 10 000 KN) and a cable rupture (Fig. 5.3).

No details were provided, unfortunately, on the capability of the containment to withstand the LOCA pressure with such a reduced prestressing load.

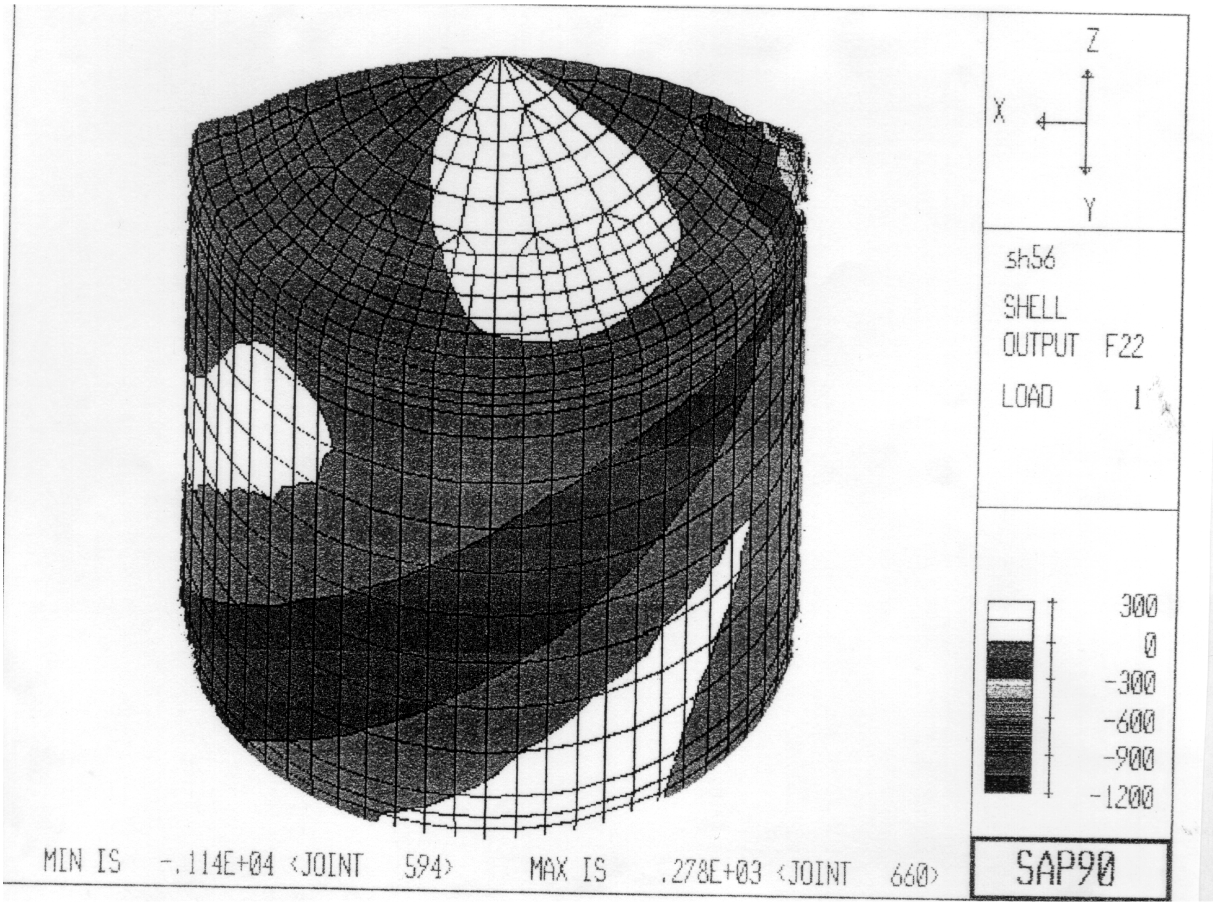


FIG. 5.3. Diagram of longitudinal forces at the containment due to pre-stressing cable break.

Furthermore, based on Fig. 5.4 it was clear that a large discrepancy between experimental and numerical results still exists, which calls for a detailed numerical-experimental campaign to resolve the open issue.

Stuessi and partners performed a design analysis for the containment with load combinations provided by the Bulgarian Academy of Sciences.

Some local overstressing of the concrete in tension was noted only for seismic loading and for the load combination of dead load + pressure + temperature + OBE seismic.

The management of the Kozloduy NPP indicated that tendons taken from the NPP were tested in order to evaluate the true failure limit.

In general, the wire properties of tendons which were new and tendons which contained ruptured wires were similar. However, it was found that there is a significant reduction in yield strength and elastic modulus when the wires are wound tightly. The principal reason given for wire rupture during tensioning is the increase in wire stress at the joints due to the friction created by the bearing loads.

Results

It has been shown that there is overstress in the concrete containment due to the degraded tendons and the increased earthquake loading.

Replacement of degraded tendons and redesign of the anchorage are recommended.

Applicability of results

This problem is generic to WWER-1000 containments. The results and recommendations are applicable to other WWERs of the same unified design.

Lessons learned

The manufacturing process and the design of the anchorage was shown to be critical to the ability of the tendons to be properly prestressed without rupture. The testing and analysis has identified the generic problem for WWER-1000 containments.

Conclusions and recommendations

Based on the studies performed, the following conclusions and recommendations can be made:

1. Tendons are subject to wire rupture at the design preload due to the tight curvature of the anchorage and due to the winding process.
2. It is recommended to replace all degraded tendons.
3. It is recommended to redesign the anchor heads.
4. It is recommended to evaluate the installation of an on-line tendon force monitoring system.

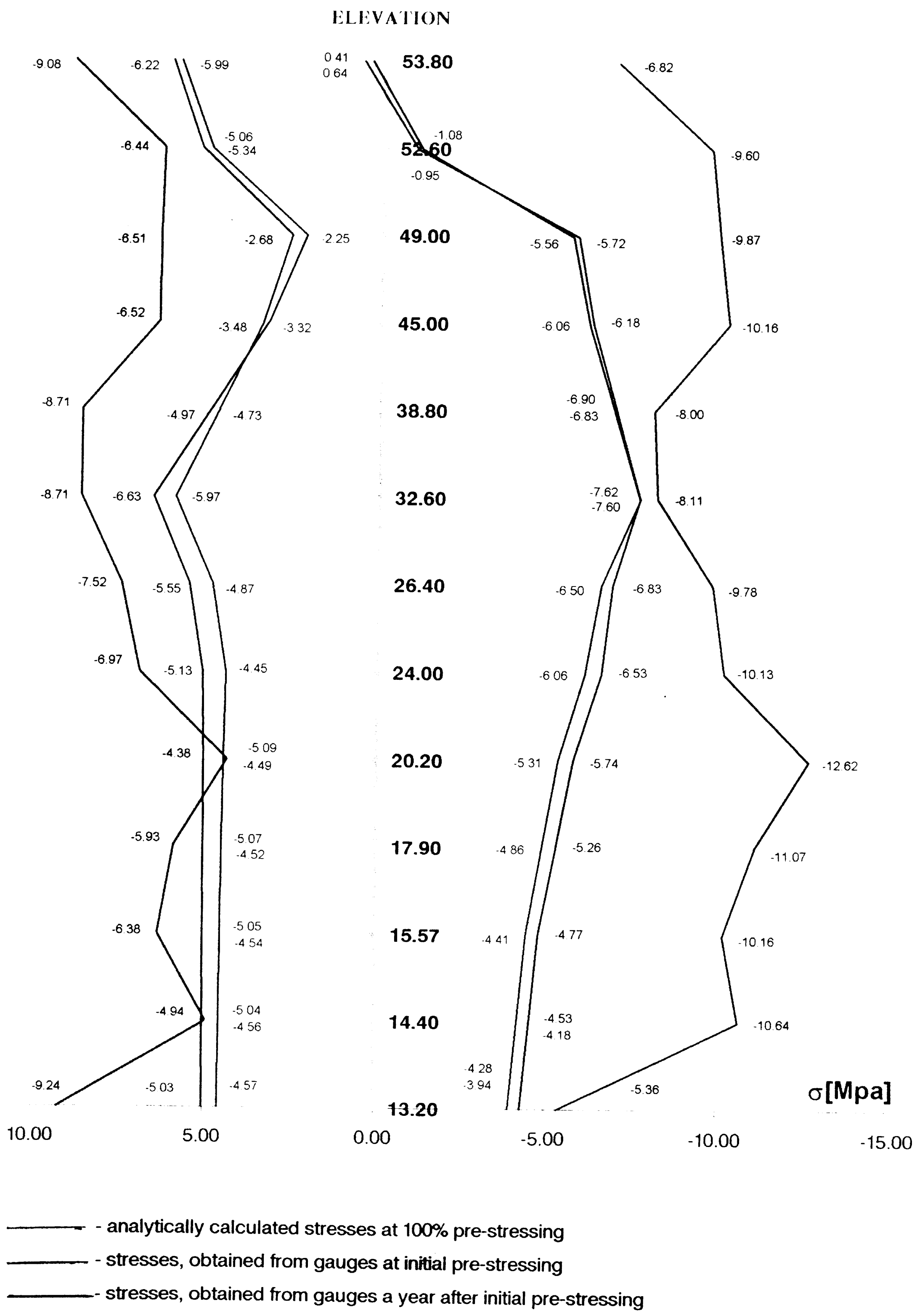


FIG. 5.4. Diagrams showing longitudinal stresses in the concrete of the cylindrical shell at the inner and outer surfaces due to prestressing.

5.5. STRESS ANALYSIS FOR SAFETY RELATED PIPING AT THE KOZLODUY NPP (TASK 16)

Objectives

To evaluate the seismic response of safety related piping and supports for increased seismic loads. This task included the analysis of the Kozloduy primary system and the main steam lines.

Summary of work done

The primary system was analysed by Siemens and Stuessi and Partners.

The main piping lines and their supports (130 altogether) were analyzed by Stuessi and Partners applying the floor response spectra calculated by Siemens at 0.2g zpa; the supports were evaluated by the Bulgarian Building Research Institute via inspection and/or welding analysis (Fig. 5.5).

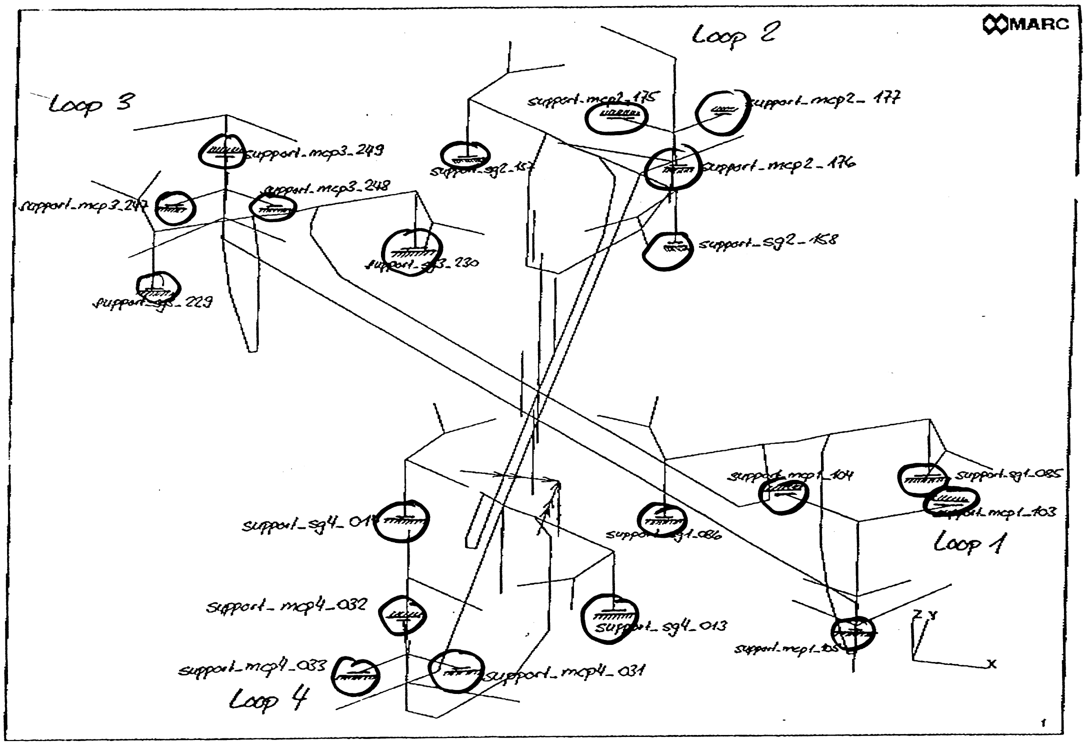


FIG. 5.5. Main loop piping — definition of supports

The main steam line was analysed by Woelfel. Analysis included local nozzles and shell stresses in the steam generator using Welding Research Council methods and a 3D finite element analysis of a tee in the steam collector.

The Siemens analysis of the primary system was a coupled analysis with the primary system modelled into a 3D finite element model of the reactor/auxiliary building.

A by-product of this analysis were spectra that can be used for conducting uncoupled analysis at other plants.

Other lines were analysed as uncoupled models using spectra from the Siemens analysis.

Results

The main coolant line and main steam line were found to be within allowable stresses. For most other piping, stresses were shown to be within the allowable limits of the ASME code. Only four lines were found to have stresses exceeding the code.

Upgrades for these lines by addition of supports were recommended.

Support devices in the primary loop and most piping supports in all of the lines analysed were found to be adequate.

A few fixed supports were found to be overloaded and replacement was recommended.

Applicability of results

These results are directly applicable to Unit 5 at Kozloduy and presumably to Unit 6. Depending upon the detail, the results are likely to be applicable to other WWER-1000s.

Lessons learned

The upgrading of the seismic level requires a general review of the piping stress level.

Conclusions and recommendations

Most piping and supports evaluated were found to be acceptable. Some were found to be overstressed and should be fixed.

Recommendations were made for the repairs which may be adopted, especially for withstanding seismic loads.

5.6. DYNAMIC ANALYSIS OF SELECTED STRUCTURES OF THE KOZLODUY NPP (TASK 17)

Objectives

To evaluate the capability of the stack to survive an SL2 earthquake and not fall on a safety related structure (the stack itself is not a safety related structure).

To evaluate the seismic capacity of the diesel generator building.

Summary of work done

Seismic analyses of the stack were conducted by Stuessi and Partners in co-operation with BRI; the diesel generator building was analyzed by BRI. The stack was evaluated for wind load (static (P=0.48 KN/mq) and dynamic effects), live load on the platform (2KN/mq), combined with SL1 (0.1g) earthquake and for an SL2 (0.2g) earthquake load.

The diesel generator building was modelled using a 2D and 3D finite element model (Fig. 5.6), also representing the crane load and the underground oil reservoirs connected with thick pipes to the elevation part. Soil-structure interaction was modelled both by soil springs and as finite elements.

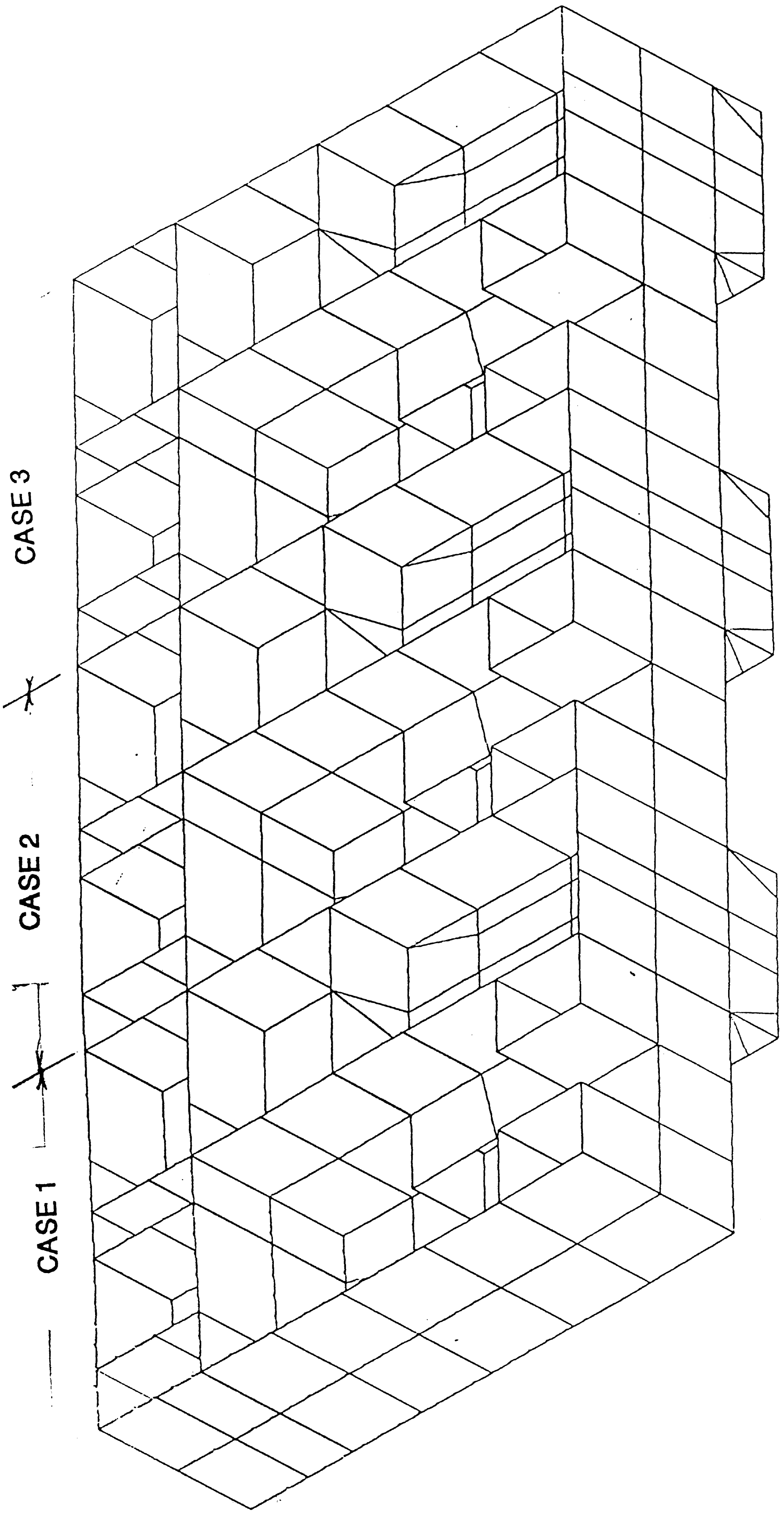


FIG. 5.6. 3D model of diesel generator building.

Results

The upper truss bars of the stack were found to be overstressed by a factor of 1.6 for the SL2 earthquake. If buckling occurs, the stack itself might buckle and fall.

The diesel generator building was found to have a structural safety margin of the order of 3 to 4 due to the fact that it was originally designed for blast loads.

Applicability of results

The results are directly applicable to Kozloduy Units 5 and 6 and to other WWERs featuring similar designs of the ventilation stack and diesel generator buildings.

Lessons learned

It was found that for the diesel generator building the protection from blast loading resulted in a robust structure capable of resisting the SL2 earthquake loading. In the case of the stack, its design is governed by earthquake rather than wind considerations.

Conclusions and recommendations

With respect to the stack, it is recommended that before initiating extensive upgrades, more refined non-linear analysis should be carried out in order to review the results of the above cited studies, even in connection with the experimental results from the blast test.

5.7. ANALYSIS OF BURIED PIPELINES FOR THE KOZLODUY NPP (TASK 20)

(see corresponding item for Paks NPP in Chapter 4.)

5.8. EVALUATION OF POTENTIAL HAZARD OF WWER-440 AND WWER-1000 REACTOR OPERATING CONTROL ROD AND DRIVE SYSTEM (TASK 26)

(see corresponding item for Paks NPP in Chapter 4.)

Chapter 6

BENCHMARKING EXERCISES — PAKS NPP AND KOZLODUY NPP

TABLE VI.1.

Task	Title	Participants	Tecdoc Chapter	WM volume
7	Dynamic analysis of Paks NPP structures (benchmarking with results of Task 8)	**ISMES**	6	3, 4
7a	Reactor building	**SIEMENS** ISMES CL MD EQE-US IVO	6	3, 4
7b	Stack	IZIIS SAGE	6	3, 4
8a	Full scale blast testing of Paks NPP	**ISMES** PNPP	6	3, 4
8b	Full scale blast testing of Kozloduy NPP Unit 5	**ISMES** KNPP	6	3, 4
21	Comparison of beam vs 3D models for Kozloduy NPP and Paks NPP structures	MD EQE-BG	6	3, 4
22	Experience database (WWER SQUG) initiation	S&A-US S&A-CZ S&A-RO EQE-US PNPP KNPP	7	5
23	Consolidation of results and reports	ISMES S&A-CZ EQE-US	/	/
24	Dynamic analysis of Kozloduy NPP Unit 5 structures (benchmarking with results of Task 8)	SIEMENS ISMES CL MD EQE-US IVO	6	3, 4
25	Comparison of blast and vibrator tests for Kozloduy NPP	ISMES IZIIS	6	3, 4

6.1. GENERAL INTRODUCTION

Chapter 6 deals with a large research programme, an important subset of the CRP activities aimed at the analysis of the dynamic response of Paks (WWER-440/213) and Kozloduy (WWER-1000) reactor buildings via experimental and numerical methods.

This special activity also generated general feedback on structural dynamics research by providing valuable evidence on the reliability of the numerical methods currently applied by the engineering community. This resulted in a set of recommendations to structural analysts as well as managers of seismic upgrading actions in different NPPs.

In December 1994 at Paks and July 1996 at Kozloduy the IAEA organized two full scale dynamic tests as the basis for a blind prediction exercise. The three phases of this exercise consisted in:

(1) two experimental campaigns, in connection with the two blast experiments on the reactor buildings, carried out by an independent organizations, with expertise in experimental testing;

(2) numerical prediction (i.e. benchmarking) of the dynamic structural response of the buildings wired with instruments for this purpose and subjected to the free field input spectrum **measured in phase 1**; numerical prediction was carried out by the five organizations with expertise in numerical simulations;

(3) comparison between experimental and numerical results, performed **only at the end** of both experimental and numerical activities.

This chapter addresses the contributions to the benchmark and to data recording activities performed on the occasion of the blast test, with the aim of presenting the different approaches selected by the participants and a final synthesis of the results. These results may prove useful for the international scientific community.

An additional contribution to the evaluation of the results is discussed at the end of the chapter dealing with a vibration test carried out by IZIIS at the Kozloduy NPP, which gave the opportunity to assess the methodology involved with an independent but limited programme.

Indeed many other experimental activities and numerical simulations have been carried out in the framework of the CRP: they are available in Volumes 3 (Paks) and 4 (Kozloduy) of the Background Documents respectively, and are not part of the benchmark, though many of their aspects can be integrated very usefully into the benchmark conclusions.

The organization of the tasks in the CRP reflects the time sequence of their implementation and not necessarily their relationships; Table VI.2 is provided for a general orientation in the background documents.

In the sections which follow, the activities have been grouped according to Table VI.2 and the particulars of the general grid.

Paks and Kozloduy activities have been collected in two subsections of the same chapter, because of the strong similarities between them and to allow an easy comparison of the results.

TABLE VI.2.

Experimental test	Participants	Numerical simulations	Participants
Task 8a (Paks)	ISMES (reactor bldg. monitoring) Paks NPP (component monitoring)	Task 7a (reactor bldg.)	Central Lab. Sofia David Int. EQE Int. IVO Int. Siemens
		Task 7b (stacks)	SAGE IZIIS
		Task 7 (result comparison)	ISMES
Task 8b (Kozloduy)	ISMES (reactor bldg. monitoring) Kozloduy NPP (reactor, diesel bldg and equipment monitoring)	Task 24 (analyses)	Central Lab. Sofia David Int. EQE Int. IVO Int. Siemens
		Task 24 (result comparison)	ISMES
Task 25 (Kozloduy)	IZIIS ISMES	Task 25 (analysis and result comparison)	IZIIS

6.2. FULL SCALE BLAST TESTING OF PAKS AND KOZLODUY NPPs

Objectives

1. To experimentally evaluate the structural dynamic response of the reactor building, diesel generation building (Kozloduy) and the stacks (in operating conditions) when subjected to a forced dynamic excitation applied to the soil.

2. To experimentally evaluate the induced vibration and therefore to tune the local seismological networks.

3. To measure the wave propagation in the field and therefore to check the local seismological networks.

Summary of work done

Activities related to the Paks site

Five experiments have been carried out with different arrangements of the explosive charge; one of them selected for the (i.e. blind prediction) purposes of the benchmark.

Three TNT charges (100 kg each) were ignited in six boreholes, at a depth of 50 m with a delay of 1.58 s, at 2440 m to the South-South-east of the axis of the reactor of Unit 1 (Figs 6.1 and 6.2).

Data were recorded at 200 Hz (velocity components) and appropriately filtered (20 Hz analogue low pass) in 200 channels: only the channels related to the following locations were selected for the benchmark purposes (Figs 6.3 and 6.4):

- one seismometric station (three components) at a depth of 1.1 m and a distance of 119 m from the reactor basemat (assumed as free field)
- seven seismometers on the foundation mat
- six seismometers on the upper reactor building
- three seismometers on the stacks.

Data have been further collected, processed and presented in the format of acceleration spectra in the range of 0 to 10 Hz for two values of damping (2 and 5%).

Activities related to the Kozloduy site

Two experiments were carried out with different arrangements of the explosive charge; one was selected for the benchmark. Two TNT charges (150 kg each) were ignited in two boreholes, at a depth of 50 m run in with a delay of 1.82 s, at 2316 m containment axis of Unit 5 (Figs 6.5 and 6.6).

Data were recorded at 200 Hz (velocity components) and appropriately filtered (20 Hz analogue low pass) in 52 channels: only the following locations were selected for the benchmark (Figs 6.7 and 6.8):

- one seismometric station (three components) at a distance of 139 m from the reactor axis and a depth of 1.1 m (assumed as free field)
- three seismometers on the foundation mat
- three seismometers at elevation 13.2;
- nine seismometers on the upper reactor building, from elevation 61 up to the top of the dome;
- six seismometers on the stacks (attachment to the dome and top)

Data were further collected, processed and presented in the format of acceleration spectra in the range 0–10 Hz for two values of damping (2 and 5%).

Furthermore, four accelerographs (SMA2 and SMA1) were installed in the field and some accelerometers were installed in the following locations of the diesel generator buildings:

- five on the foundation slab (support of the electric pump and diesel generator);
- three at elevation 4.2 m (water pump location);
- four on the roof.

Data were recorded at 200 Hz (acceleration components) and processed in order to derive power spectral densities.

Results

Paks site

The maximum acceleration value input in the soil (assumed as free field) was 0.06 m/s^2 (both horizontal directions) and 0.16 m/s^2 (vertical direction). Figure 6.9 shows the time history for the components of the free field input.

The FFT of the free field signal has shown a wave amplitude distribution clustered at 2–4 and 10–14 Hz, with major amplitudes in the low frequency range, relevant to the low frequency induced by the combination of the three blasts (and more representative of a seismic excitation) and the high frequency range induced by the single blasts, respectively.

Further analyses extended to the signals recorded on the structures have shown the mutual independence of the two wave trains.

Kozloduy site

The maximum acceleration value input in the soil (assumed as free field) was 0.06 m/s^2 (both horizontal directions) and 0.15 m/s^2 (vertical direction). Figure 6.10 shows the time history for the three components of the free field input.

The FFT of the free field signal has shown a wave amplitude distribution clustered at 2–4 and 10–14 Hz, with major amplitudes in the low frequency range, relevant to the low frequency induced by the combination of the two blasts (and more representative of a seismic excitation) and to the high frequency range induced by the single blasts, respectively. Further analyses extended to the signals recorded on the structures, have shown the mutual independence of the two wave trains.

With reference to the diesel generator building, a comparison was carried out with ambient data recorded before the blast test: the cross correlation between the two phases has been shown to agree well with the response amplification at 10–12 Hz and the natural frequencies of the whole building evaluated with the ambient excitation.

Finally, the comparison between experimental geophysical data recorded by the accelerographs and the wave field predicted by attenuation theory have confirmed the reliability of the local network.

Applicability of the results

Even if related to very different soil properties and structural layout, the results recorded are representative of the coupled soil–structure response of similar reactors and of the wave propagation patterns at sites with large buildings and similar general properties.

Lessons learned

A proper delay between blasts can actually generate a low frequency range similar to a seismic record. However, the results presented stem from a blast excitation in the soil which has some unavoidable differences with a typical seismic excitation:

1. the amplitude (a trip of the operating reactors must be avoided)
2. the frequency content and distribution in the time record
3. the ratio between horizontal and vertical components (inverted with respect to a typical seismic record)
4. the kind of waves generated: mainly P-type instead of S-type, and originating in a superficial source.

Nevertheless, there are good reasons to apply full scale tests in seismic re-evaluation:

1. they allow a proper evaluation of the transfer function (at low strain) between input signal and coupled soil-structure model, as it involves many variables usually not explicitly considered in numerical analysis: scattering in soil properties, interface between soil and foundation, presence of adjacent buildings, etc.

2. they provide a global confirmation of the reliability of available data (geotechnical, geophysical, structural) in existing plants where diagnostic campaigns are often no longer available and data are affected by ageing

3. they provide a reliable global evaluation of the structural response in the low frequency range, usually the most critical for these structures, where the "soil deformation" modes are dominant over the structural ones (i.e. the presence of high frequencies does not modify the global response).

Such explosive tests can therefore provide useful validation for the numerical models applied in seismic design. The artificial noise, always recorded in the high frequency range of the signal, is related to the hardware and it can be easily filtered.

Conclusions and recommendations

The blast tests at the Paks and Kozloduy NPPs have been successfully carried out and have generated recorded data suitable for further processing and comparisons. The blast tests have been recognized as the site testing technique most suitable which is currently available for the analysis of the dynamic response of complex structures: this technique can provide information to numerical analysts on how to improve their codes and to the managements of utilities on the reliability and conservativeness of the numerical simulations used as a basis for backfitting actions.

Text cont. on p. 91.

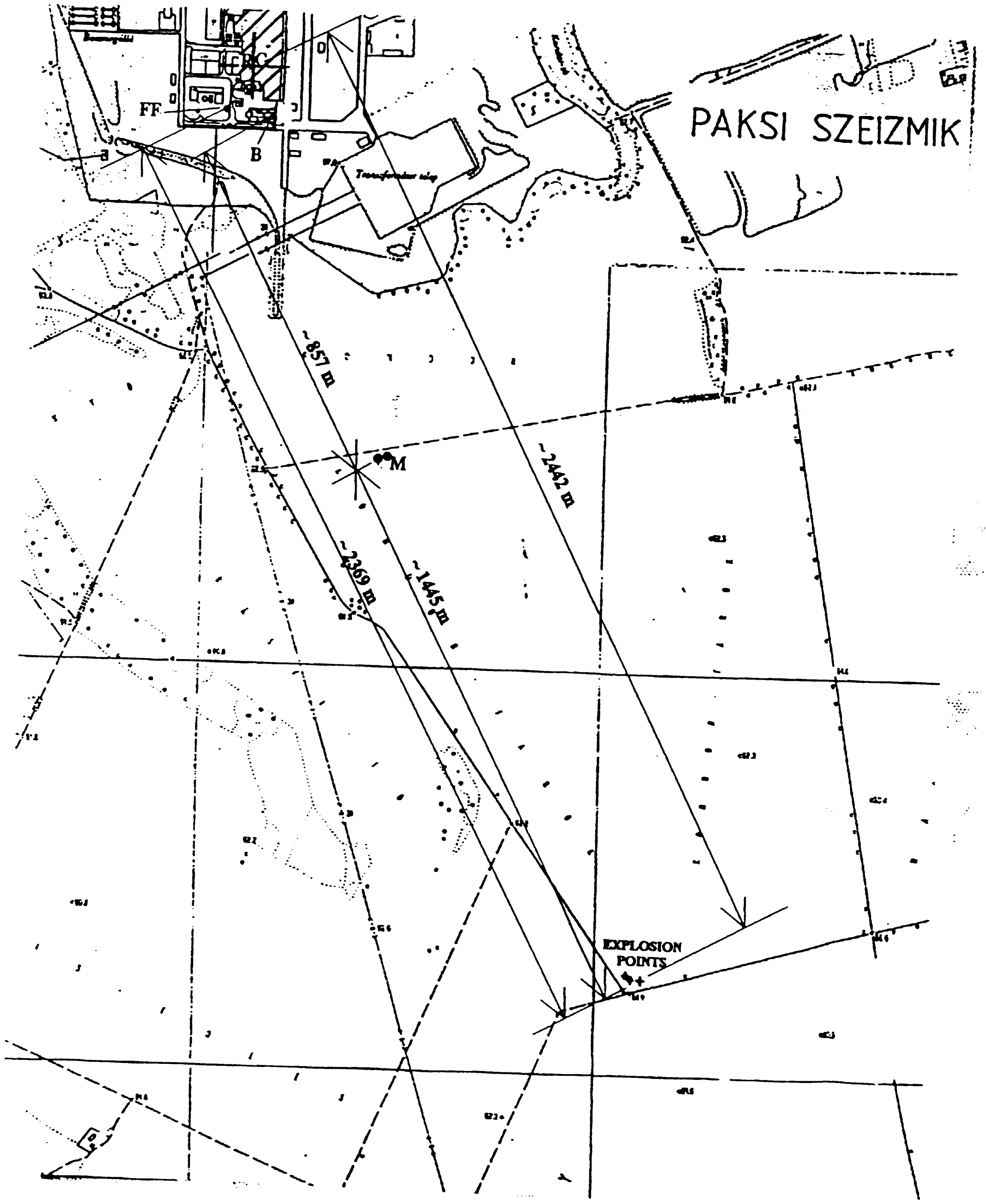


FIG. 6.1. General layout of the earthquake simulation experiments at the Paks NPP site.

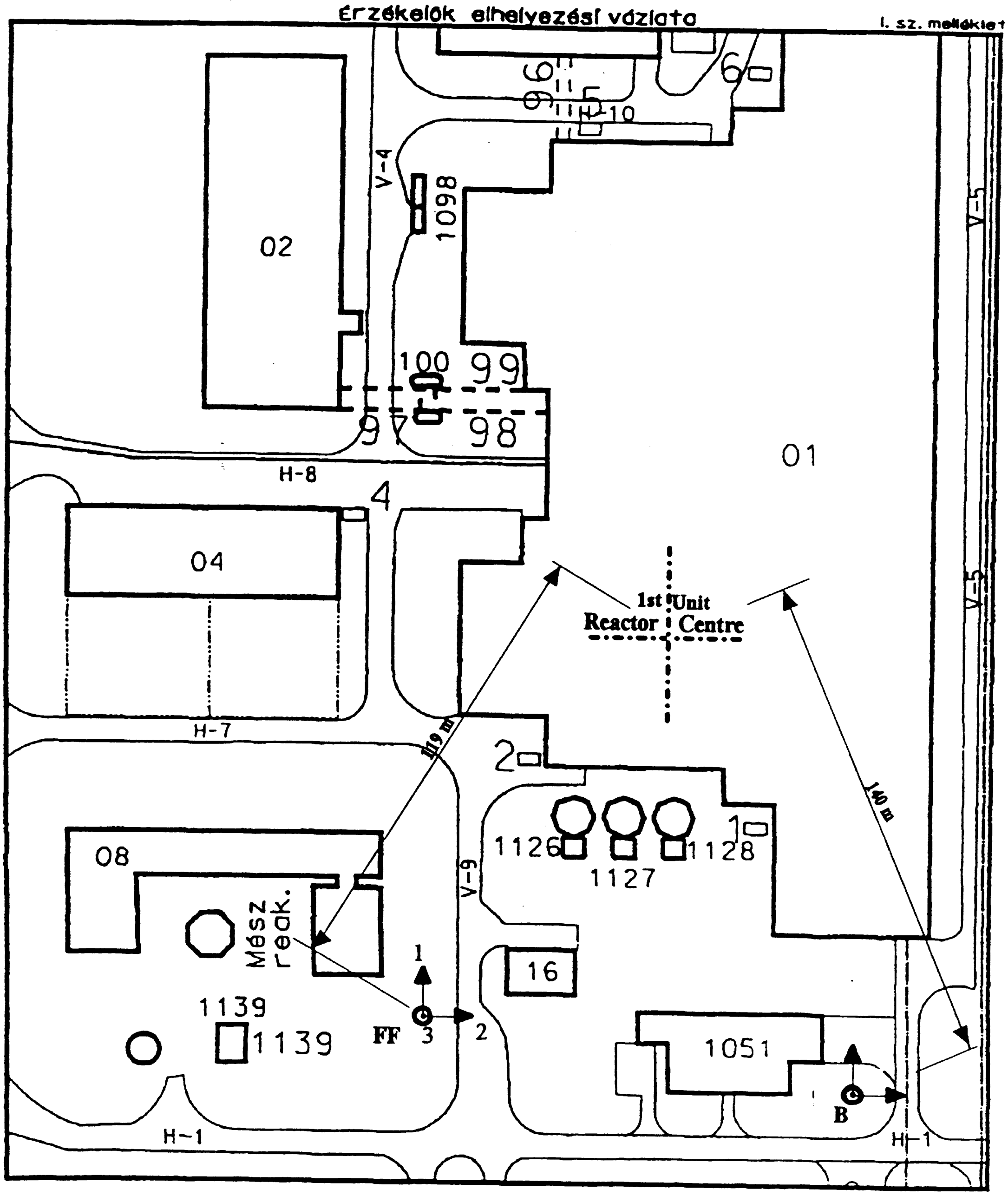


FIG. 6.2. Free field and first geophysical measurement stations installed at the Paks NPP Site.

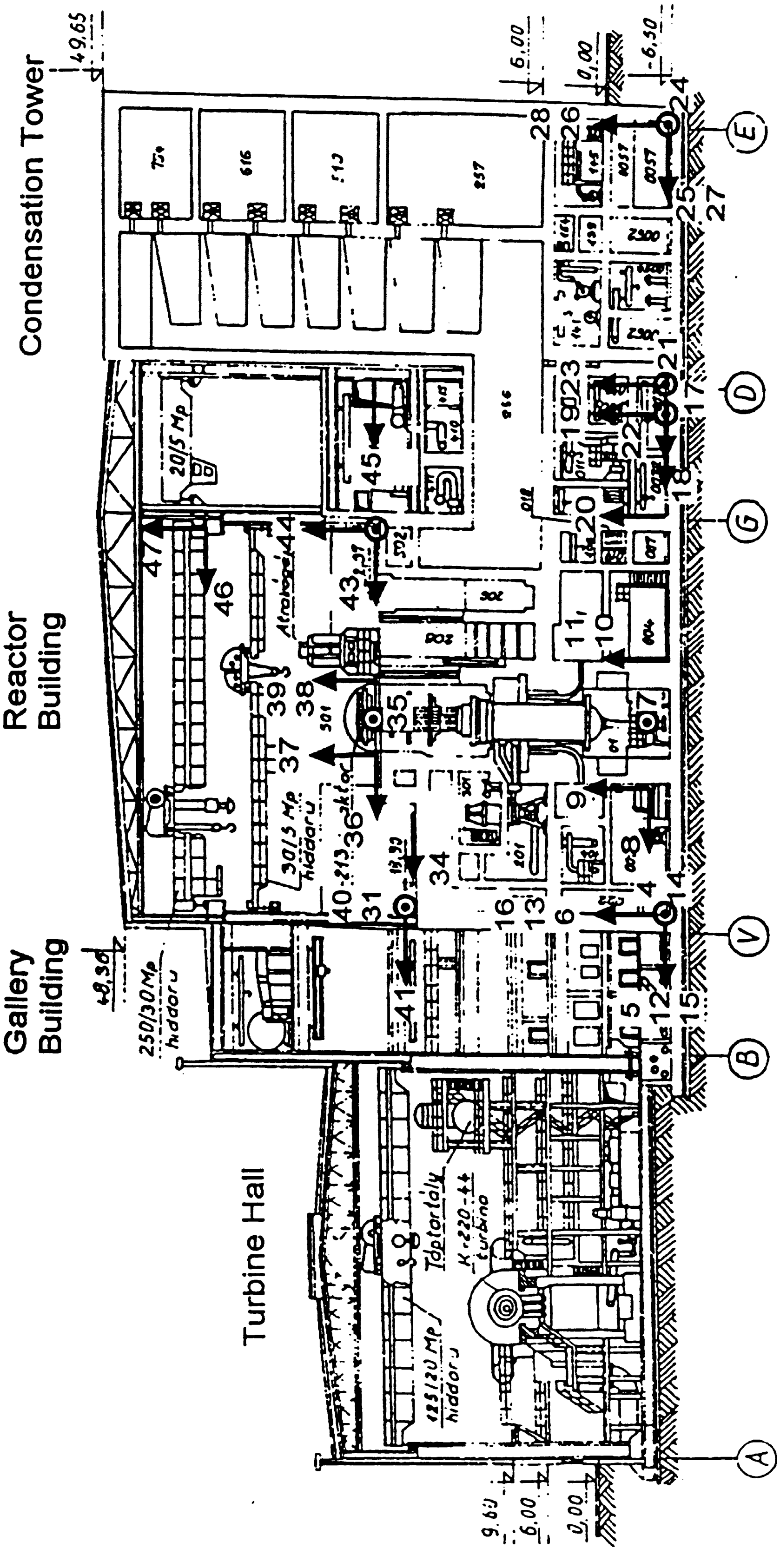


FIG. 6.3. Instrumentation layout for the first experiment at Paks NPP — transverse cross-section view.

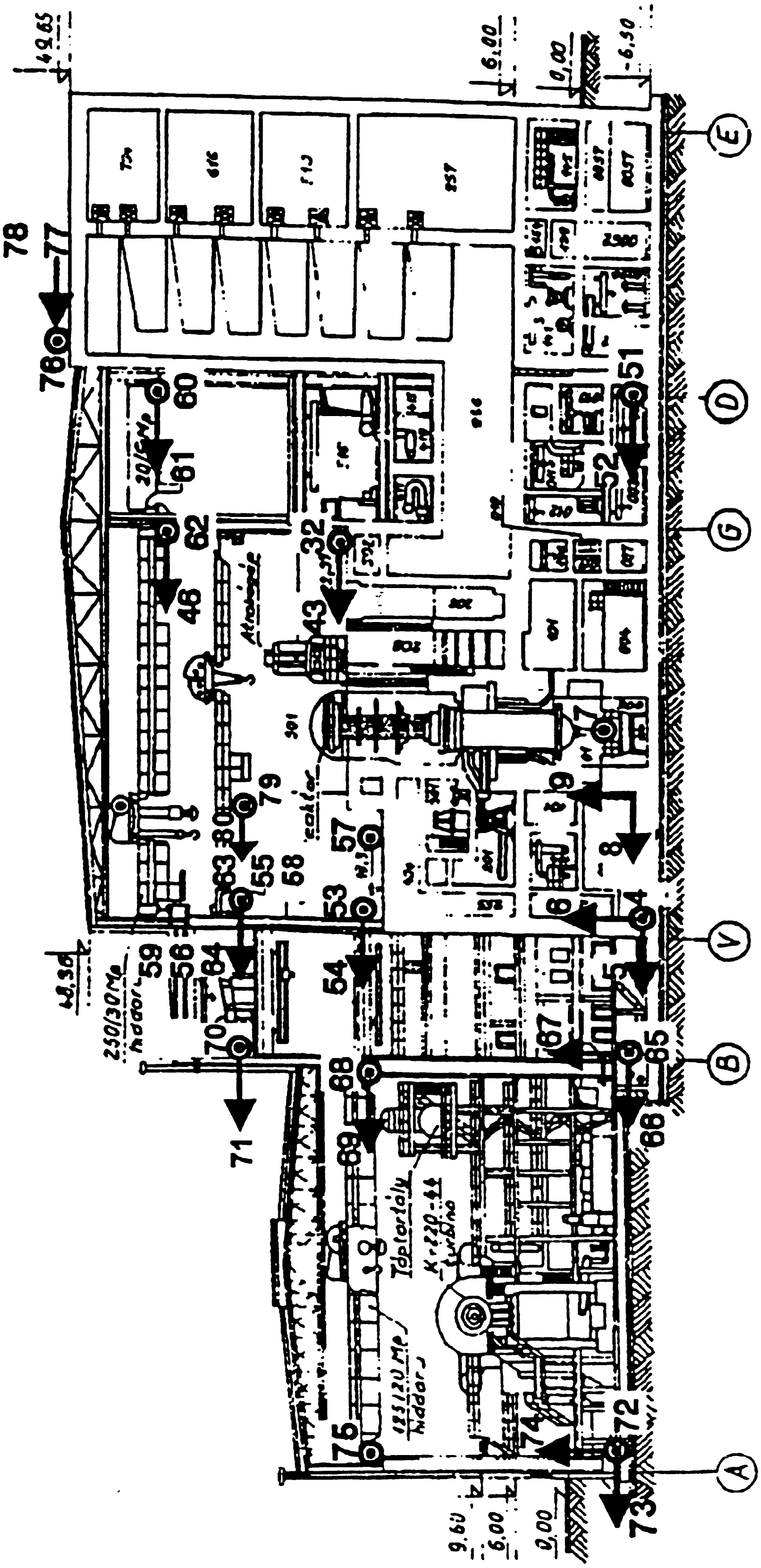
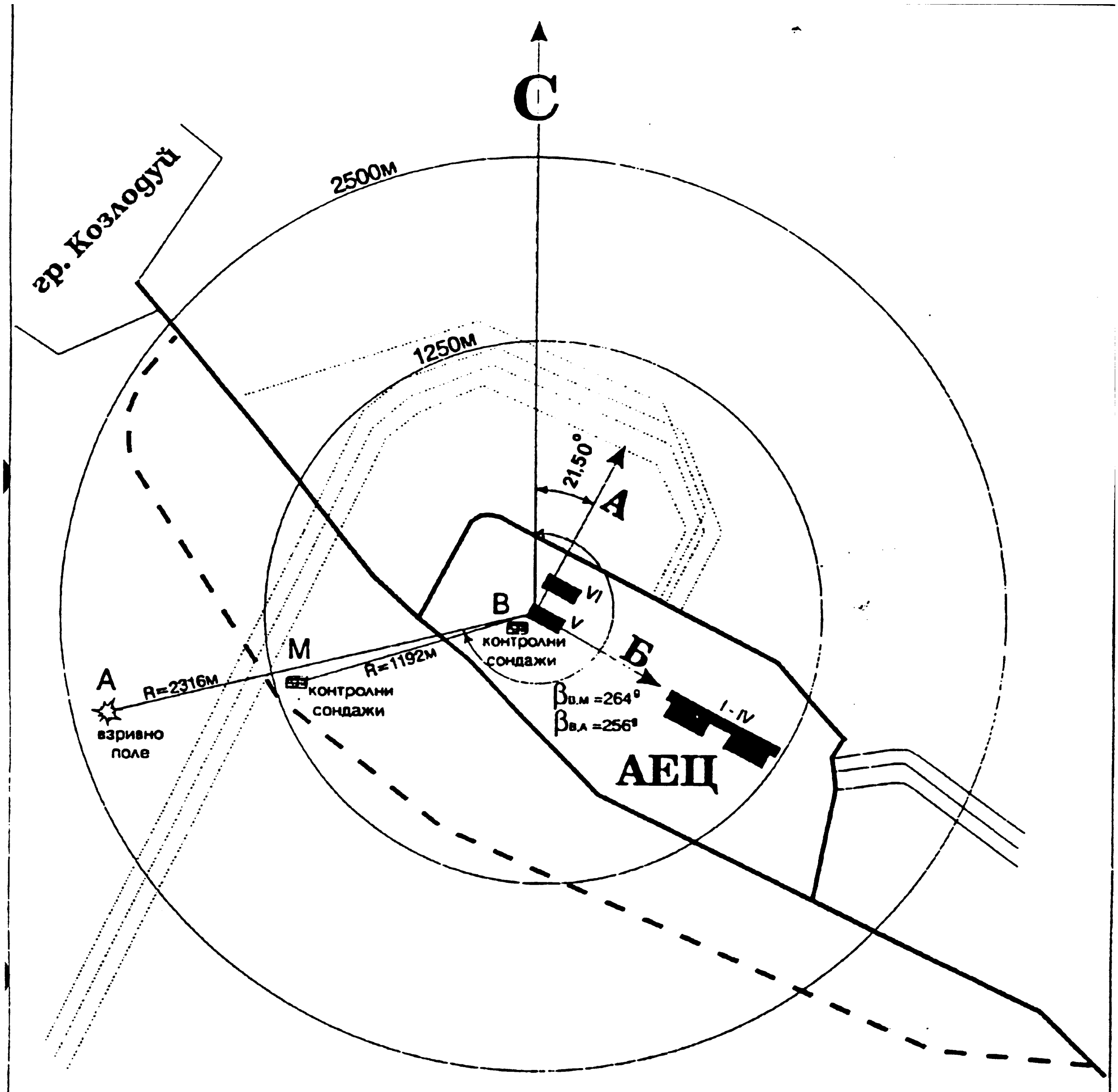


FIG. 6.4. Instrumentation layout for the second experiment at Paks NPP — main reactor building (1^{st} Block) — transverse cross-section view.



Точка	А	Б	Н
А	-388.49	-1832.59	57.09
М	127.88	-822.42	47.48
В	834.10	78.10	35.00

НЕК - АД, клон "АЕЦ - Козлодуй"			No XTC - 97
Обект: АЕЦ - Козлодуй			25.06.1996 г.
Проект: "BENCHMARK" - IAEA Пълномащабни динамични изпитания на блок V	Длъжност	Име	Подпис
	Н-к цех ХТС и СК	М. Миланов	
Схема за разположение на взривното поле и контролните сондажи	Риск Инженеринг	М. Костов	
	ISMES	M. Da Rin	

FIG. 6.5. General layout of the ground excitation experiments at the Kozloduy NPP site.

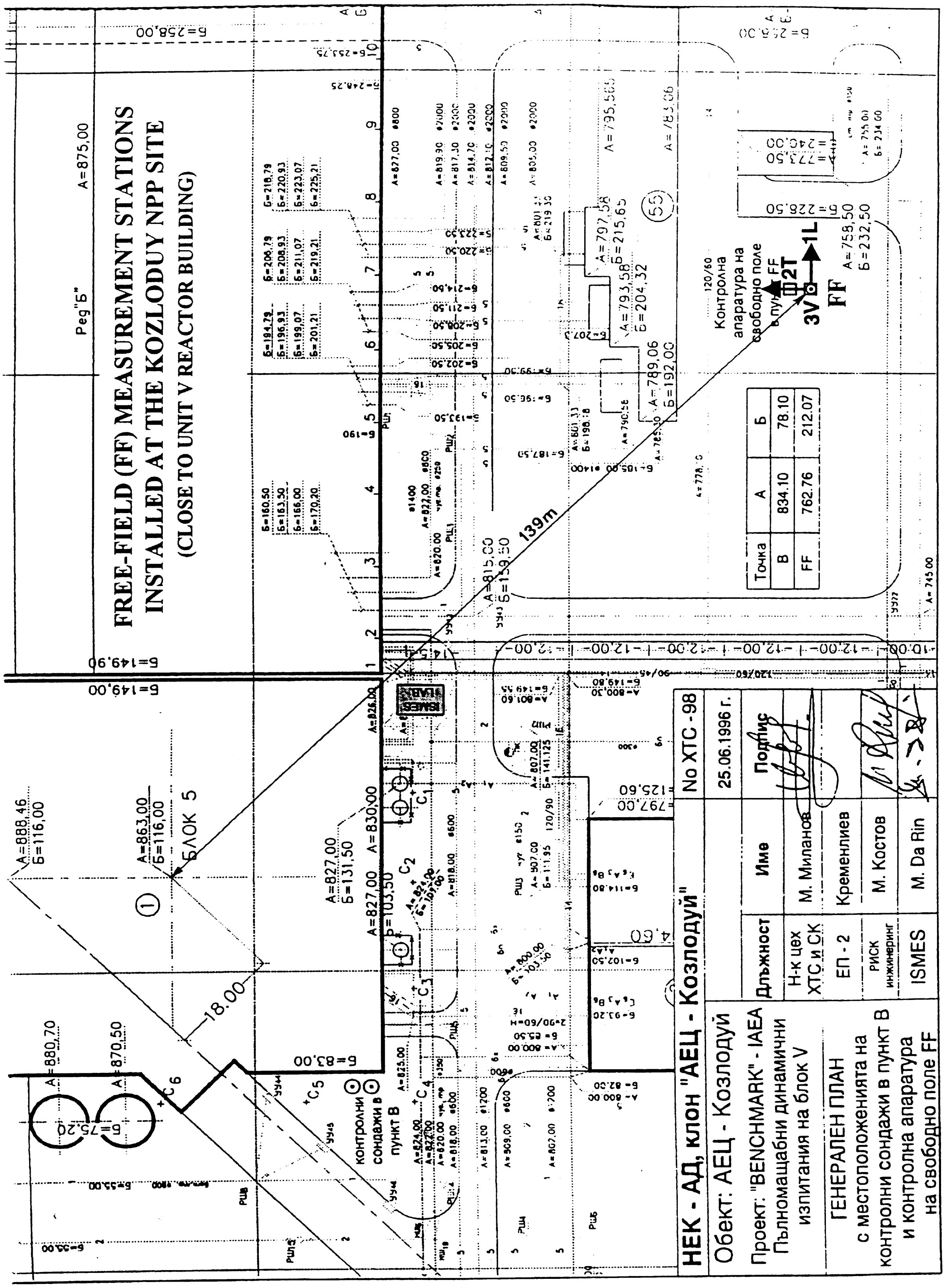
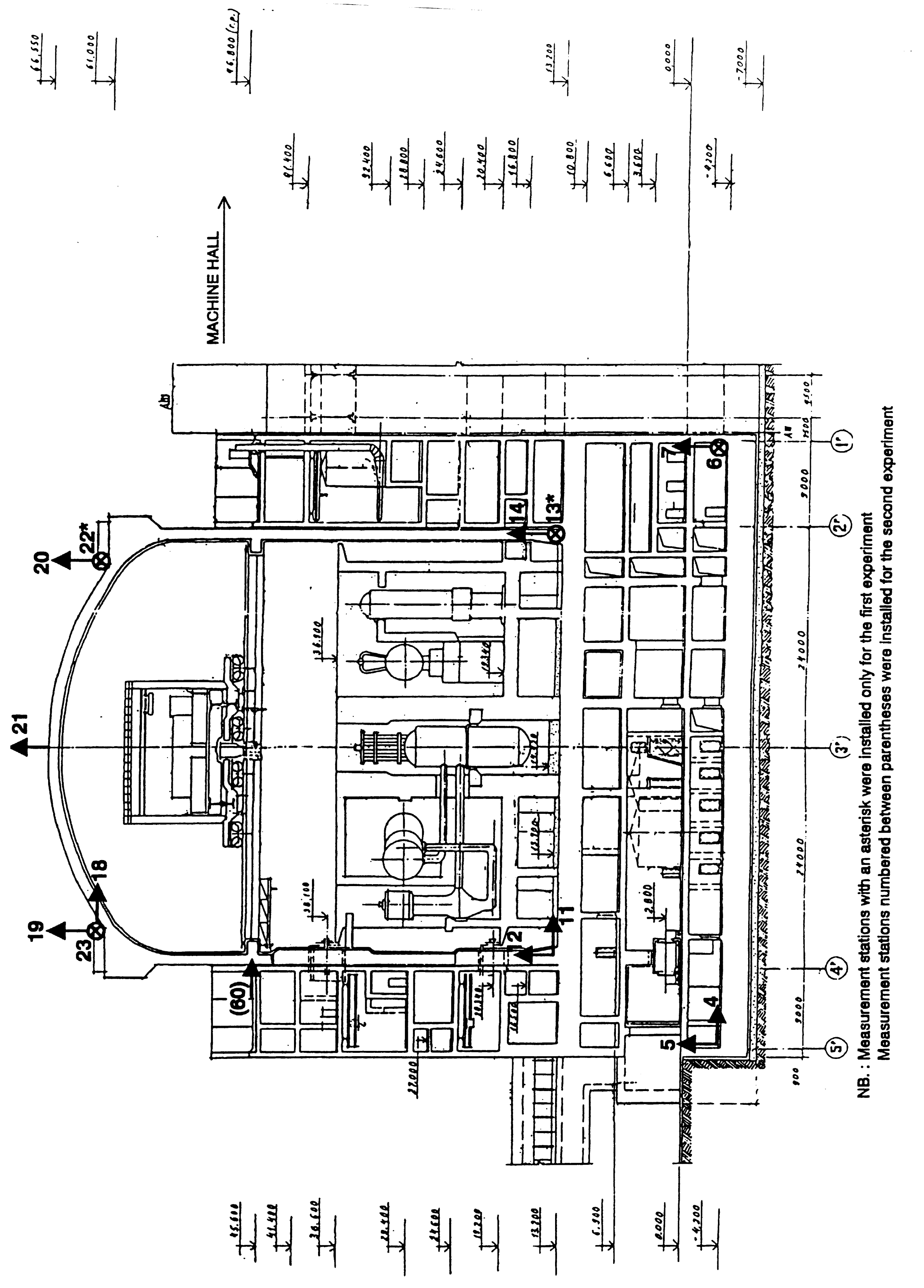
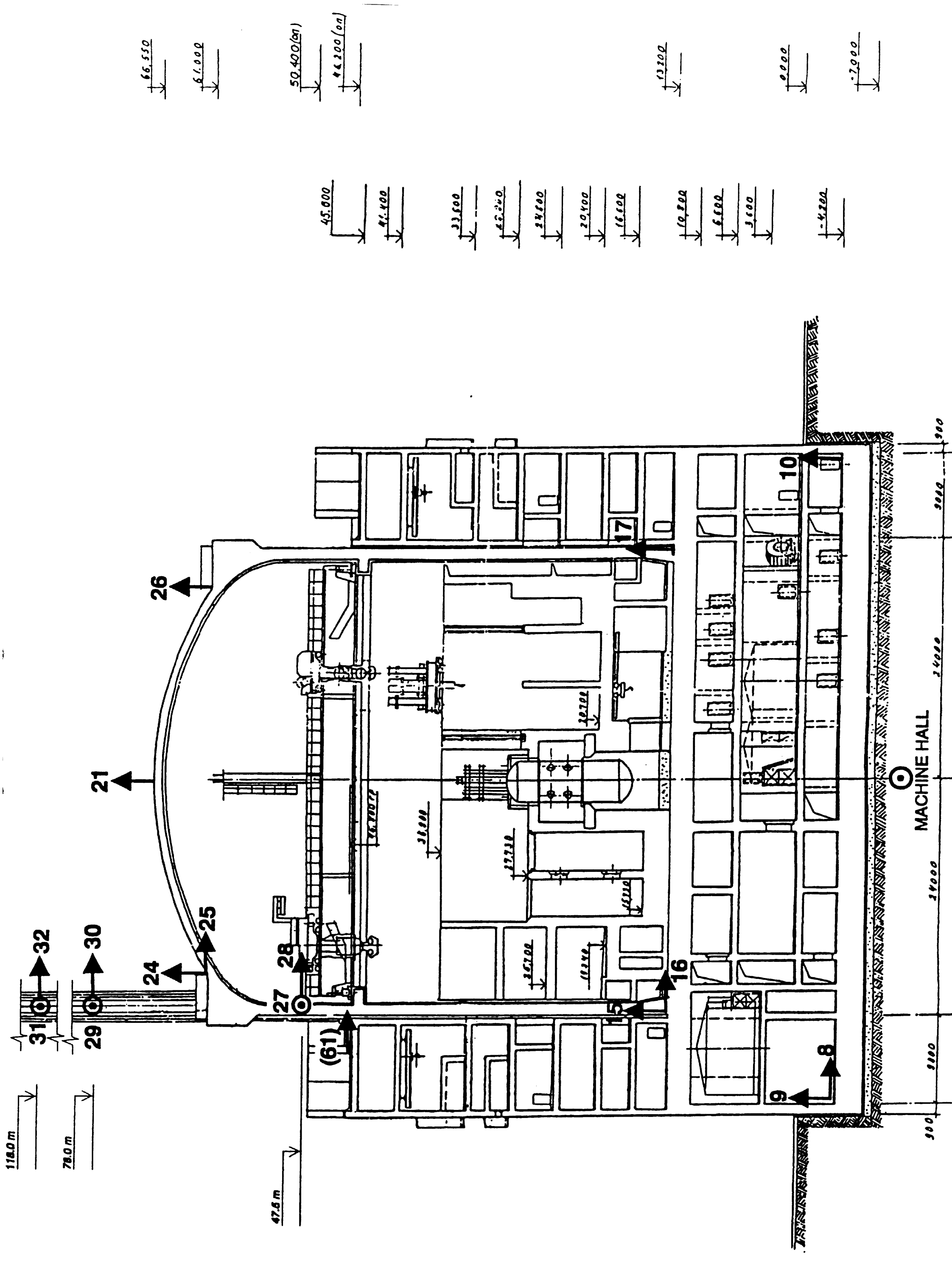


FIG. 6.6. Free field (FF) measurement stations installed at the Kozloduy NPP site (close to Unit 5 reactor building).



NB. : Measurement stations with an asterisk were installed only for the first experiment
Measurement stations numbered between parentheses were installed for the second experiment

FIG. 6.7. Dynamic testing of Kozloduy NPP Unit 5 structures — instrumentation layout in the reactor building — longitudinal cross-section view.



NB. : Measurement stations numbered between parentheses were installed for the second experiment

FIG. 6.8. Dynamic testing of Kozloduy NPP— Unit 5 structures — instrumentation layout in the reactor building — transverse cross-section view.

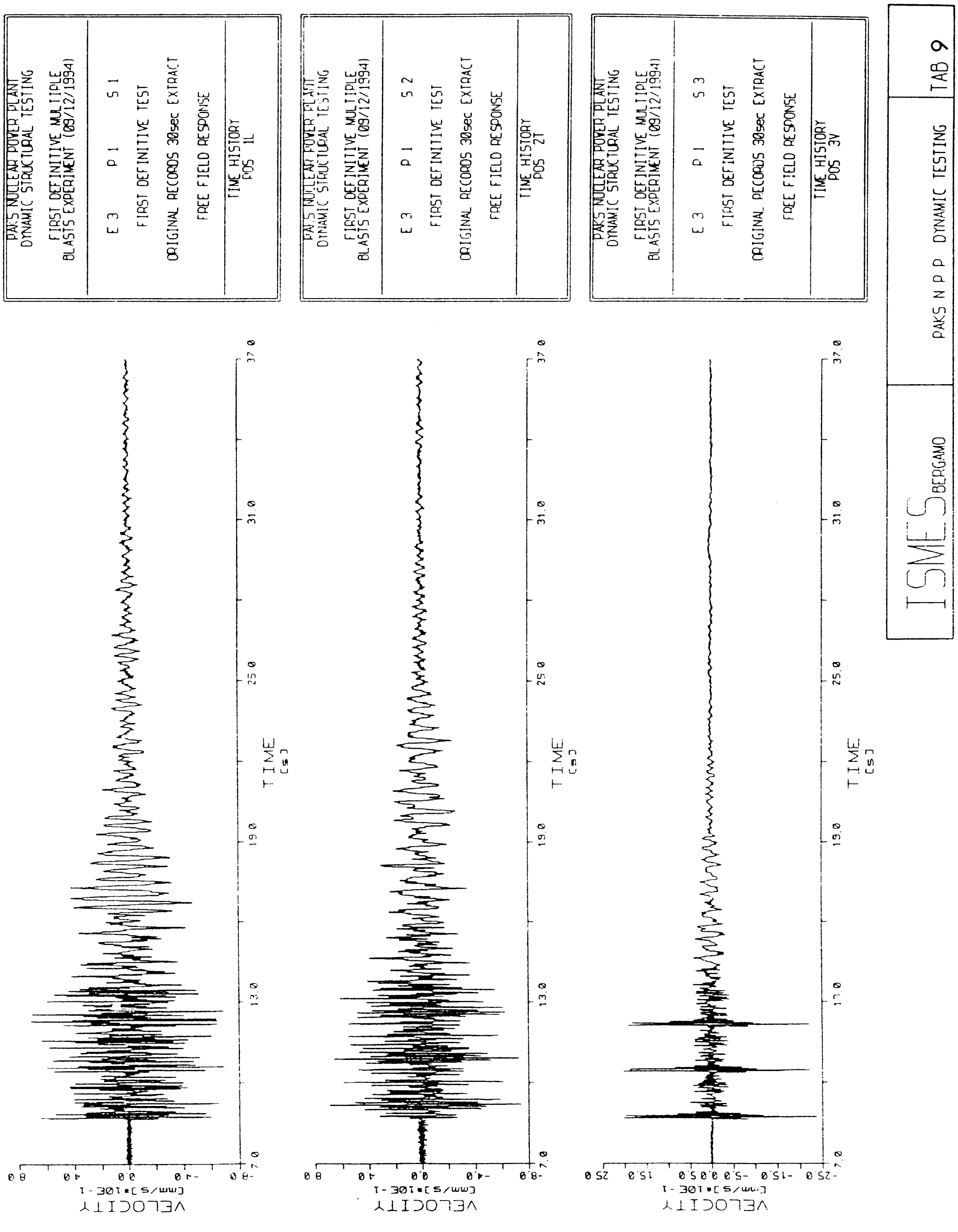


FIG. 6.9. Free field input for Paks NPP.

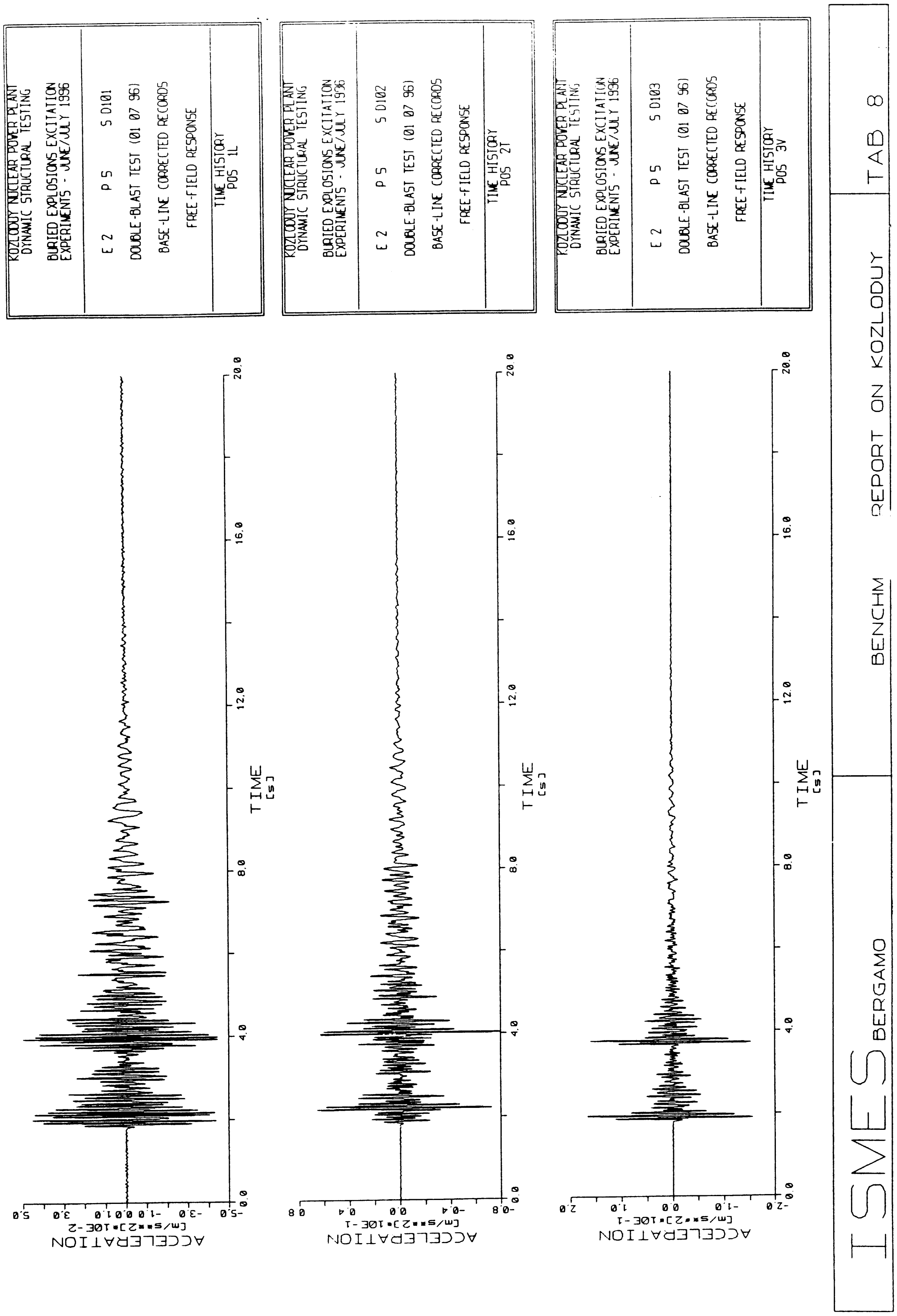


FIG. 6.10. Free field input for Kozloduy NPP.

6.3. NUMERICAL ANALYSES OF PAKS AND KOZLODUY NPPS

Objectives

To simulate the structural dynamic response of the reactor buildings and the stacks (only for the Paks site) when subjected to the same forced dynamic excitation applied to the soil measured in the experiment of Task 8.

Summary of work done

All the participants have generated a finite element model consistent with the specifications provided by the IAEA, but with many specific assumptions related to soil and structural properties based on company experience and engineering judgement. As these differences are responsible for the result scattering among participants, a short tabular summary is provided in Tables VI.3 and VI.4.

Results

Paks simulation

Following the same grid proposed in the preceding Section, the main conclusions of the participants are summarized below in graphic and tabular form; the amplification ratios are shown for the longitudinal and vertical response spectra components. This is intended to summary highlight the different propagation fields through the soil, at the basemat (only for the Paks analysis) and at different elevations of the reactor building.

For a better comparison some assumptions have been introduced:

- the frequency range considered for the acceleration spectra is 0–10Hz;
- the values refer to the peak of the response spectra (acceleration), independently from the location on the frequency axis. This assumption is not critical, as all the participants had peaks approximately at the same frequency.

Paks analysis

Figure 6.23 shows an example participants’ results for the purposes of comparison. A global comparison is available in the Background Documents. A short summary is provided in the Table VI.5.

TABLE VI.3. NUMERICAL MODELS FOR THE PAKS BUILDINGS — MAIN CHARACTERISTICS

Organization	FE model	no. of d.o.f.s.	Soil damping	Computer code for SSI	Computer code for FRS calculation	Input motion
CL	3D shell (Fig. 6.11)			SASSI	SASSI (frequency domain)	Free field at the foundation level deconvoluted motion at the foundation level
MD	3D shell (Fig. 6.12)	6450	15% hor 30% vert	/	NISA & STARDYNE (time domain)	Deconvoluted motion at the foundation level
EQE	3D shell, 9 separate foundations (Fig. 6.13)		3–4–5%	CLASSI	CLASSI (frequency domain)	Deconvoluted motion at the foundation level (vertical prop. S– waves)
IVO	3D shell (Fig. 6.14)		2%	SASSI	SASSI (frequency domain)	Deconvoluted motion at the foundation level
Siemens	3D shell (Fig. 6.15)			CLASSI – SASSI	STRUDYN (time domain)	Deconvoluted motion at the foundation level
IZIIS (only the stacks)	3D shell and 3D solid (foundation) (Fig. 6.16)	2937 (nodes)		/	SAP90	Deconvoluted at the bedrock
SAGE (only the stacks)	beam (Fig. 6.17)					Free field

TABLE VI.4. NUMERICAL MODELS FOR THE KOZLODUY BUILDINGS — MAIN CHARACTERISTICS

Organization	FE model	no. of degrees of free-dom	Soil damping	Computer code for SSI	Computer code for FRS calculation	Input motion
CL	3D stick, 3 comp., shell foundation slab (Fig. 6.18)	5922	2.5%	SASSI	SASSI (frequency domain)	Free field at the foundation level Deconvoluted motion at the foundation level
MD	3D shell (Fig. 6.19)	7086	15%	/	NISA (time domain)	Free field at the foundation level
EQE	3D stick, 3 comp., shell foundation slab (Fig 6.20)		4.6%	CLASSI	CLASSI (frequency domain)	Deconvoluted motion at the foundation level (vertical prop. S-waves) Horiz prop. S-waves along EW Horiz prop. S-waves along WSW
IVO	3D shell (Fig. 6.21)	18000		SASSI	NASTRAN (frequency domain)	Deconvoluted motion at the foundation level
Siemens	3D single stick (Fig. 6.22)			CLASSI-SASSI	STRUDYN (time domain)	Deconvoluted motion at the foundation level

TABLE VI.5. SUMMARY OF THE RESULTS FOR THE PAKS MODELS

Organization	First nat freq.	Ampl. hor. basemat vs ff (14/1)	Ampl. vert. basemat vs ff (16/3)	Ampl. hor. in basemat (14/4)	Ampl. vert. in basemat (16/6)	Ampl. hor. in elev (36/14)	Ampl. vert. in elev (37/16)
Central lab. Sofia		0.53	0.67	/	/	1.88	1.00
		0.49	0.73	/	/	1.76	0.91
David		0.87	1.80	1.00	1.50	0.69	0.64
EQE		0.87	0.53	1.00	0.89	0.77	1.00
IVO		1.73	1.33	0.96	1.00	0.46	0.90
Siemens		1.00	0.53	0.94	0.40	0.53	1.25
IZIIS (only stacks)	0.4						
SAGE (only stacks)	0.4–2 × 4.8 y						

Kozloduy analysis

Figure 6.24 shows a global comparison of results. A complete comparison is available in the Background Documents. A short summary is provided in Table VI.6.

TABLE VI.6. SUMMARY OF THE RESULTS FOR KOZLODUY MODELS

Organization	First nat freq.	Ampl. hor. basemat vs ff (4/1)	Ampl. vert. basemat vs ff (5/3)	Ampl. hor. in elev. (18/4)	Ampl. vert. in elev. (19/5)
CL		0.91	0.03	2.60	0.89
		0.41	0.02	2.67	0.86
MD		1.73	0.05	2.11	1.25
EQE		0.82	0.02	2.56	1.00
IVO		0.91	0.03	4.50	1.50
Siemens		0.91	0.02	1.20	1.29

(Shaded cells refer to 3D shell models.)

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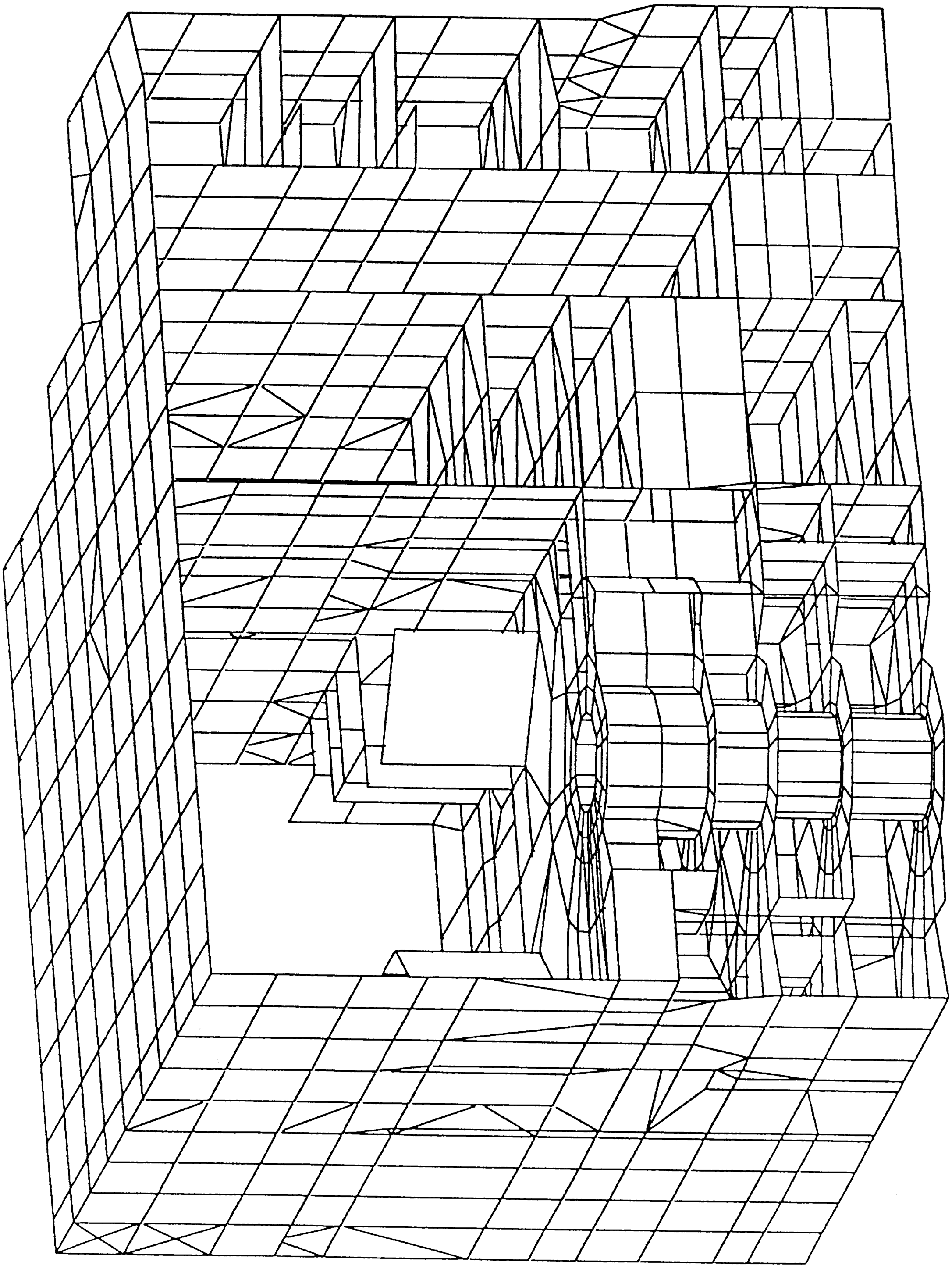

FIG. 6.11. PAKS NPP, vertical cross-section through reactor building.

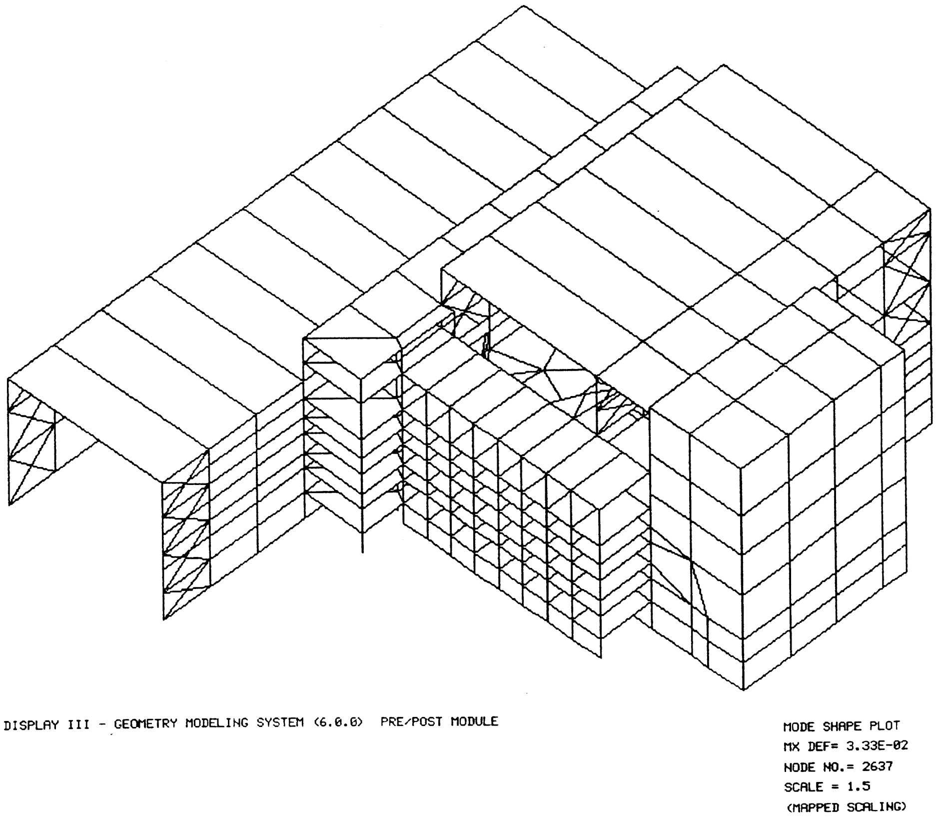

FIG. 6.12. 3D shell model of Paks NPP (by MD).

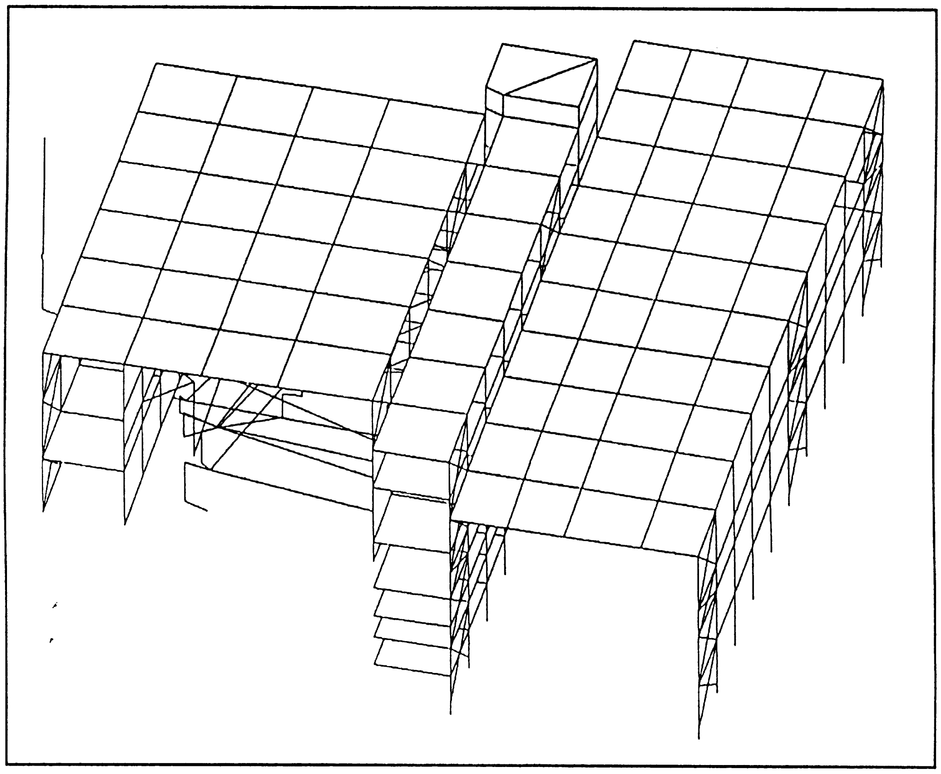

FIG. 6.13. Structural model of Paks NPP (by EQE).

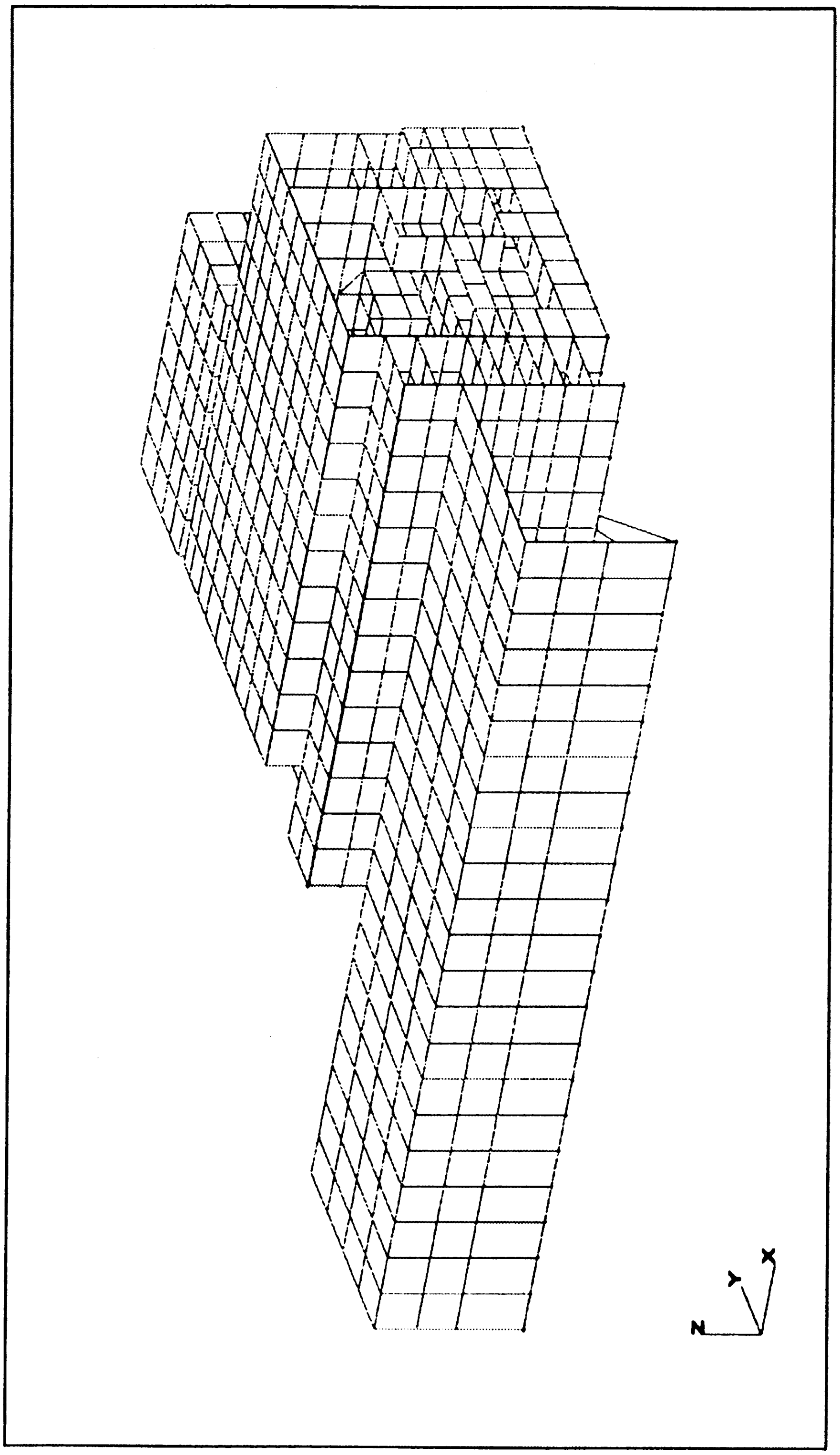

FIG. 6.14. The finite element structural model of the Paks reactor building complex (by IVO).

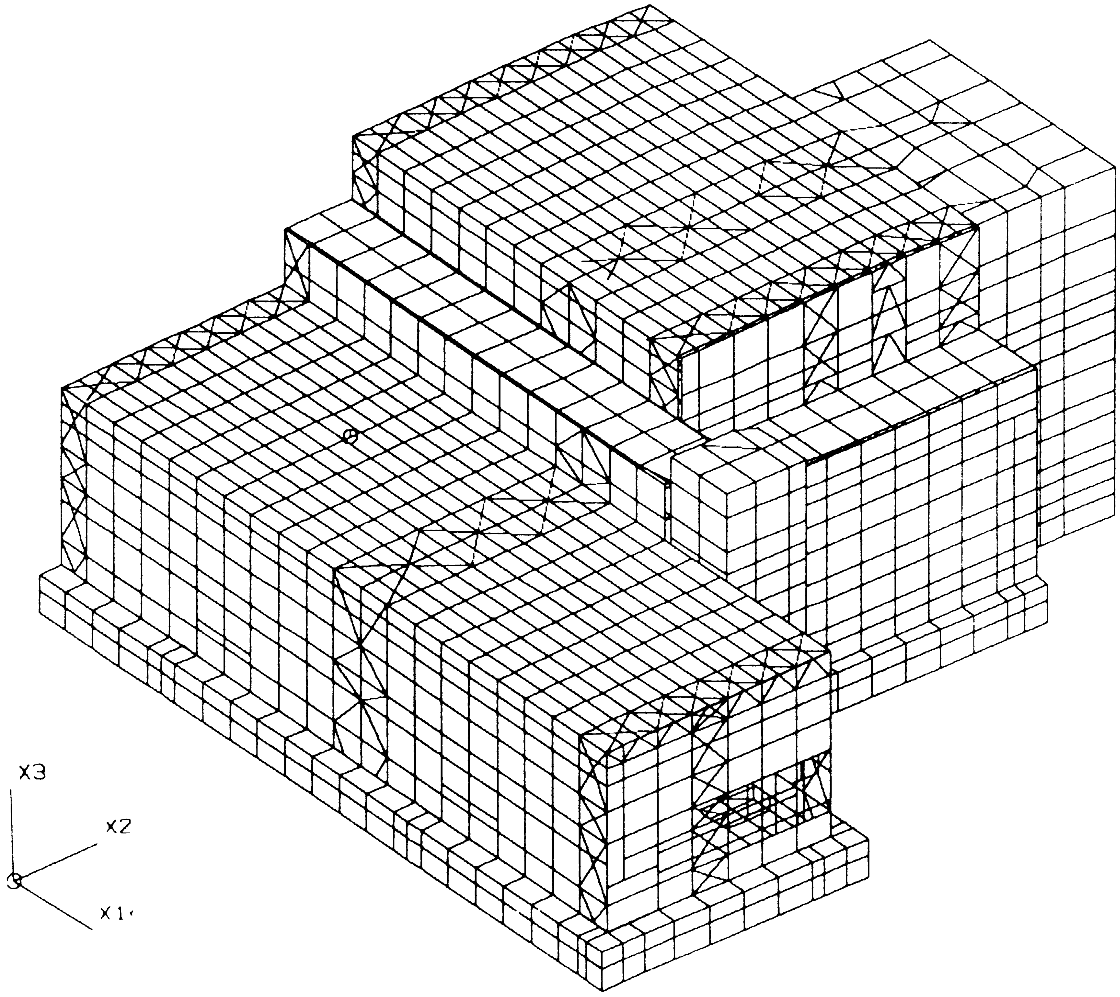

FIG. 6.15. Mathematical model (3D) of the Paks main building complex (by SIEMENS).

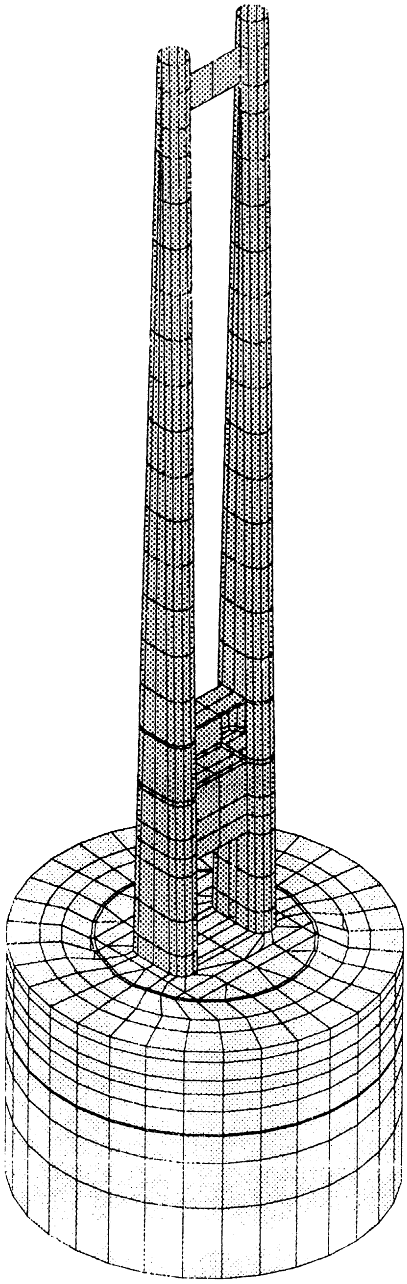

FIG. 6.16. Paks NPP stacks undeformed shape (by IZIIS).

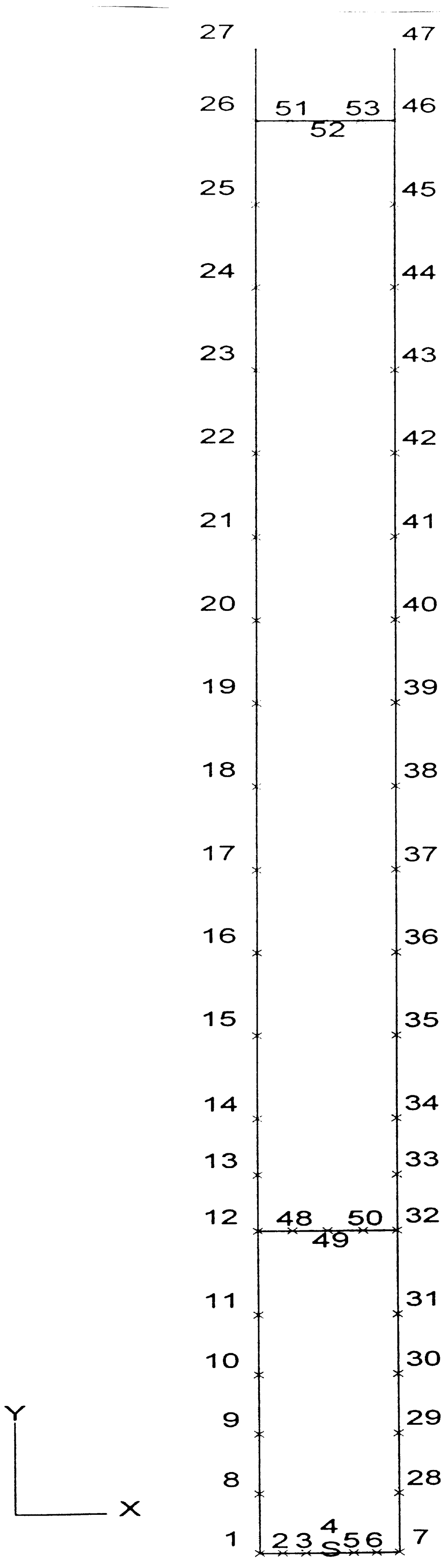

FIG. 6.17. Beam model of the stacks at the Paks NPP (by SAGE).

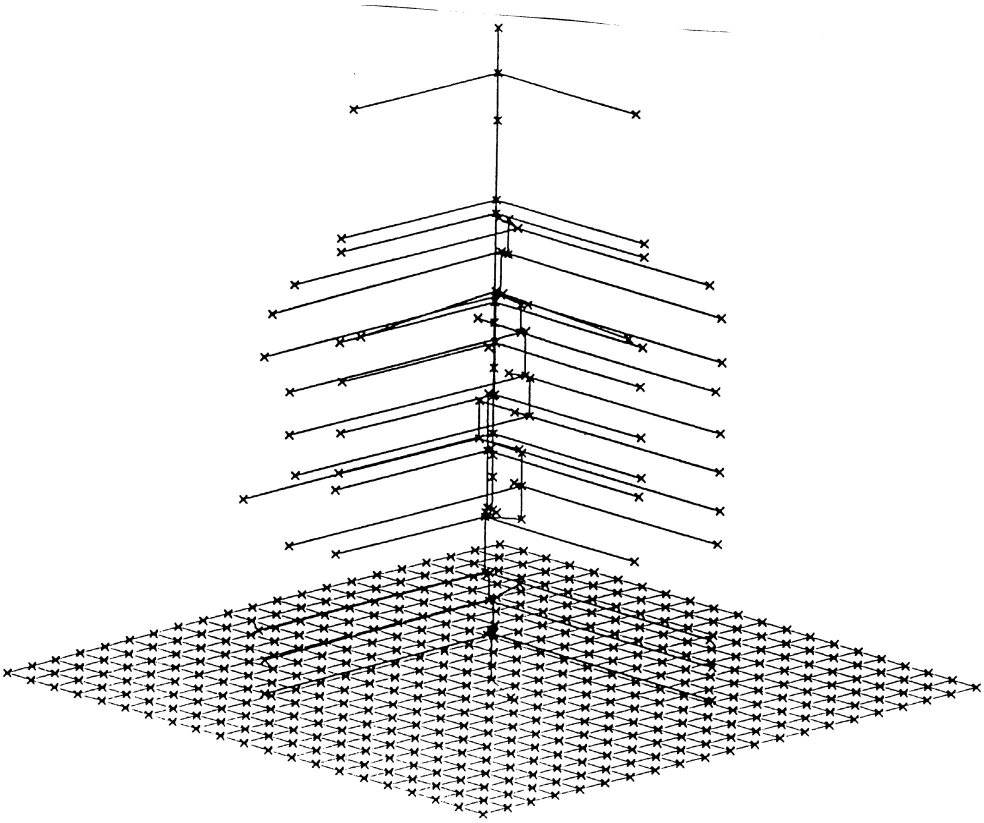

FIG. 6.18. NPP Kozloduy, Unit 5, 3D stick model — general view(by CL).

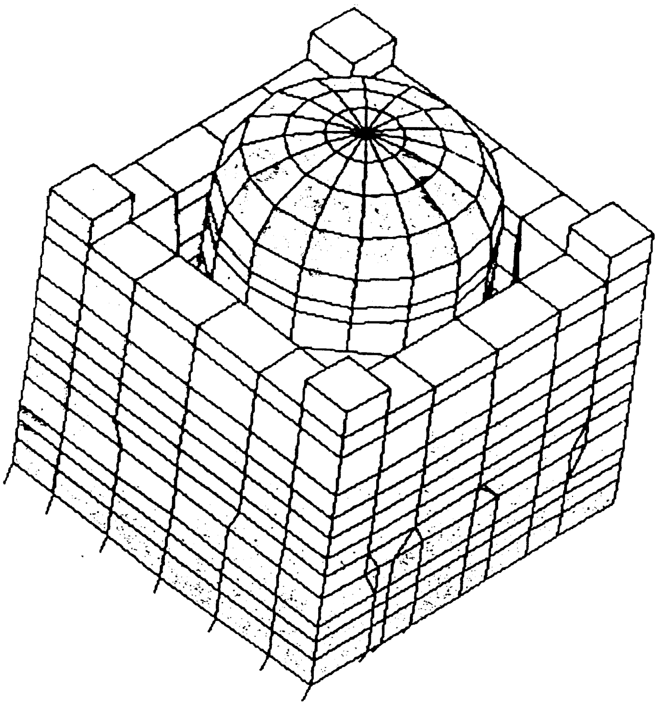

FIG. 6.19. Three-dimensional shell model of the Kozloduy NPP (by MD).

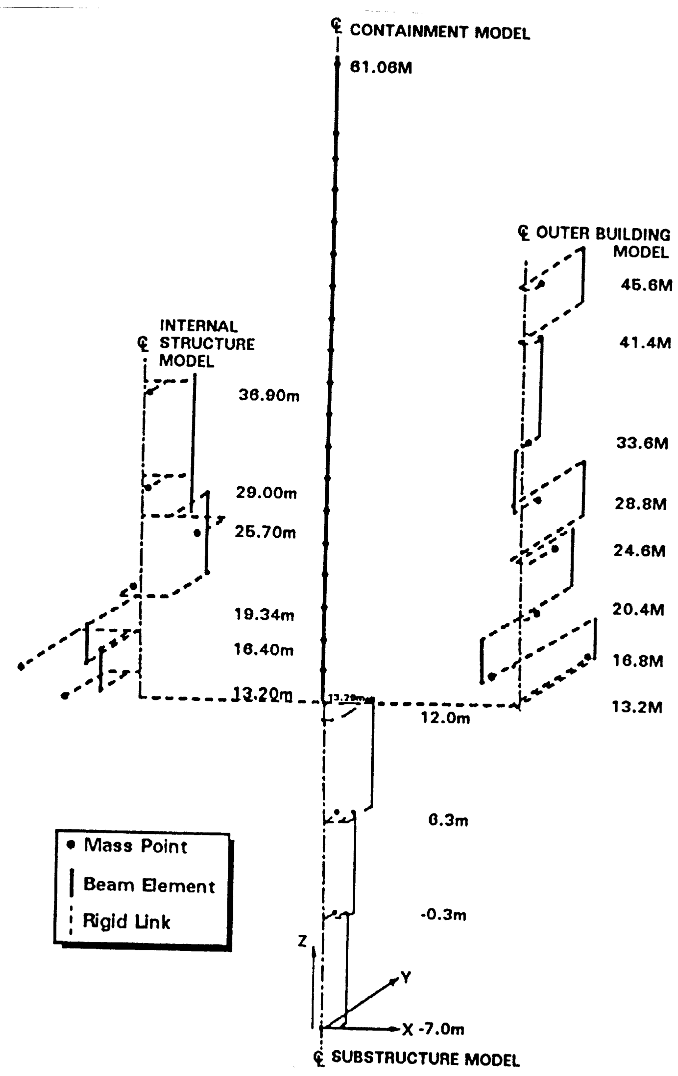

FIG. 6.20. Three-dimensional stick model of the Kozloduy NPP (by EQE).

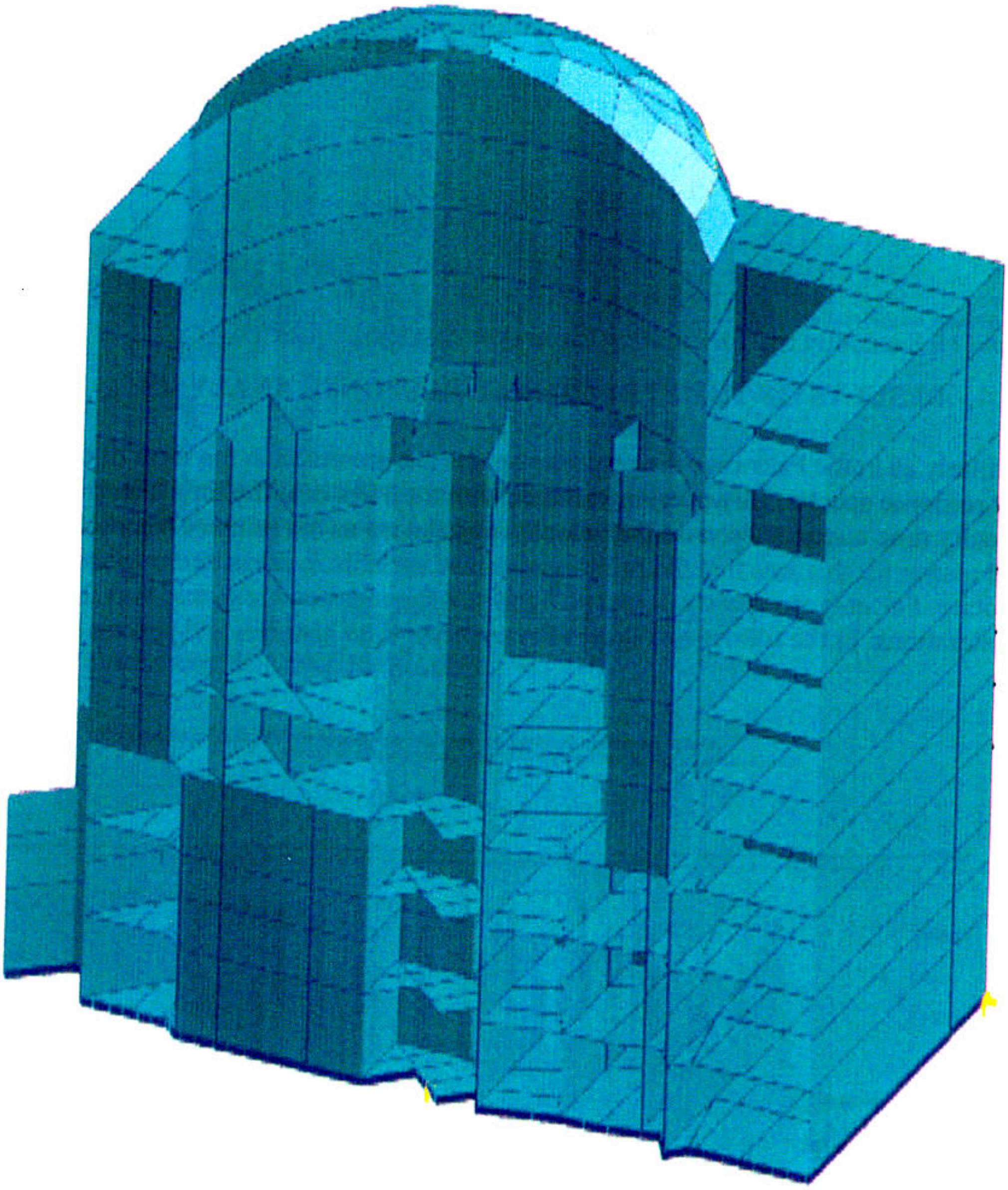

FIG. 6.21. Isometric shaded view of the interior of the Kozloduy reactor building model (by IVO).

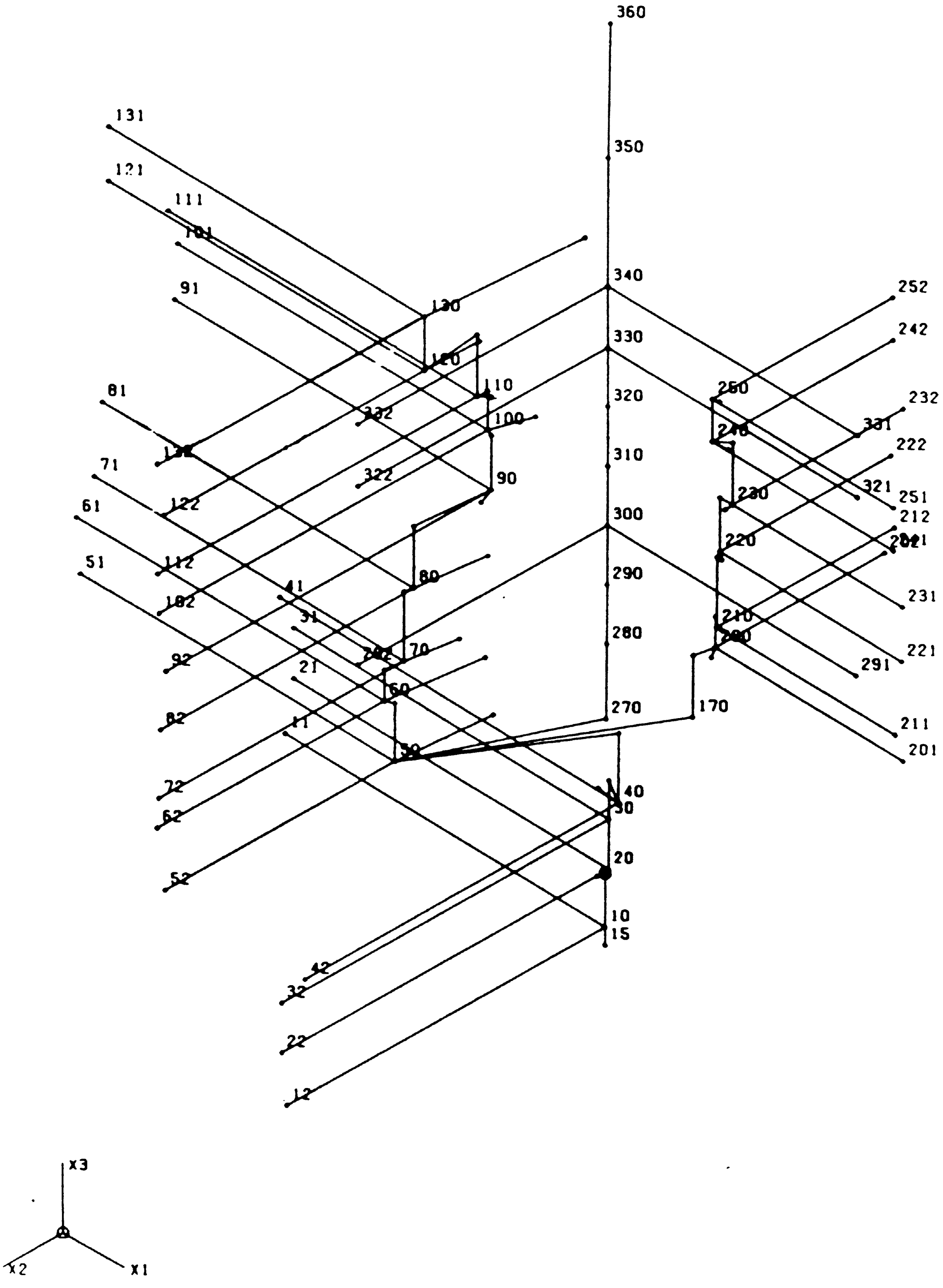

FIG. 6.22. Beam model of the Kozloduy WWER-1000 MW reactor building (by SIEMENS).

Applicability of the results

The two analyses are quite representative of the two buildings and the two site conditions. Having recognised the soil impedance values as the main source of scattering among the participants, the analyst should be aware of the following factors to extend the applicability of the results to other sites:

- The small differences in structure layout among the unified reactors of the WWER series do not essentially influence the results.
- The water table of the Paks site is approximately at the ground level, whereas that of Kozloduy is estimated at a depth of 50 m: this can influence superficial wave propagation and filter the P-wave content.

Lessons learned

The results agree well with each other in the frequencies of the response spectra peaks, but are significantly scattered in the amplitude of the floor response spectra, such scattering is not directly correlated with any specific choice assumed by the analysts.

Some general conclusions can be derived as to the reliability of such analyses from the results of both analyses:

- The participants have shared a limited number of computer codes and therefore the differences among their results do not seem to be related to code selection.
- The differences in the results related to the geometry of the FE model (3D shell or stick) are comparable with the effects of the soil parameter assumptions, at least for the response in the low frequency range (0–10Hz), where the "soil" modes are dominant over the structural modes.
- The differences in response integration (time or frequency domain) are enveloped by the effect of the soil parameters scattering.
- The deconvolution of the input motion induces a certain reduction in the response, also related to the embedment which at Kozloduy is 7m, but this is probably not the only reason for the large scattering shown in the results.
- The assumptions for the soil damping factor and stiffness, and therefore in the soil impedances, are probably responsible for most of the differences: in fact the strain energy in the model up to 3.5 Hz has been found essentially in the soil part, which tends to exclude an important role for the structural modelling in the low frequency response of the coupled model. Furthermore, the very low strain values exclude the influence of the strain level on the soil equivalent stiffness and damping influence of the stiffness and damping dependency with the strain level.

Preliminary sensitivity studies supported this conclusion, showing a variation of +–20% in the first natural frequencies (hor. and vert.) when the soil properties range in the "min-max" boundaries and a variation of 0.1g in the response spectrum at the top of the containment and a uniform variation of 10 Mpa in soil stiffness are applied.

- The foundation modelling, especially for large buildings with a complex structural layout, has a significant influence on the response, but mainly above 10 Hz.
- The results are extremely sensitive to the assumptions on the wave propagation field which affects the amplification of the motion in elevation with factors ranging from 2 to 4 depending on the propagation direction. As the benchmark problem involves a superficial explosion at a point source, this parameter strongly effects the matching with the experimental result.
- The analysis of the blast response on the stacks reveals many decoupled modes of the stacks which can stress the structure of the connection.

Conclusions and recommendations

- The scattering in the analyses results point out the different sensitivities in the responses to the engineering assumptions usually made in numerical analyses. The most significant conclusion in this framework is the essential role played by the soil parameters which affect the results even more than the geometry modelling.

In seismic re-evaluation of NPPs, it is therefore necessary to consider this factor and attempt to limit soil parameter scattering, while it may be possible to accept more significant uncertainties in the structural layout model. The consequences are twofold:

- **for the analysts**: the selection and tuning of an appropriate model for the soil properties evaluation (impedances) should cover most of their efforts, and extended comparisons and multiple analyses may be justified.
- **for the utilities**: geotechnical and geophysical campaigns focused on data definition should receive a great deal of attention in order to bracket the engineering assumptions. The scattering in input data leads directly to high scattering in the final results.

6.4. COMPARISON BETWEEN EXPERIMENTS AND NUMERICAL RESULTS

Objectives

To compare experimental data and numerical results in order to validate the numerical procedures.

Summary of work done

Data from the Paks and Kozloduy sites have been processed in an identical way. Experiments have been carried out with similar acquisition systems and the free field data have shown quite similar frequency content and amplitudes. Some preliminary activities have been carried out on the input signals in order to better define their properties:

1. Derivation of the acceleration records from velocity.
2. FFT analysis of both velocity and acceleration records in order to identify the dominant frequency contents.
3. FFT analysis on sub-records (first and second wave trains) and comparison with the FFT on the complete records in order to assess the mutual influence of the two wave trains.

General processing of the above data then generated comparable records (acceleration response spectra) as follows:

1. Plotting of the contributions on homogeneous scales in the ranges 0–30 Hz and 0–10 Hz. High frequencies on the response.
2. Analysis of EQE and IVO time histories in order to assess the influence of the high frequencies on the response.

Results

The comparison of the results for some selected locations is shown in Figs 6.23 and 6.24.

A shifting in the frequencies of the spectral peaks is particularly evident for the Kozloduy analysis, while for Paks site the natural frequencies of the coupled model essentially match the data.

However, a systematic error is clearly seen in the spectral amplitudes, indicating that an additional source of uncertainty other than scattering in soil parameters has affected the results, producing a quite constant magnification factor of 3–4 in the numerical response spectra. This error source has been generally identified in the representation of the wave field: some participants have already inspected its influence in the results, although with very rough methods, confirming the validity of the interpretation. In fact the application of conventional soil-structural approaches to the benchmark implies a uniform shear wave excitation propagating in the vertical direction.

The experiment also involved a superficial explosion at a point source lateral to the foundation. Therefore the experiment probably generated a P-wave excitation rather than a typical S-wave train, especially for Paks site, where a very high water table could have magnified this effect.

The analysis of the stacks for the Paks site has shown quite a good matching with experimental data, at least as to the time histories of the acceleration peaks. The response has been evaluated with 10% of global modal damping of the whole model (soil+structure), based upon a general engineering judgement on the overall behaviour of the model and therefore not mathematically derived from the input data.

Applicability of the results

The large difference between experimental and numerical result has been proven not to be site dependent and therefore it is more related to the applied simulation techniques than to local site effects.

The high frequency part of the explosion spectrum is not far from some records of real earthquakes with shallow source and near site. This fact implies that the results of the described explosive tests could be really used in the validation of the simulation tools to be applied to generic sites.

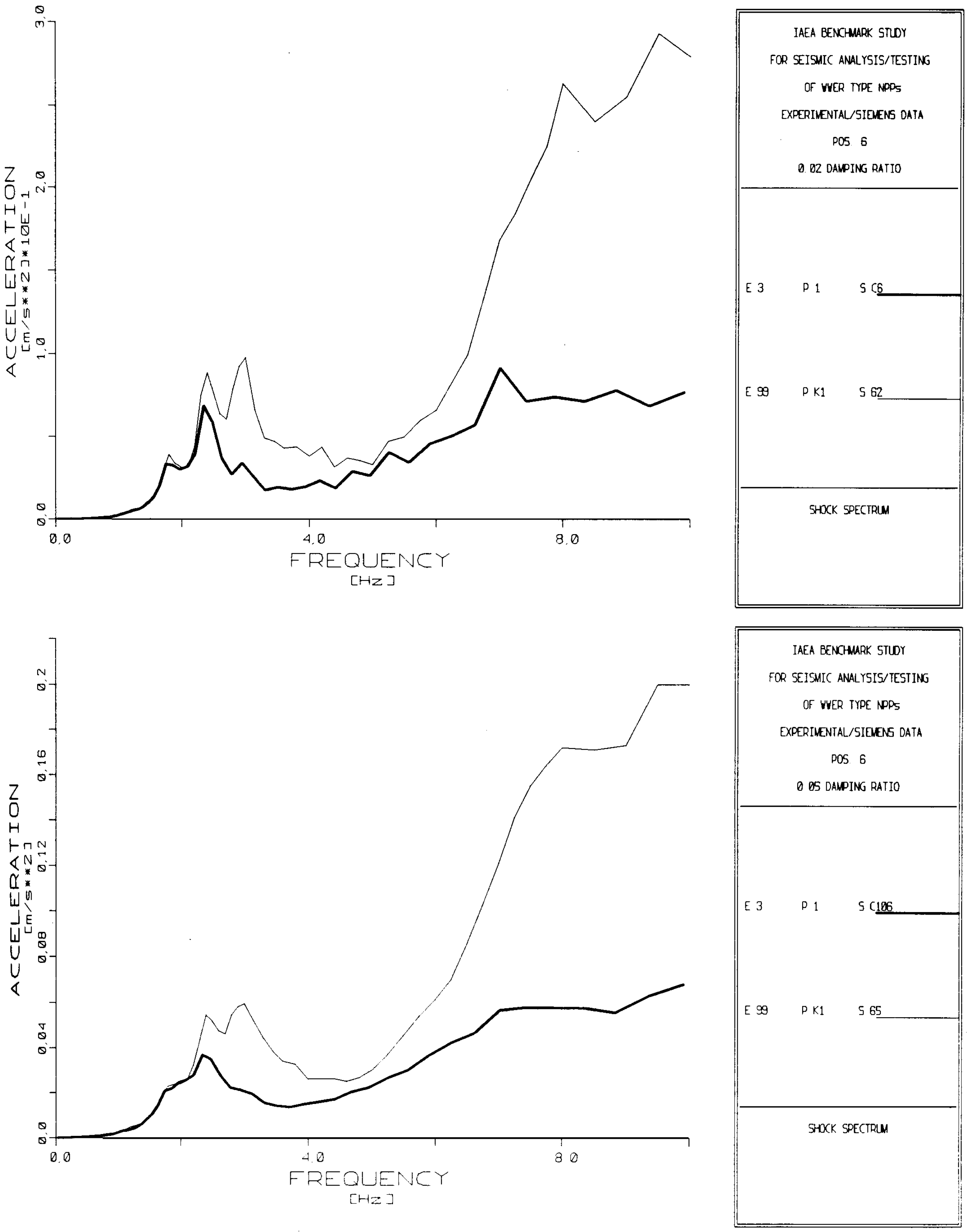

FIG. 6.23. Comparison of the results of the Paks NPP models.

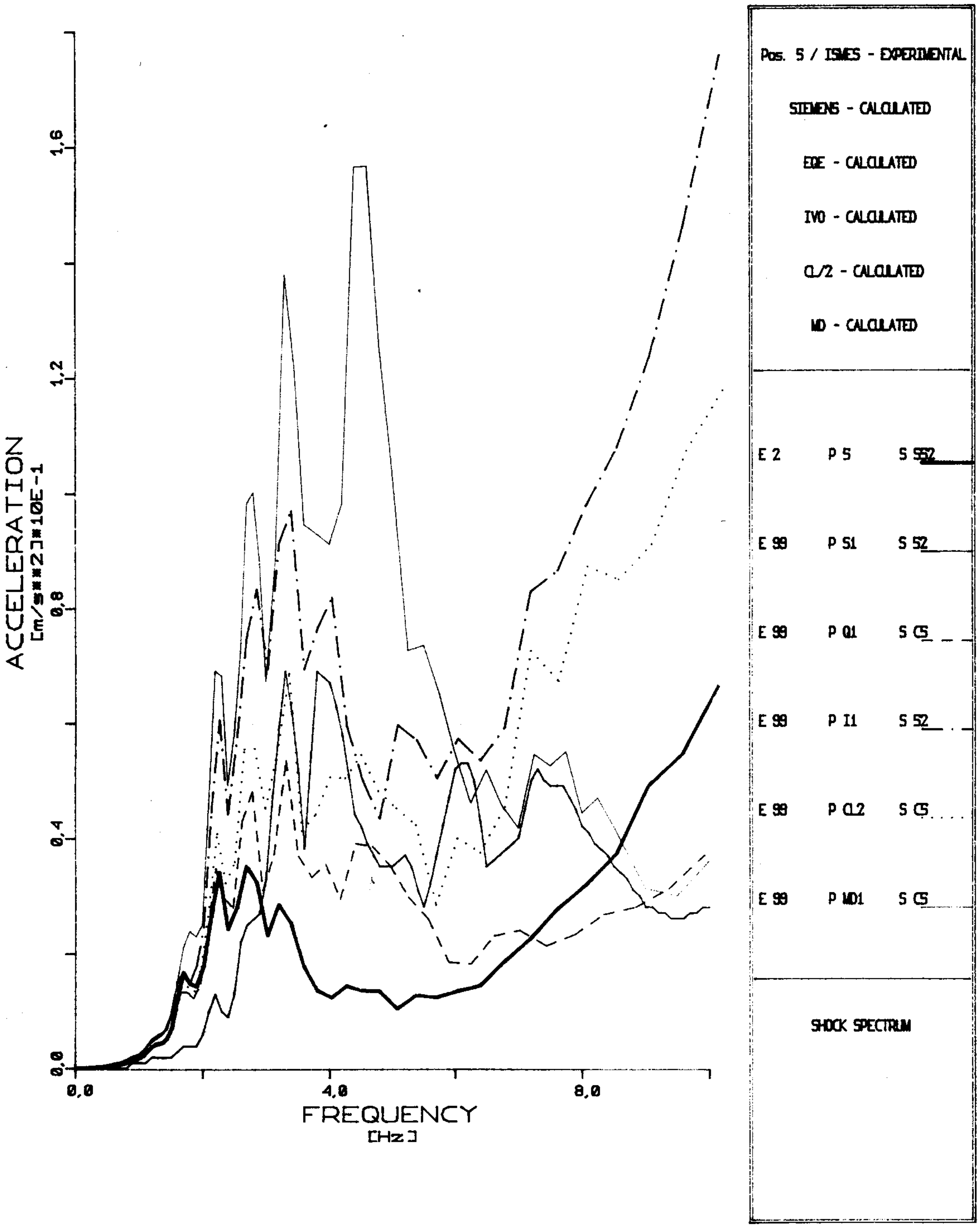

FIG. 6.24. Comparison of the results of the Kozloduy NPP models.

Lessons learned

There is no clear evidence as to the sources of the discrepancy between the experimental data and numerical results. However three main sources of error have generally been identified and accepted:

1. scattering in the soil properties (already evaluated in preliminary sensitivity analyses)
2. the representation of the wave field
3. the interaction of the foundation size with the input wave length.

This hypothesis should be verified by additional numerical investigations, but a general confirmation of the main role played by the definition of the input signal seems to be reasonable and accepted by all the CRP participants.

The conclusions given above are therefore confirmed and the recommendations to both utilities and analysts are reinforced. In this framework, global experimental tests, involving both soil and structure, have gained an essential validity as a supplementary tool in a seismic re-evaluation process.

Conclusions and recommendations

The comparison of data discussed in this task has confirmed the significant role of the engineering assumptions in the seismic assessment of the two reactor buildings. It was, therefore, very useful to have the opportunity of conducting detailed experimental and numerical analyses in order to obtain a reliable judgement on the seismic upgrading demand of a plant. Experimental campaigns can be designed according to sensitivity analyses on the input data; analysts should select those parameters which most significantly affect the results.

In fact, a large uncertainty in the floor response spectra, as shown in the results of the benchmark, would indicate a difficult decision about the seismic re-qualification for safety related equipment and components. As an alternative to full scale tests, very detailed experimental campaigns on input data (the benchmark has highlighted the most critical ones!), will also benefit analysts involved in seismic re-evaluation programmes.

6.5. ANALYSIS OF TEST PROCEDURES — COMPARISON BETWEEN BLAST AND VIBRATION TEST

Objectives

To assess testing methodologies on full scale models with a view to evaluating the soil-structure interaction effects on buildings and structures.

Summary of work done

The activity was carried out in the following steps:

1. review of a technical report related to ambient and forced vibration tests on the Kozloduy NPP
2. definition of a reliable procedure to provide soil and structure equivalent parameters from experimental data, based on simple analytical algorithms

3. definition of optimal requirements for an experimental test focused on soil structure interaction study
4. definition of general requirements for an optimal experimental campaign focused on seismic safety margin assessment.

Results

The procedures have been defined and described in the technical report. Comments and recommendations on the test performed in Kozloduy have been summarized in the revision report.

Applicability of the results

The research activity was quite general. The target of the research itself was not related to any specific site but to the definition of general procedures in the field of seismic requalification of existing structures.

Lessons learned

The main problem areas seem to be the quality of the excitation:

1. the ambient excitation is generally affected by noise, explores very low excitation amplitudes and the only reliable results are the natural frequencies of the building (not the forced structural response)
2. the forced harmonic vibration test is quite useful for the high frequency range, while for the low range (more representative of the seismic excitation), the amplitude is very low and often insignificant
3. the blast test in the ground, if it can produce a significant low frequency wave, is probably the best alternative and can provide essential data on the forced response of the coupled soil-structure system.

Conclusions and recommendations

Very detailed testing procedures and data processing methodologies should be set up before the execution of the test itself in order to guarantee the usefulness and reliability of the data for numerical evaluation.

REFERENCE TO CHAPTER 6

A. *Post SMiRT Paper*

[6.1] HAUPTENBUCHNER, B., DAVID, M., Summary of structural analysis and comparison with experimental results for Paks NPP - Paper4, Post SMiRT seminar No. 16, Post SMiRT 14, Vienna, (1997).

Chapter 7

EXPERIENCE DATA

TABLE VII.1.

Task	Title	Participants	Tecdoc Chapter	WM volume
10	On-site testing of equipment at Paks and Kozloduy NPPs	**PNPP** **KNPP** VNIIAM	5, 7	3, 5
11	Preliminary component test data	**S&A-RO** AEP VNIIAM IZIIS CKTI	7	5
12	Experience data from Vrancea and Armenia earthquakes	**EQE-US** S&A-RO	7	5
13	Experience data from US earthquakes	**EQE-US**	7	5
22	Experience database (WWER SQUG) initiation	S&A-US S&A-CZ S&A-RO EQE-US PNPP KNPP	7	5
28	Vrancea Hazard	EQE-US S&A-RO	7	5

7.1. ON-SITE TESTING OF EQUIPMENT AT PAKS AND KOZLODUY NPPs (TASK 10) AND PRELIMINARY COMPONENT TEST DATA (TASK 11)

Objectives

The objective of these tasks was to prepare a detailed summary of (a) on-site testing of equipment at Paks and Kozloduy NPPs performed within the scope of the IAEA CRP, and, (b) preliminary seismic tests of equipment components to be used for general purposes.

Summary of work done

Several documents cover these tasks:

(a) The document prepared by S&A-RO gives in its second part a description of seismic tests already performed in Romania (Eurotest SA). These seismic tests were performed generally in accordance with the current international standards such as IEEE Std 344-77, IEEE Std 344-87, or IEC 980-89. The classes of equipment components that were tested include:

- different types of valves and valve drivers,
- vertical and horizontal pumps,
- low voltage switchgears,

- instruments themselves and instrument racks,
- fans,
- control panels and several I&C cabinets,
- temperature and other sensors.

The second document also prepared by S&A-RO contains additional valuable results of shaking table tests of mechanical and electrical equipment components performed by Eurotest SA. Figure 7.1 presents a view of the Eurotest seismic testing hall.

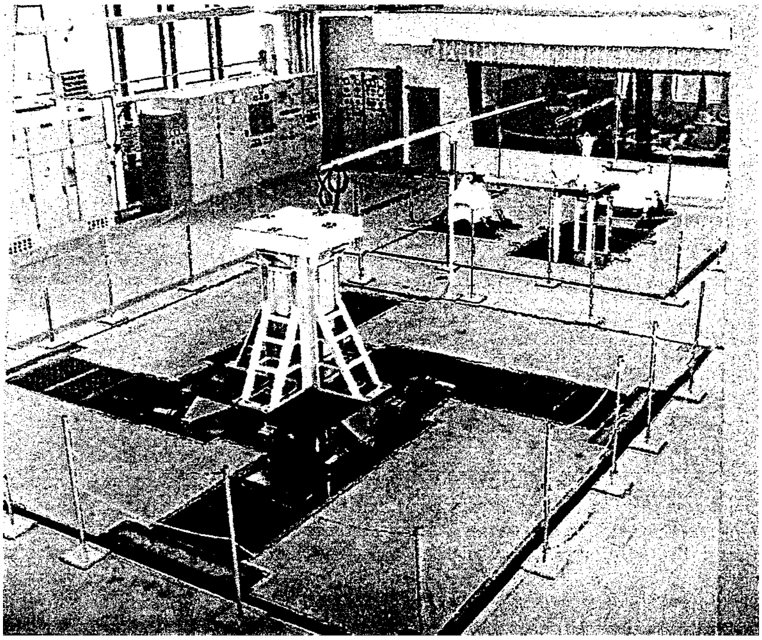

FIG. 7.1. Eurotest Seismic Testing Hall

(b) The document prepared by IZIIS gives a description of seismic tests of different equipment components performed in Skopje, Macedonia. These tests have mostly concentrated on the seismic functional qualification of active mechanical and electrical components based on shaking table testing. Tests were performed according to the internationally recognized standards (IEEE, US NRC Regulatory Guides, IEC documents etc.). A detailed description of testing equipment used for these seismic qualification tests is also provided. The classes of equipment components that were tested include:

- high voltage switchgears,
- high voltage isolators,
- low voltage switchgears,
- transformers,
- valves and valve drivers,
- electromechanical driving assemblages,
- control panels,
- vibration isolators,
- measurement and control elements.

IZIS operates three seismic testing systems:

- a biaxial shaking table (5 × 5 m, capacity up to 40 Mg, simultaneous excitations in horizontal and vertical directions),
- a uniaxial shaking table (maximum specimen mass of 3 Mg, excitations in horizontal direction only),
- a small electromechanical shaking table (maximum specimen mass of 50 kg, excitation alternatively in horizontal or vertical direction).

The document contains a short description of testing equipment performances, a set of seismic test results of twenty equipment components and a description of the development of testing methodology, acceptance criteria, processing of test results and application of the methodology and criteria to selected test specimens. The functional parameters of the tested specimen are measured directly or indirectly. For each specimen, the problem of functional parameter monitoring and data acquisition is considered individually. A programmable high speed multi-channel data acquisition system is used for data collection.

(c) Many on-site vibration tests were carried out by VNIIAM. This approach is useful to recognize at least the lowest natural frequency of the component. If the equipment components are weakly anchored, then their lowest natural frequencies are mostly less than about 8 Hz and, therefore, their seismic upgrading is usually required. This traditional VNIIAM practice is also documented in the published papers (see the references to this Chapter). Over the last 15 years, VNIIAM tested the equipment listed below at several WWER type NPPs:

- miscellaneous heat exchangers,
- coolers,
- deaerators,
- filters,
- pressure relief and other types of fluid and motor operated valves,
- vertical and horizontal tanks,
- horizontal pumps,
- I&C panels,
- pipelines,
- condensers.

(d) The current Russian practice for shaking table tests of equipment and in particular of electrical components is also described in the documents prepared by AEP. It should be noted that this practice is now based on the new Russian standards which are closer to the current international ones, but still differ significantly. Results of tests on electrical equipment components already installed at the Kozloduy NPP demonstrate important vulnerabilities of their structures and anchorage (the corresponding HCLPF values are as low as 0.15g) as well as significant problems of relay chatter and other functional failures for relays and other elements installed inside the cabinets tested (their HCLPF seismic margin capacity was generally observed to be less than 0.10g).

(e) CKTI has also supplied important information about seismic tests of WWER-440/213 and WWER-1000 control rods. These results indicate that the functional characteristics of control rods strongly depend on the level of seismic input. The time of their accident insertion is significantly increased when subjected to strong seismic motion.

Results

The results that have been obtained within the scope of this task, and in particular those which are presented in the references, include the following basic information:

- description of the equipment component tested,
- summary of testing methodology and standards used,
- description of testing devices,
- description of applied seismic inputs,
- summary of critical functional parameters controlled or checked during the test,
- results of seismic testing in the form of tables and graphs,
- conclusion as to the qualification of the tested equipment component for the given seismic input and comments.

Applicability of results

The results obtained within the scope of this task can be used as follows:

- for seismic qualification of the same or similar equipment components and the same or smaller seismic input,
- as an example of how to build seismic experience database using already performed seismic tests,
- to understand differences between the Soviet/Russian and Western or current international seismic testing procedures.

Results obtained by VNIIAM and AEP have significant practical importance for both referenced NPPs.

It should also be emphasized that the results relating to the seismic behaviour of control rod systems that have been presented by CKTI are significant and directly applicable to the Paks and Temelin NPPs.

Lessons learned

Valuable information has been extracted from preliminary seismic tests which can be used in at least two ways:

- to demonstrate for both the Paks and Kozloduy NPPs the adequacy (or not) of the seismic capacity of tested components and to show means by which they could be upgraded if necessary,
- as an additional background for a database on the WWER-type equipment of earthquake experience (GIP-WWER),

There are still significant differences between the original and current Soviet/Russian seismic test approaches and the corresponding procedures in accordance with the current international documents.

Conclusions and recommendations

Earthquake experience data, and in particular those obtained from already performed seismic tests were recognized as a useful basis for a simplified verification procedure for the seismic adequacy of different types of equipment components. This work should continue and the collection procedure should be based on a pragmatic basis, as proposed in Task 22.

7.2. EXPERIENCE DATA FROM VRANCEA AND ARMENIA EARTHQUAKES (TASK 12) AND EVALUATION OF VRANCEA HAZARD (TASK 28)

Objectives

The objective of this task was to present comprehensive information about the following significant earthquakes:

- the Armenia earthquake (7 December 1988),
- the earthquakes in the Vrancea area of Romania over some 60 years (from 1940 to the present).

Summary of work done

There are three basic documents in relation to this task:

(a) The first is the report prepared by EQE in which a detailed description of the Armenia earthquake and its consequences is presented with the main emphasis on the following aspects:

  - geology and seismology of the area,
  - Soviet building design and earthquake performance,
  - consequences of this earthquake as recognized during inspection of industrial and power facilities in this area.

(b) The second and third documents were prepared by S&A–RO and consist of the following:

  - collection of available information about the earthquakes in the Vrancea area,
  - probabilistic hazard analysis of earthquakes in Vrancea,
  - determination of some relationships and correlations between the focal depth, earthquake magnitude and local soil conditions.

These documents provide information on several important earthquakes in the Vrancea region which affected Romania and its neighbouring countries, including the Kozloduy NPP site. The reports also include the investigation of the seismic performance and adequacy of mechanical and electrical equipment components installed in affected industrial facilities.

Lessons learned

The Armenia earthquake provides lessons and interesting observations which are generally useful and applicable to industrial facilities and in particular to power plants.

(a) Extensive damage was sustained by industrial facilities within the epicentral area. While the majority of damage can be attributed to poor design and construction resulting in complete collapse, several conclusions can be drawn:

  - properly engineered and constructed structures would have been essential in preventing the extensive loss of life, capital, jobs, and financial loss due to business interruption that occurred in this earthquake (the dominant contributors to building damage were structural element connections, floor-to-wall connections and beam-to-column connections),
  - properly anchored equipment, when structural collapse did not occur, was undamaged in those areas with the highest shaking intensity (unanchored equipment performed poorly and it is a lesson repeated in nearly all major earthquakes affecting industrial facilities).

(b) The effects on power facilities in the epicentral area were much less severe than for industrial facilities. General conclusions related to power facility performance are:

  - as shown in past earthquakes, high-voltage switchyard equipment shows the greatest susceptibility to damage (particularly vulnerable are large high-voltage transformers on wheels supported by rails with no restraints),
  - switchyard insulator damage is generally minor,
  - unanchored on marginally anchored electrical and I&C cabinets and panels are susceptible to damage,
  - unrestrained station batteries are extremely susceptible to damage and properly restrained batteries and racks are necessary to ensure continued power for control and instrumentation function during and after an earthquake,

(c) Units 1 and 2 of the Armenian VWWER-440 type NPP are located some 75 km south of the epicenter. Officials reported that the 7 December earthquake caused neither scram nor damage at the plant. Following the earthquake, the plant was shut down for a safety inspection.

Very interesting and useful data relating to the performance of structures and equipment of three Romanian power plants (Bucharest West, Bucharest South and Brazi) during and after the 1977, 1986 and 1990 earthquakes are summarized in the document here below.

(a) Power Plant Bucharest West (two units 125 MWe)

  - During the 1977 earthquake, the turbine roof collapsed and fell on the operating turbo-generator (triggering plant shutdown). The turbine cooling and lubricating systems were damaged and the turbine bearings melted. The main damages reported were due to building structure damage. Some steam boiler systems were damaged due to the collapse of structural parts.
  - No damages were observed during the 1986 and 1990 earthquakes.

(b) Power Plant Bucharest South (two 50 MWe units, two 100 MWe units and two 130 MWe units)

- Unit 1 (50 MWe)
  - 1977 earthquake: unit shut down due to blackout, no damage reported
  - 1986 earthquake: unit shut down due to turbine trip, failure of cooling pipe system and pre-heat low pressure system, the steam regulator was damaged due to a nozzle break
  - 1990 earthquake: no damage reported.
- Unit 2 (50 MWe)
  - 1977 earthquake: unit shut down triggered automatically, no damage reported
  - 1986 earthquake: unit shut down triggered automatically, no damage reported
  - 1990 earthquake: no shut down, no damage.
- Unit 3 (100 MWe)
  - 1977 earthquake: unit shut down, no damage reported
  - 1986 earthquake: unit shut down, no damage reported
  - 1990 earthquake: no shut down, no damage reported.
- Unit 4 (100 MWe)
  - 1977 earthquake: unit shut down, no damage reported
  - 1986 earthquake: unit shut down, no damage reported
  - 1990 earthquake: unit shut down, no damage reported.
- Unit 5 (130 MWe)
  - 1977 earthquake: unit shut down, oil pump failure, turbine bearings damaged, oil pipes damaged, one transformer damaged
  - 1986 earthquake: no shutdown, a crack was detected on the medium pressure pipe system
  - 1990 earthquake: no shutdown, no damage reported.
- Unit 6 (130 MWe)
  - 1977 earthquake: unit shut down, damages were detected on the supporting steel structure of the steam boiler and on the main steam line supports
  - 1986 earthquake: no shutdown, no damage reported
  - 1990 earthquake: no shutdown, no damage reported.

(c) Brazi power plant (only data on electrical equipment components are available)

- electrical panels and cabinets (6 kV and 0.4 kV) – no damage,
- transformers – displacement or jump
- batteries – damage due to lack of anchorage

Conclusions and recommendations

It is generally recommended to perform detailed seismic investigation walkdowns after each significant earthquake, as already proposed by many investigators. Results of such walkdowns can be widely used as an additional background to already existing earthquake experience database for indirect verification of the seismic adequacy of WWER type NPP structures and equipment.

7.3. EXPERIENCE DATA FROM EARTHQUAKES IN THE USA (TASK 13)

Objectives

The objective of this task was to perform a detailed summary of the US earthquake experience database.

Summary of work done

Well known, strong motion earthquakes frequently occur throughout the Pacific Basin, where many power plants and other industrial facilities are located. By studying the seismic performance of these facilities and their equipment in particular, a large inventory can be compiled of various types of equipment items that have experienced substantial seismic motion.

The primary purposes of the seismic experience database are summarized as follows:

- to determine the most common sources of seismic damage, or adverse effects, on equipment items typical of industrial facilities,
- to determine the thresholds of seismic motion corresponding to various types of seismic damage,
- to determine the general performance of equipment during earthquakes, regardless of the levels of seismic motion,
- to determine minimum standards in equipment construction and installation, based on past experience, to assure the ability to withstand anticipated seismic effects.

The primary assumption in compiling an experience database is that the actual seismic hazard to industrial facilities is best demonstrated by the performance of similar installations in past earthquakes.

Results

Standard procedures used in surveying database facilities focus on collecting all information on damage or adverse effects of any kind caused by the earthquake. A summary of sites reviewed in compiling experience database is presented in the references to the reports developed in this task.

Because of the extent of the changes in the requirements for seismic qualification of equipment over the years, the U.S. Nuclear Regulatory Commission (NRC) initiated Unresolved Safety Issue (USI) A-46 “Seismic Qualification of Equipment in Operating Plants” in 1980. The purpose of USI A-46 was to verify the seismic adequacy of essential equipment in older operating plants not qualified in accordance with more recent criteria.

The use of seismic experience for verification of seismic adequacy of existing power plants, the seismic design basis of which does not meet current regulatory standard criteria, was suggested as a prospective and practical solution to this USI. To this end, a Seismic Qualification Utility Group (SQUG) was formed to jointly develop a methodology based on seismic experience to resolve USI A-46. Over about 15 years, performance data from major earthquakes were collected and compiled into a comprehensive database. The data were studied to determine what attributes of the equipment led to seismic failures and which attributes were inherently rugged. Tentative screening rules were then proposed. These proposed rules were extensively reviewed by a Senior Seismic Review and Advisory Panel (SSRAP) composed of industry experts.

Ultimately, comprehensive and systematic criteria for assessing the seismic adequacy of operating NPPs were assembled into a Generic Implementation Procedure (GIP) which was approved for use by the US NRC.

The second document also prepared by EQE presents several interesting examples of practical applications of the US earthquake experience database to the verification of the seismic adequacy of some WWER-type equipment components.

Applicability of results

This task was performed as an information summary only and its results are not directly applicable for evaluation of WWER-type equipment components. However, it is the best example and a tool for putting together a pragmatically comparable seismic database for European or other equipment components. In general, the seismic experience based methodology

The SQUG database consists primarily of the performance equipment manufactured in the USA However, there is a substantial amount of equipment in the database manufactured by western European and Japanese suppliers. The GIP methodology may be also applied for WWER-type equipment components, if the experienced seismic capability engineers are sure that the verified equipment components are similar to those presented in the SQUG database.

Conclusions and recommendations

More than 15 years ago earthquake experience data was recognized in the U.S.A. as an effective basis for a simplified and indirect seismic verification procedure mostly for mechanical and electrical equipment components.

This is an ongoing process described in detail in the literature. Its results are or can be used not only in the USA but worldwide. Seismic experience database is based on systematic collection and processing of experience data on seismic resistance of equipment components.

It means that this process should be continued and extended towards building a database of equipment manufactured in central and eastern Europe and the former Soviet Union which has experienced strong motion earthquakes.

7.4. EXPERIENCE DATABASE (WWER SQUG) INITIATION (TASK 22)

Objectives

The objective of this task was to initiate actions towards the creation of a specific seismic experience database for WWER type equipment.

Summary of work done

This task was performed in parallel with Tasks 11, 12, and 13 with the aid of the following three tools:

- the Windows-based EXPDB software for collection, evaluation, documentation and storage of seismic experience data as performed and proposed by S&A-R,
- the seismic experience and test data collected from three Romanian earthquakes and also from a set of seismic tests performed by Eurotest SA,
- the expert system GIP-WWER for verification of seismic adequacy of WWER equipment as performed and proposed by S&A-CZ.

The EXPDB software is a good tool for practical collection, evaluation, documentation and storage of seismic experience data received from already performed seismic tests and analyses and post-earthquake walkdowns. The database created by this software includes the following information:

- equipment descriptors
- size, weight, and manufacturer/model code number,
- year of testing/seismic event,
- type of tests performed and test documentation or seismic event information,
- anchorage description,
- quantification of available test response spectra or seismic review team report,
- any exceptions or comments related to performance during testing or seismic event,
- description of observed failures or malfunctions.

After all the information has been entered into the database, it is reviewed and independently checked for accuracy.

The seismic experience data already collected from seismic tests performed by Eurotest SA include the following equipment classes:

- different types of valves and valve drivers,
- vertical and horizontal pumps
- low voltage switchgears,
- instruments and instrument racks,
- fans,
- control panels and several I&C cabinets,
- temperature and other sensors.

The seismic experience data already collected from walkdowns performed after three strong Vrancea earthquakes in 1977, 1986 and 1990 cover (several items per equipment class):

- vertical and horizontal liquid storage tanks,
- heat exchangers and similar components (condenser coolers etc.),
- fans,
- horizontal and vertical pumps,
- air compressors,
- engine generators,
- piping,
- motor, fluid and hand operated valves and valve drivers,
- steam boilers, turbines, turbogenerators,
- distribution panels,
- transformers,
- battery racks,
- I&C panels,
- electrical cabinets, medium and low voltage switchgears.

These data, together with other data collected by S&A-CZ from already performed seismic tests and seismic analyses, provide additional background information for the modified Generic Implementation Procedure (GIP) entitled GIP-WWER. The GIP-WWER procedure has been prepared using available public information on the original GIP and this additional background.

As shown in Fig. 7.2, the GIP-WWER is primarily a screening procedure. The basic criteria to verify seismic adequacy of an equipment item during the screening walkdown are:

- seismic capacity greater than seismic demand,
- similarity of the equipment item in the seismic experience database,
- adequate anchorage of equipment,
- potential seismic interactions evaluated.

The scope of equipment covered by the current version of GIP-WWER is more or less identical with the scope covered by GIP. The following generic classes of mechanical and electrical equipment are included:

- motor control centres,
- low and medium voltage switchgears,
- transformers,
- horizontal and vertical pumps,
- fluid, motor, and solenoid operated valves,
- ventilators,
- air handlers and chillers,
- air compressors,
- motor and engine generators,
- distribution panels,
- batteries on racks and battery chargers and inverters,
- instruments on racks,
- temperature sensors,
- I&C panels and cabinets.

European and particularly WWER type relays, switches, transmitters, and electric penetrations are quite different from those which are included into the original U.S. seismic experience database. Therefore, these classes of equipment have been excluded from the GIP-WWER and their seismic qualification should be based mostly on testing.

In addition, this procedure includes guidelines for simplified seismic evaluation of the following classes of equipment:

- vertical and horizontal tanks,
- vertical and horizontal heat exchangers,
- cable and conduit raceway systems,
- small bore and large bore pipes,
- HVAC ducts,
- anchorage of equipment (special guidelines).

Applicability of results

The EXPDP software is a good tool for practical collection, evaluation, documentation and storage of seismic experience data received from seismic tests, analyses and post-earthquake walkdowns.

This seismic experience data, together with other data collected by S&A-CZ from performed seismic tests and seismic analyses represent an important additional background for the modified Generic Implementation Procedure (GIP) designated as GIP-WWER. The GIP-WWER procedure has been prepared using available public information about the original GIP and this additional background.

The GIP-WWER expert system (computer version of the GIP–WWER procedure) is generally applicable to the verification of seismic adequacy of WWER–type equipment.

However, the GIP-WWER screening criteria must be used with caution and with additional engineering justification. Some classes of WWER type equipment are still not adequately represented in the seismic experience database.

Lessons learned

The seismic experience data collection, review and validation must be a continuous activity. The database will become fully operational when each class of equipment will have between 20 and 30 or more records.

Conclusions and recommendations

It is anticipated that:

(1) the already initiated seismic experience database collection, review and validation will continue for typical WWER type mechanical and electrical equipment components, as recommended by many investigators,

(2) the GIP-WWER will become a more or less standard procedure for verification of seismic adequacy of equipment installed on existing WWER type NPPs.

The data collection, review and validation must be ongoing. The database will become fully operational when each class of equipment considered will have between 20 and 30 or more records.

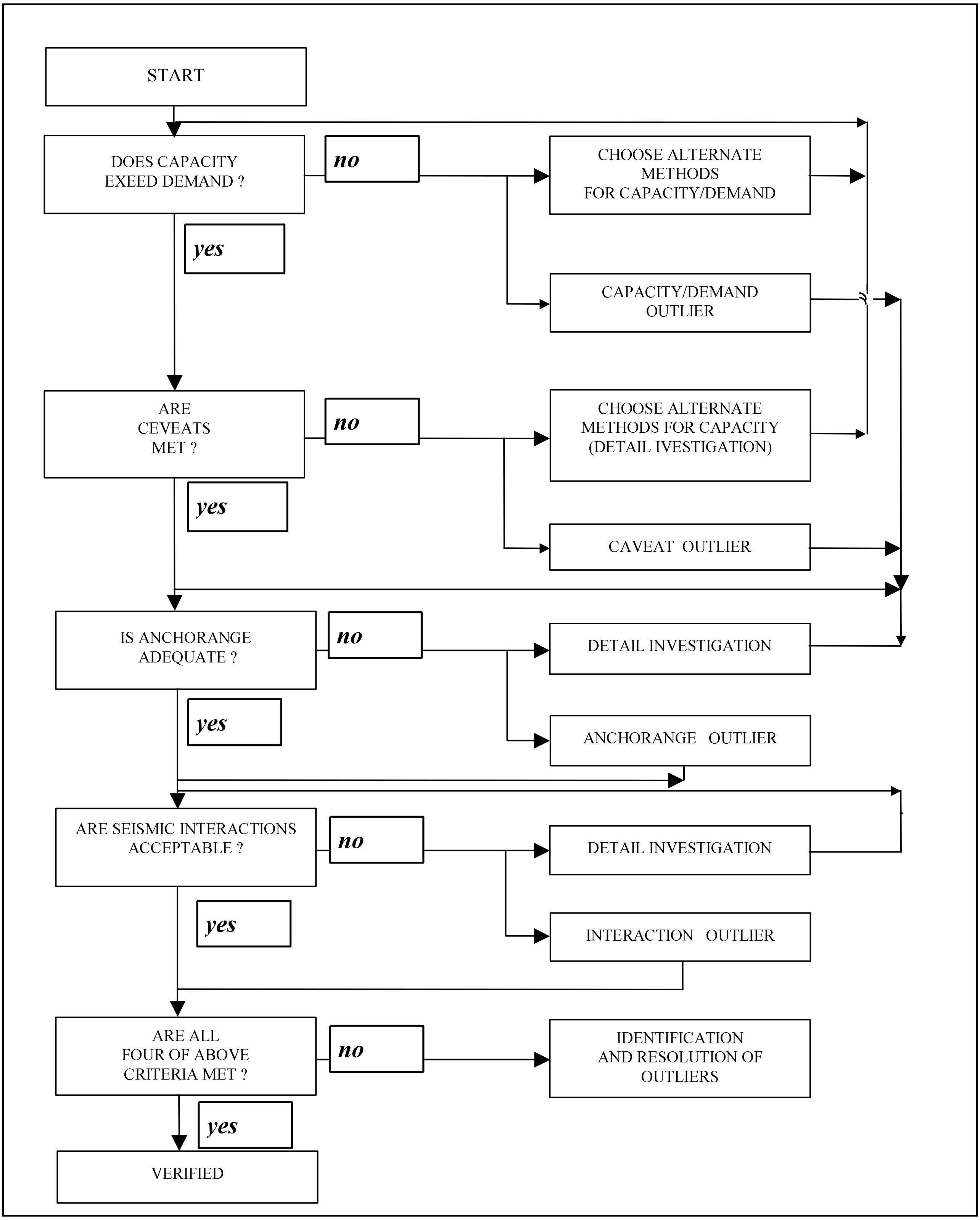

FIG. 7.2. Screening verification and walkdown procedure of GIP-WWER.

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Chapter 8

RECOMMENDATIONS FOR FUTURE RESEARCH

The recommendations collected in this chapter can essentially be grouped in two categories, related to the main targets of the CRP:

- the demand for a general, agreed assessment of guidelines and criteria for the seismic re-evaluation of existing plants, including all the facilities relevant to safety;
- the full understanding of the engineering results of the benchmark, which is preliminary to further research in the field of the seismic response of soil, structures, components and equipment.

Both categories can drive the scientific community towards future activities in the field. The conclusions of the CRP and the identification of future tasks represent a great success for the CRP: plant authorities were in fact able to devote efforts towards a better selection of their suppliers, more technically substantiated workplans, more focused research tasks, thereby achieving a general improvement in the reliability of their action.

(1) The full scale blast tests have shown their value in seismic re-qualification of large existing structures for their intrinsic capability to represent the true structural transfer functions. Numerical codes in fact have shown a strong dependency from a set of engineering assumptions about initial data and boundary conditions, reflected in their mathematical formulations, which are not always applicable to physical reality.

A collection of guidelines and recommendations dedicated to the seismic re-qualification of existing structures has been further requested, with special emphasis on the optimal balance of tests and numerical analyses able to provide reliable planning for large seismic upgrading investments.

(2) The results from the blast tests for the Paks and Kozloduy NPPs and the blind prediction results from the five benchmark participants showed significant differences (to varying degrees for different participants). There were also appreciable differences among the analytical results.

The scattering in soil property assumptions has been generally recognized by the participants as one of the main sources of difference among the results. A systematic error related to wave field modelling has been identified, but not fully inspected.

Therefore, further work is required to explain in detail the root causes for these differences and, possibly, to improve the computer code formulations in the specific functions identified as sources of large uncertainties.

Some final reliability models should validate the hypothesis and confirm the influence of data scattering on result uncertainty, providing new methodologies for input data processing.

A mixed numerical-experimental approach could add reliability to the seismic re-evaluation process: simple excitations, ambient vibration analysis, micro earthquake response analysis and similar techniques could in fact drive and tune the numerical models, reducing the number of expensive geotechnical inspections with the support of modern structural identification techniques. This combination of different techniques should be more deeply investigated in a general framework of global costs and reliability optimization.

(3) From both full scale blast tests, a very substantial amount of data was obtained in the free field (downhole and surface), at different elevations of the structures, the stack and some tanks and components. Most of the data have not been utilized so far. Other comparison studies can be conducted using these records in two main fields: wave propagation in the soil and structural response of the coupled models of soil and structure. One specific way of using the data involves systems identification; i.e. the identification of structural dynamics parameters based on the input and response quantities.

(4) It was recognized that the seismic analysis of buried pipelines involves methods which lie outside the routine analytical procedures applicable to building structures. It is recommended to perform further research on this subject to gain a better understanding of the underlying issues.

(5) In the seismic re-evaluation and upgrading of nuclear facilities (including NPPs), it is important to identify the SSEL in accordance with safety requirements, including consequences of potential failures. This could also be useful for nuclear power plants which are being converted to other nuclear facilities (spent fuel storage). Some work was initiated on a graded approach for seismic categorization of NPP items. It is recommended to pursue this work and if possible provide general guidelines.

(6) For most of the NPPs in eastern Europe the seismic re-evaluation phase has been completed along with some easy fix programmes. The major task in the near future would involve seismic upgrading of structures, a both costly and time consuming proposition. It is recommended to carry out research in the area of methods and concepts of seismic upgrading of typical structures found in WWER NPPs.

(7) Seismic instrumentation in the WWER type NPPs in eastern Europe may be used for triggering alarm systems to initiate operator actions or tripping the plant automatically. The advantages and the disadvantages of automatic seismic scram were discussed and documented earlier. However, the required pre-earthquake preparations and post-earthquake actions (inspections, operator controlled scram, etc.) are still not defined by clear criteria. Research should be conducted to develop these criteria as well as operational procedures.

(8) The seismic re-evaluation and upgrading programme in the USA made extensive and efficient use of earthquake experience data and developed a utility database for further investigations (SQUG). It may be possible to develop a similar database for eastern European NPPs (both for laboratory tests and earthquake experience). The use of such data for new nuclear facilities should also be explored as a viable means for seismic qualification.

Annex

LIST OF DOCUMENTS ISSUED BY THE CRP PARTICIPANTS

(Available at the project officer's office, upon request)

ABBREVIATIONS USED FOR INSTITUTES IN LIST OF DOCUMENTS ISSUED BY THE CRP PARTICIPANTS

Abbreviation	**Institute**	**Country**	**Participants**
AEP	Atomenergoproect – Moscow	Russian Federation	Y. Ambriashvili
ANL/AES	Argonne National Lab. – Argonne	USA	D. Ma
BRI	Building Research Institute – Sofia	Bulgaria	S. Sachanski G. Sachanski
CKTI	CKTI – Vibroseism – St. Petersburg	Russian Federation	V. Kostarev
CL	Bulgarian Academy of Sciences, Central Laboratory for Seismic Mechanics and Earthquake Engineering – Sofia	Bulgaria	M. Kostov
EP	National Electric Company – Sofia	Bulgaria	S. Simeonov
EQE–BG	EQE Bulgaria	Bulgaria	M. Jordanov K. Mihaylov
EQE–US	EQE International Inc. – San Francisco	USA	R.D. Campbell A. Asfura
ISMES	ISMES S.p.A.	Italy	F. Muzzi M. Zola P. Contri
IVO	IVO Group – Vantaa	Finland	P. Varpasuo
IZIIS	Institute of Earthquake Engineering and Engineering Seismology, University "St. Cyril and Methodius" – Skopje	Republic of Macedonia	D. Jurukovski D. Petrovski
KNPP	Kozloduy Nuclear Power Station	Bulgaria	Z. Boyadjiev
MD	Ing. M. David	Czech Republic	M. David
NIED/IHI	Japan Power Engineering and Inspection Corp., National Research Institute for Earth Science and Disaster Prevention	Japan	N. Ogawa T. Chiba
PNPP	Paks Nuclear Power Station – Paks	Hungary	T. Katona
S&A–CZ	Stevenson and Associates, Czech Office	Czech Republic	R. Masopust P. Zeman
S&A–RO	Stevenson and Associates, Bucharest Office	Romania	O. Coman
S&A–US	Stevenson and Associates	USA	J.D. Stevenson
S&P	Stuessi und Partner – Zurich	Switzerland	U. Stuessi
SAGE	SAGE Engineering S.A.	UK	D. Cathie

Abbreviation	**Institute**	**Country**	**Participants**
SAS	Slovak Academy of Sciences, Institute of Construction and Architecture – Bratislava	Slovak Republic	E. Juhásová
SIEMENS	Siemens AG – Offenbach	Germany	N. Krutzik P. Halbritter
VNIIAM	All-Russia Scientific Research Institute of Atomic Machine Construction – Moscow	Russian Federation	S. Kaznovsky
WESE	Westinghouse Energy Systems Europe – Brussels	Belgium	P. Monette G. Dellopoulos
WO	Woelfel Beratende Ingenieure GmbH & Co. – Hoechberg bei Wuerzburg	Germany	F. Henkel

LIST OF DOCUMENTS ISSUED BY THE CRP PARTICIPANTS

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
AEP	Y. Ambriashvili	October 1994	Design Floor Response Spectra for Kozloduy NPP	Background Documents Vol. 1
AEP	Y. Ambriashvili	June 1994	Seismic Stability of NPPs in Eastern Europe	Background Documents Vol. 2
AEP	Y. Ambriashvili	September 1995	Analysis of Design Floor Response Spectra and Testing of Electrical Systems	Background Documents Vol. 3E
AEP	Y. Ambriashvili	December 1995	Testing of Components on the Shaking Table Facilities of AEP and Contribution to Full Scale Dynamic Testing of Kozloduy NPP	Background Documents Vol. 3E
AEP	Y. Ambriashvili	1996–1997	Shaking Table Tests of Electrical Equipment of Unified NPP	Not included in the Background Documents
AEP	Y. Ambriashvili	October 1994	Design Floor Response Spectra for Kozloduy NPP	Background Documents Vol. 3H
AEP	Y. Ambriashvili	December 1995	Testing of Components on the Shaking Table Facilities of AEP and Contribution to Full Scale Dynamic Testing of Kozloduy NPP – Final Report	Background Documents Vol. 3H
AEP	Y. Ambriashvili	December 1996	Seismic Stability of Nuclear Power Plants in Eastern Europe	Not included in the Background Documents
AEP	Y. Ambriashvili	February 1997	Testing and Probabilistic Analysis of Seismic Stability of the Electrical Equipment of Unified Type WWER-1000	Background Documents Vol. 3H
ANL/AES	D. Ma	June 1995	Analysis and Testing of Model Worm Type Tanks	Not included in the Background Documents
ANL/AES	D. Ma	June 1995	Analysis and Testing of Model Worm Type Tanks on Shaking Table	Background Documents Vol. 4D
AN L/AES	D. Ma	Unknown	Experimental Study of the Fluid-Structure Interaction Behaviour of the Worm Tank	Not included in the Background Documents
BRI	S. Sachanski	April 1994	Experimental Investigations and Seismic Analyses for Benchmark Study of 1000 MW WWER Type	Background Documents Vol.3B

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
			(Water Cooled and Water Moderated Reactor) NPP Kozloduy	
BRI	S. Sachanski	November 1995	Experimental Investigations and Seismic Analysis for Benchmark Study of 1000 MW WWER Type Units	Background Documents Vol. 3E
BRI	S. Sachanski	Unknown	IAEA Benchmark Study for 1000 MW Units NPP Kozloduy – Stages I to III	Not included in the Background Documents
BRI	S. Sachanski	December 1994–December 1996	Experimental Investigations and Seismic Analysis for Benchmark Study of 1000 MW WWER Type Units – Kozloduy NPP	Not included in the Background Documents
BRI	S. Sachanski	October 1995	Experimental Investigations and Seismic Analysis for Benchmark Study of 1000 MW WWER Type Units – Kozloduy NPP	Background Documents Vol. 3I
BRI	S. Sachanski	November 1994–May 1995	Experimental Investigations and Seismic Analysis for Benchmark Study of 1000 MW WWER Type Units – Kozloduy NPP – First Stage	Not included in the Background Documents
BRI	S. Sachanski	December 1995–December 1996	Experimental Investigations and Seismic Analysis for Benchmark Study of 1000 MW WWER Type Units – Kozloduy NPP	Not included in the Background Documents
BRI	S. Sachanski	December 1996	Experimental Investigations and Seismic Analysis for Benchmark Study of 1000 MW WWER Type Units – Kozloduy NPP	Background Documents Vol. 3I
BRI	S. Sachanski	May–August 1995	Experimental Investigations and Seismic Analysis for Benchmark Study of 1000MW WWER Type – Kozloduy NPP	Not included in the Background Documents
BRI	S. Sachanski	December 1997	IAEA Benchmark Study for 1000 MW Units, Kozloduy NPP	Not included in the Background Documents
CKTI	V. Kostarev	June 1994	WWER 440–213 NPP: Primary Coolant Loop: Seismic Analysis with Different Antiseismic Devices	Background Documents Vol. 4A

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
CKTI	V. Kostarev	October 1995	Evaluation of Potential Hazard for Operating WWER Control Rods under Seismic Excitation	Background Documents Vol. 4D
CKTI	V. Kostarev	October 1995	Evaluation of Potential Hazard for Operating of Water cooled and Water Moderated Reactor (WWER) Control Rods under Seismic Excitation. Experimental and Computer Analysis Approaches.	Background Documents Vol. 3H
CKTI	V. Kostarev	June 1996	Seismic Analysis of the WWER-1000 Control Rod Drive System	Not included in the Background Documents
CKTI	V. Kostarev	June 1996	ASME BPVC and PNAE Comparative Seismic Analysis of the WWER-1000 Unit Primary Coolant Loop System	Not included in the Background Documents
CKTI	V. Kostarev	February 1997	Evaluation of Potential Hazard for Operating of Water cooled and Water Moderated Reactor (WWER) Control Rods under Seismic Excitation. Experimental and Computer Analysis Approaches – Seismic Analysis of the WWER-1000 Control Drive System	Not included in the Background Documents
CKTI	V. Kostarev	October 1997	CKTI-Vibroseism Study – Parts I to IV	Background Documents Vol. 2B
CL	M. Kostov	October 1994	Seismic Soil-Structure Equipment Interaction Analysis of Units 5/6, Kozloduy NPP	Background Documents Vol. 3B
CL	M. Kostov	June 1996	Response of the Main Building, PAKS NPP (Hungary) to Explosion Input Motion	Background Documents Vol. 4F
CL	M. Kostov	January 1996	Probabilistic Seismic Response and Capacity Assessment of Kozloduy NPP Units 5/6	Background Documents Vol. 3G
CL	M. Kostov	December 1996	Blind Prediction of the Results of NPP PAKS Full Scale Dynamic Testing	Not included in the Background Documents
CL	M. Kostov	October 1997	Response of the Main Building, Unit 5, Kozloduy NPP (Bulgaria) to an Explosion Input Motion	Background Documents Vol. 3G
EP	S. Simeonov	June 1994	Soil Liquefaction Testing and Evaluation for	Background Documents

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
			Kozloduy NPP Units 5 and 6	Vol. 3B
EP	S. Simeonov	February 1996	Final Report on Soil Liquefaction Testing and Evaluation for Kozloduy NPP Units 5/6.	Background Documents Vol. 3I
EQE-BG	M. Jordanov	October 1994	Structural Response of Kozloduy 1000 MW WWER	Background Documents Vol. 3C
EQE-BG	M. Jordanov	June 1995	Structural Response of PAKS NPP Main Reactor Building	Background Documents Vol. 4D
EQE-BG	M. Jordanov	Unknown	Seismic Qualification of Hard Disk Drive CM-5400	Not included in the Background Documents
EQE-BG	M. Jordanov	June 1995	Structural Response of PAKS 440 MW Main Reactor Building	Not included in the Background Documents
EQE-BG	M. Jordanov	June 1995	Structural Response of PAKS 440 MW Main Reactor Building	Not included in the Background Documents
EQE-BG	M. Jordanov	June 1996	Structure Response of Paks NPP 440 MW Main Reactor Building – Progress Report	Not included in the Background Documents
EQE-BG	M. Jordanov	April 1997	Structural Capacity Assessment of WWER-1000 MW Reactor Containment	Background Documents Vol. 3G
EQE-BG	M. Jordanov	May 1997	Structural Response of PAKS NPP WWER-440 MW Main Building Complex to Blast Input Motion – Final Report	Background Documents Vol. 4G
EQE–BG	M. Jordanov	June 1996	Blast Input Motion Response of PAKS NPP 440 MW Main Building Complex	Not included in the Background Documents
EQE–BG	M. Jordanov	October 1997	Blast Input Motion Response of Kozloduy NPP 1000 MW Reactor Building Structure	Background Documents Vol. 3G
EQE–BG	M. Jordanov	October 1997	Blast Input Motion Response of PAKS NPP 440 Main Building Complex	Not included in the Background Documents
EQE-US	R.D. Campbell	June 1995	The 7 December 1988 Armenia Earthquake effects on selected power, Industrial and Commercial Facilities	Background Documents Vol. 5B
EQE-US	A. Asfura	June 1994	Summary of IAEA Research Co-ordination	Not included in the

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
			Meeting for Benchmark Studies for Seismic Analysis and Testing of WWER NPPS	Background Documents
EQE-US	R.D. Campbell	June 1995	Use of Seismic Experience Data for Seismic Verification of WWER Reactors	Not included in the Background Documents
EQE-US	R.D. Campbell	October 1997	Summary of the Earthquake Experience Database	Background Documents Vol. 5C
EQE-US	A. Asfura	October 1997	Analysis of Buried Pipelines at Kozloduy	Background Documents Vol. 3H
IHI, NIED		October 1997	A Seismic Analysis of Worm Tank	Not included in the Background Documents
ISMES	F. Muzzi	January 1994	Review of Studies Pertaining to the Seismic Input at PAKS NPP	Background Documents Vol. 1
ISMES	F. Muzzi	May 1994	Revision Report about the On site Tests of 1000 MW Unit 5 Kozloduy (Bulgaria)	Background Documents Vol. 3A
ISMES	F. Muzzi	September 1994	Review Report on the Dynamical Study of the Main Building of the PAKS NPP	Background Documents Vol. 4B
ISMES	P. Contri	June 1995	Optimal Organization of Structural Analysis and Site Inspection for the Seismic Re-qualification of PAKS NPP	Background Documents Vol. 4D
ISMES	P. Contri	June 1994	A General Procedure for the Optimal Organization of Structural Analysis and Site Inspection of Existing NPPs	Not included in the Background Documents
ISMES	F. Gatti	September 1994	Review Report of the Dynamical Study of The Main Building of the PAKS NPP	Background Documents Vol. 4E
ISMES	E.M. Da Rin	March 1995	Full Scale Dynamic Testing of PAKS Nuclear Power Plant Structures	Not included in the Background Documents
ISMES	R. Fregonese	May 1995	Optimal Organization of Structural Analysis and Site Inspection for the Seismic Requalification of the Nuclear Power Plant of PAKS, Hungary	Background Documents Vol. 4E
ISMES	E.M. Da Rin	May 1995	Full-Scale Dynamic Testing of PAKS Nuclear	Not included in the

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
			Power Plant – Measurement Instrumentation Locations and Free-Field Response Data	Background Documents
ISMES	E.M. Da Rin	June 1996	Full-Scale Dynamic Testing of PAKS Nuclear Power Plant Structures	Background Documents Vol. 4E
ISMES	E.M. Da Rin	December 1996	Full-Scale Dynamic Testing of Kozloduy NPP Unit V Structures	Not included in the Background Documents
ISMES	M. Zola	April 1997	Task 7a – Dynamic Analysis of PAKS NPP Structures: Reactor Building	Background Documents Vol. 4E
ISMES	M. Zola	July 1997	Task 24 – Dynamic Analysis of Kozloduy NPP Unit 5 Structures: Reactor Building	Not included in the Background Documents
IVO	P. Varpasuo	October 1997	Blast Excitation Response of Kozloduy Unit 5 WWER-1000 NPP Reactor Building	Background Documents Vol. 4F
IVO	P. Varpasuo	December 1997	IVO Participation in IAEA Benchmark for WWER-Type NPPs Seismic Analysis and Testing	Background Documents Vol. 3F
IZIIS	D. Jurukovski	June 1995	Seismic Functional Qualifications of Active Mechanical and Electrical Component based on Shaking table Testing	Background Documents Vol. 5B
IZIIS	D. Jurukovski	Unknown	Seismic Functional Qualification of Active Mechanical and Electrical Components Based on Shaking Table Testing – Final Report	Not included in the Background Documents
IZIIS	D. Jurukovski	Unknown	Seismic Testing of Relays Used on NPP “Kozlody” Unit 5	Background Documents Vol. 3H
IZIIS	D. Jurukovski	Unknown	Seismic Functional Qualification of Active Mechanical and Electrical Components Based on Shaking Table Testing – Progress Report	Not included in the Background Documents
IZIIS	D. Jurukovski	January 1995	Seismic Functional Qualification of Active Mechanical and Electrical Components Based on Shaking Table Testing	Background Documents Vol. 3H
IZIIS	D. Jurukovski	December 1995	Expert Evaluation of Technical Documentation “Analysis of Structures of Blocks 1–5 of the	Background Documents Vol. 3H

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
			Kozloduy NPP for the Seismic Effect of Local Earthquakes”	
IZIIS	D. Jurukovski	June 1996	Dynamic Response of the PAKS NPP Chimney	Background Documents Vol. 4G
IZIIS	D. Jurukovski	December 1996	Seismic Functional Qualification of Active Mechanical and Electrical Components Based on Shaking Table Testing – Application of the Methodology and Criteria to Selected Test Specimen	Background Documents Vol. 3H
IZIIS	D. Jurukovski	October 1997	Dynamic Response of the PAKS NPP Chimney	Not included in the Background Documents
KNPP	Z. Boyadjiev	June 1994	Drawings Kozloduy NPP	Background Documents Vol. 1
KNPP	Z. Boyadjiev	June 1994	Initial Data of Seismic Input and Soil Conditions of Kozloduy NPP Site	Background Documents Vol. 1
KNPP	S. Simeonov	November 1994	Full Scale and On site Tests on the Structures and Sites of Kozloduy and Belene NPPs	Background Documents Vol. 1
KNPP	Z. Boyadjiev	1994	Investigations Related to Failure of Pre-stressing Tendons	Background Documents Vol.3A
KNPP	Z. Boyadjiev and M. Kostov	June 1995	Floor Response Spectra of WWER-1000, NPP Kozloduy Generated from Local Seismic Excitation	Background Documents Vol. 3E
KNPP	Z. Boyadjiev and M. Kostov	June 1995	Floor Response Spectra of WWER-1000, NPP Kozloduy Generated from Local Seismic Excitation	Background Documents Vol. 3E
KNPP	Z. Boyadjiev	Unknown	Full-Scale Dynamic Testing of Buildings and Equipment at Unit 5 of Kozloduy NPP – Final Report	Not included in the Background Documents
MD	M. David	1993–1994	Standards, Criteria, Comparative Study – Final Report 1993–1994	Background Documents Vol. 2

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
MD	M. David	October 1994	1st Draft: Seismic Analyses of Structures	Background Documents Vol. 4A
MD	M. David	December 1994	Seismic Analyses of Paks RB	Background Documents Vol. 4A
MD	M. David	Unknown	Blast Excitation Response of Kozloduy Unit 5 WWER-1000 NPP Reactor Building	Background Documents Vol. 3I
MD	M. David	Unknown	Task – Dynamic Analysis of Paks NPP Structures Reactor Building	Not included in the Background Documents
MD	M. David	April 1996	Task 7a: Dynamic Analysis of Paks NPP Structures Reactor Building	Background Documents Vol. 4G
NIED/IHI			Part 4 - Plan of Shaking Table Test of Worm Tank Model	Background Documents Vol. 4G
NIED/IHI		June 1996	Analysis and Testing of 1/3 Scaled Worm Tank	Not included in the Background Documents
NIED/IHI		March 1998	Task 7c. Worm Tank – Parts 1–3	Background Documents Vol. 4G
NIED/IHI		June 1996	Preliminary Report of the Vibration Test of the 1/3 Scale Worm Tank Model	Background Documents Vol. 4F
NIED/IHI		June 1995	Vibration Test of a Worm Tank Model	Background Documents Vol. 4D
PNPP	T. Katona	1983	Reference Book: Paks Nuclear Power Plant, Blocks 3 and 4	Background Documents Vol. 1
PNPP	T. Katona	April 1992	Seismic Safety Programme at NPP Paks	Background Documents Vol. 1
PNPP	T. Katona	1993	Experimental and Analytical Investigation of Paks NPP Building Structures	Background Documents Vol. 1
PNPP	T. Katona	September 1994	Isometric Drawings, Paks NPP	Background Documents Vol. 1
PNPP	T. Katona	May 1993	Geological Evaluation of the Paks NPP site	Background Documents Vol. 1

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
PNPP	T. Katona	May 1993	Seismic Safety of Paks NPP	Background Documents Vol. 1
PNPP	T. Katona	April 1993	Dynamical Study of the Main Building of the Paks NPP	Background Documents Vol. 4B
PNPP	T. Katona	1994	Shake Table Investigation at Paks NPP	Background Documents Vol. 4B
PNPP	T. Katona	June 1996	Experimental Modal Analysis of the Low-Pressure Emergency Core Cooling System (LP ECCS) Tank of the Unit No.1 NPP Paks	Not included in the Background Documents
PNPP	T. Katona	November 1996	Co-ordinated Research Programme, Benchmark Study for Seismic Analysis and Testing of WWER-Type NPPs	Not included in the Background Documents
PNPP	T. Katona	1997	Analysis of the Dynamic Behaviour of the Low-Pressure Emergency Core Cooling System Tank at Paks NPP	Background Documents Vol. 4F
S&A-CZ	R. Masopust	June 1995	Seismic Margin Assessment and Earthquake Experience based on methods for WWER-440/213 Type NPPs	Background Documents Vol. 4D
S&A-CZ	R. Masopust	October 1997	Expert System GIP-WWER for Verification of Seismic Adequacy of WWER Equipment	Background Documents Vol. 2B
S&A-CZ	R. Masopust	June 1996	Summary of Research Performed Since 1995	Not included in the Background Documents
S&A-CZ	R. Masopust	October 1997	Summary of Research Performed Since 1996 and Final Summary	Background Documents Vol. 4G
S&A-CZ	P. Zeman	October 1997	Evaluation of Seismic Resistance of Low Voltage Switchgear, NNP V1 Jaslovske Bohunice, Slovakia	Background Documents Vol. 4G
S&A-CZ	R. Masopust	October 1997	Guidelines for Evaluation of Anchorage Adequacy for Safety-Related Equipment Typically Used in	Background Documents Vol. 2B

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
			WWER Type NPPs	
S&A–CZ	R. Masopust	September 1994	Original Seismic Design Data and Application of SMA & GIP Methodologies – Volume 1	Background Documents Vol. 2
S&A-RO	O. Coman and J.D. Stevenson	November 1995	Experience Database of Romanian Facilities Subjected to the Last Three Vrancea Earthquakes	Background Documents Vol. 5A
S&A-RO	O. Coman	Dec 1996	Final Report Summary of Experience Database of Romanian Facilities Subjected to the Last Three Vrancea Earthquakes	Background Documents Vol. 5C
S&A-RO	O. Coman	March 1995	Experience Database of Romanian Facilities Subjected to the Last Three Vrancea Earthquakes	Background Documents Vol. 5C
S&A-RO	O. Coman	Oct 1995	Final Report – Experience Database of Romanian Facilities Subjected to the Last Three Vrancea Earthquakes	Background Documents Vol. 5C
S&A-RO	O. Coman	March 1995	Research Report – Part I – Probabilistic Hazard Analysis to the Vrancea Earthquakes in Romania	Not included in the Background Documents
S&A-RO	O. Coman	October 1997	Test and Experience Database – Vrancea Earthquake Data	Not included in the Background Documents
S&A–US	J.D. Stevenson	December 1994	Criteria for Seismic Evaluation and Potential Design Fixes for WWER Type NPPs	Background Documents Vol. 2
S&P	U. Stuessi et al.	January 1996	Piping systems, Containment Pre–Stressing and Steel Ventilation Chimney	Background Documents Vol. 3E
SAGE	D. Cathie		Dynamic Analysis of Ventilation Stacks – Paks NPP	Not included in the Background Documents
SAGE	D. Cathie	October 1997	Paks NPP – Further Vibration Analysis of the Stacks	Background Documents Vol. 4G
SAS	E. Juhásová	July 1995	Investigation and Analysis of SSI Effects in Seismic Response of NPPs EMO and EBO	Background Documents Vol. 4D
SAS	E. Juhásová	July 1995	Project Investigation and Analysis of Soil–Structure Interaction Effects in Seismic Response of NPPS EBO, EMO, Slovakia – First Year	Not included in the Background Documents

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
			Progress Report	
SAS	E. Juhásová	1996	Project Investigation and Analysis of Soil-Structure Interaction Effects in Seismic Response of NPPS EBO, EMO, Slovakia – Task III – Comparison of Seismic Response in Different Soil Conditions EBO, EMO	Not included in the Background Documents
SAS	E. Juhásová	February 1998	Project Investigation and Analysis of Soil-Structure Interaction Effects in Seismic Response of NPPS EBO, EMO, Slovakia – Final Report	Background Documents Vol. 4F
Siemens	N. Krutzik	May 1994	Dynamic Analysis of the Reactor Building for Soft (Kozloduy) and Hard (Temelin) Soil Conditions and Different Seismic Loading	Background Documents Vol. 3A
Siemens	N. Krutzik	June 1995	Dynamic Analysis of the Primary System of the WWER 1000 MW Reactor for Soft Soil Conditions (Kozloduy)	Background Documents Vol. 3D
Siemens	N. Krutzik	June 1995	Reactor Building WWER 1000 Mw Upper Range Design Response Spectra for Soft Soil sites (Kozloduy)	Background Documents Vol. 3D
Siemens	N. Krutzik	June 1995	Reactor Building WWER 1000 Mw Real Range Design Response Spectra for Soft Soil Sites (Kozloduy)	Background Documents Vol. 3D
Siemens	N. Krutzik	June 1995	Derivation of Design Response Spectra for Analysis and Testing of Components and Systems	Background Documents Vol. 3D
Siemens	N. Krutzik	June 1995	Derivation of Design Response Spectra for Analysis and Testing of Components and Systems	Background Documents Vol. 4C
Siemens	N. Krutzik	June 1995	Main Building Complex WWER 440/213. Upper range Design Response Spectra for Soft Soil Conditions (Paks)	Background Documents Vol. 4C
Siemens	N. Krutzik	June 1996	Analysis of a Buried Pipeline at Paks WWER 440/213 NPP	Background Documents Vol. 4F

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
Siemens	N. Krutzik	June 1996	Blind Pre-analysis of the Main Building Complex WWER-440/213 of Paks for Comparison of Analytical and Experimental Results Obtained by Explosive Testing	Background Documents Vol. 4F
Siemens	N. Krutzik	October 1997	Summary of Structural Analysis and Comparisons with Experimental Results for Paks WWER 440/213 NPP	Background Documents Vol. 4F
Siemens	N. Krutzik	October 1997	Blind Pre-analysis of the Main Building Complex - WWER-1000 Kozloduy NPP	Background Documents Vol. 3G
VNIIAM	S. Kaznovsky	September 1995	Calculational-Experimental Examination of WWER Type NPPS	Background Documents Vol. 3E
VNIIAM	S. Kaznovsky	June 1994	Final Report: Calculational-Experimental Examination and Ensuring of Equipment and Pipelines Seismic Resistance at Starting and Operating Water Cooled and Water Moderated Reactor WWER-Type NPPs	Background Documents Vol. 4B
VNIIAM	S. Kaznovsky	Nov 1994–October 1995	Calculation Experimental Examination and Ensuring of Equipment and Pipelines Seismic Resistance at Starting and Operating Water Cooled and Water Moderated Reactor WWER-Type NPPs	Not included in the Background Documents
VNIIAM	S. Kaznovsky	June 1994	Project INT/9/122 1101 – Kozloduy Units 5/6 Seismic Safety Review (Bul)	Not included in the Background Documents
VNIIAM	S. Kaznovsky	1995	Calculation Experimental Examination and Ensuring of Equipment and Pipelines Seismic Resistance at Starting and Operating Water-Cooled and Moderated Reactor WWER-Type NPPs	Background Documents Vol. 3I
VNIIAM	S. Kaznovsky	1996	Calculational-Experimental Examination and Ensuring of Equipment and Pipelines Seismic Resistance at Starting and Operating WWER-Type	Background Documents Vol. 3I

ORGANIZATION	AUTHOR	DATE	TITLE	REFERENCE
			NPPs	
VNIIAM	S. Kaznovsky	1997	Calculation Experimental Examination and Ensuring of Equipment and Pipelines Seismic Resistance at Starting and Operating Water-Cooled and Moderated Reactor WWER-Type NPPs	Background Documents Vol. 4G
VNIIAM	S. Kaznovsky	1997	Seismic Resistance of WWER Equipment	Background Documents Vol. 3I
VNIIAM	S. Kaznovsky	1997	Generalised Analysis of Results of Calculational–Experimental Examination and Ensuring of Equipment and Pipelines Seismic Resistance at Starting and Operating WWER-Type NPPs	Not included in the Background Documents
VNIIAM	S. Kaznovsky	November 1997	Concise Report – CRP on Benchmark Study for the Seismic Analysis and Testing of WWER-Type NPPs	Not included in the Background Documents
WESE	P. Monette	September 1994	Systems Required During and After and Earthquake – Summary Report	Background Documents Vol. 1
WESE	P. Monette	October 1997	Functionality of WWER electrical and I&C Components	Background Documents Vol. 4G
WO	F.O. Henkel et al	December 1995	Seismic Evaluation of the Main Steam Line 2 of the WWER-1000 Kozloduy NPP	Background Documents Vol. 3E

ABBREVIATIONS

ASME	American Society of Mechanical Engineers (USA)
BPVC	ASME BPVC, US standard for mechanical design
CRDS	control rod drive system
DG	diesel generator
ECC	emergency core cooling
FE	finite element
FEM	finite element method
FFT	fast Fourice transform
FLM	fixed latching mechanism
GIP	generic implementation procedure
HCLPF	high confidence of low probability of failure
I&C	instrumentation and control
MLM	moving latching mechanism
NPP	nuclear power plant
NUREG	report by the staff of the NRC
PGA or pga	peak ground acceleration
PiNAE	Russian standards for mechanical design
RB	reactor building
SMA	seismic margin assessment
SMiRT	Conference on Structural Mechanics in Reactor Technology
SQUG	Seismic Qualification Utility Group
SSEL	seismic safety equipment list
SSI	soil–structure interaction
USI	NRC unresolved safety issue
NRC	Nuclear Regulatory Commission (USA)
WWER	water cooled, water moderated energy reactor (Soviet design)
ZPA	zero period acceleration

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