Title: **Seismic margin assessment and earthquake experience based methods for WWER-440/213 type NPPs**

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IAEA BENCHMARK STUDY FOR SEISMIC ANALYSIS AND TESTING OF WWER-TYPE NPPs

SUMMARY OF RESEARCH PERFORMED SINCE JUNE 1994

Prepared for:

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REVIEW OF ALREADY COMPLETED STUDIES

a) CONTRIBUTION TO THE TASK 1 - SAFE SHUTDOWN SYSTEM IDENTIFICATION AND CLASSIFICATION FOR NPP V2 - JASLOVSKÉ BOHUNICE, SLOVAKIA

Completed by September 1994, see the S&A report rep16-94.iae, published in the IAEA Working Material, vol. 2, 1995.

b) TASK 4 - STANDARDS, CRITERIA - COMPARATIVE STUDY

Completed by September 1994, see the S&A report rep16-94.iae, published in the IAEA Working Material, Vol. 2, 1995.

CURRENTLY ONGOING WORKS FOR THE IAEA BENCHMARK STUDY

SEISMIC MARGIN ASSESSMENT AND EARTHQUAKE EXPERIENCE BASED METHODS IN APPLICATION TO SEISMIC EVALUATION AND VERIFICATION OF STRUCTURES AND EQUIPMENT COMPONENTS ON THE OPERATING WWER- 440/213 TYPE NPPs

Based on experience from the NPP Paks, Hungary, and the NPP V2 Jaslovské Bohunice, Slovakia (see the following transparents).

WORKPLAN FOR THE REMAINING TIME AND NEW PROPOSALS

a) The report „PRACTICAL APPLICATION OF SMA & GIP METHODS TO SEISMIC EVALUATION AND VERIFICATION OF STRUCTURES AND EQUIPMENT COMPONENTS ON THE OPERATING WWER-TYPE NPPs WITH EMPHASIS TO MECHANICAL EQUIPMENT AND PIPES AND WWER-440/213 PLANTS“ SHOULD BE FINISHED BY THE END OF 1995.

b) The new tasks - special topics proposed by S&A, Czech Republic and Russia:

- SEISMIC RE-EVALUATION OF SELECTED SAFETY-RELATED MECHANICAL EQUIPMENT AND PIPES OF NPP PAKS

  Based on the actual seismic input data, results of already done inspections, and improved theoretical and experience background. This task should include also several special subtasks (seismic resistance of small bore pipes, buried pipes, anchorage of equipment etc.).

- ACTUAL SEISMIC ISSUES OF THE NPP TEMELÍN (WWER 1000 TYPE), CZECH REPUBLIC

  Basic information about improvements of the original design related to seismic resistance of this plant.

1. SEISMIC MARGIN ASSESSMENT

The Seismic Margin Assessment (SMA) method has been developed in the U.S.A. and also in the international community to evaluate seismic resistance of existing NPPs. This method studies the question whether the capacity of the already built NPP exceeds the target Seismic Margin Earthquake (SME), which was selected for review. Using SMA, only those structures, distribution systems, and equipment components (SDSEC) needed to bring the plant to safe shutdown condition after an earthquake, and maintain it in a safe shutdown conditions for a certain period, should be evaluated. The objective is to identify seismic vulnerabilities and to show that the plant can withstand with high confidence the effects of SME. The SMA method is one of the recommended methods for evaluation of seismic resistance of existing WWER-Type NPPs and consists of the following steps:

- selection of SME,
- selection of seismic assessment team,
- preparatory works prior to walkdowns,
- system and element selection walkdown,
- seismic capability walkdowns,
- SMA analyses (HCLPF capacity estimations) and works,
- documentation.

The concept of High Confidence Low Probability Failure (HCLPF) capacity is used in SMA reviews to quantify the seismic margins. In simple terms it correspond to the earthquake level at which, with high confidence (more than 95%) it is unlikely that failure of the SDSEC required for safe shutdown of the plant will occur (less than 5% probability). The concept of HCLPF seismic capacity is used to:

- screening out from further consideration those SDSEC, which have seismic capacity evidently higher than SME,
- identify and evaluate seismic capacities of the SDSEC which are required for safe shutdown which need some modifications to be able to withstand SME.

Two candidate methods to determine the HCLPF seismic capacities have been developed:

- the Fragility Analysis (FA),
- the Conservative Deterministic Failure (CDFM) method.

One aspect of the FA method is that it means to determine for each SDSEC a suite of curves corresponding to different confidence levels) of probabilities of failure versus ground motion levels. The fragility of SDSEC is represented by a double lognormal model using the median ground acceleration capacity A_m and logarthmic standard deviations β_R and β_U representing randomness in the capacity and uncertainty in the median value respectively. Using the FA method, the HCLPF seismic capacity is then calculated as:

$$\text{HCLPF} = A_m \exp [-1.65 (\beta_R + \beta_U)]$$

2. CONSERVATIVE DETERMINISTIC FAILURE MARGIN IN APPLICATION TO SEISMIC EVALUATION OF WWER-TYPE NPPs

Table 1. Summary of Conservative Deterministic Failure Margin Approach

Load Combination	Normal Operating Loads (NOL) + SME
Ground Response Spectrum	84% NEP
Damping	Median values
Structural Model	Best estimate (median) + uncertainty
Soil-Structure-Interaction	Best estimate + parameter variation
Material Strength	Code specified minimum strength (national standards) or 95% exceedance actual strength if test data available
Capacity Equations	Code ultimate strength for concrete and steel structures (national standards), Service Level D (ASME) or functional limits for mechanical equipment
Inelastic Energy Absorption	For non-brittle failure modes and linear analysis use 80% of computed seismic stresses to account for ductility benefits, or perform nonlinear analysis and go to 95% exceedance ductility levels.
In-Structure (Floor) Response Spectra Generation	Frequency shifting rather than peak broadening to account for uncertainty plus use median damping

a) Load Combinations and ultimate stress and strength

- concrete and steel structures

  1.0 D + 1.0 L + 1.0 T + 1.0 SME $\leq$ ultimate strength as given by national standards,

- pipes and pressure equipment components

  1.0 D + 1.0 L + 1.0 P + 1.0 $[SME^2 + SAM^2]^{1/2}$ $\leq$
  $\leq$ ASME BPVC III, Service Level D,

- HVAC ducts and non-pressure equipment components

  1.0 D + 1.0 L + 1.0 $[SME^2 + SAM^2]^{1/2}$ $\leq$ ASME BPVC III, Service Level D, or national standards and guides for steel structures,

- piping and equipment component supports and anchorage

  (for ductile failure modes)

  1.0 D + 1.0 L + 1.0 $[SME^2 + SAM^2]^{1/2}$ $\leq$ ASME BPVC III, Service Level D, or national standards and guides for steel structures and anchorage,

  (for brittle failure modes)

  1.0 D + 1.0 L + 1.0 T + 1.0 $[SME^2 + SAM^2]^{1/2}$ $\leq$ ASME BPVC III, Service Level D, or national standards and guides for steel structures and anchorage,

where D = the dead load incl. permanently instaled equipment,
L = the live load applicable at the time of occurance of SME (about 25% of normal design live load),
P = the normal operating pressure,
T = the loading due to restraint of free thermal expansions under normal operating temperature,
E = the inertia loads due to SME reduced by the appropriate ductility factor, ,
SAM = the seismic anchor movement, if any.

a) Damping

- for linear seismic analysis the median damping values a given by NUREG/CR-0098 are considered to be appropriate so long as the structure or equipment component is significantly stressed by an earthquake (i.e. 5% for welded steel structures, pipes and equipment components, up to 15% for cable supporting structures when fully loaded),
- lesser values should be used for non-linear seismic analysis.

c) Ductility and Seismic Margin

- nearly all structures, distribution systems, and equipment components exhibit at least some ductility, i.e. the ability to strain beyond the elestic limit before failure,
- when the linear analysis is applied, the easiest way to account for the ductility is to reduce seismic response by the appropriate ductility factor,
- detail recommendations given by Stevenson (Criteria for Seismic Evaluation and Potential Design Fixes for VVER Type Nuclear Power Plants),
- the HCLPF seismic capacity, when calculated, may be expressed as

$$HCLPF = SME \times k_D \times (C - D_{NS}) / (D_S + \delta C_S)$$

where
k_D = the ductility factor,
C = capacity,
δC_S = the reduction of the capacity due to concurent seismic loading (f.e. SAM),
D_S = the linear elastic seismic demand,
D_{NS} = the concurent non-seismic demand due to all non-seismic loads in the load combination.

- when based on seismic testing, the HCLPF seismic capacity can be expressed as

HCLPF = the lowest (TRS/ISRS + margin)

where
TRS = the test response spectrum,
ISRS = the In-Structure Response Spectrum
(the value of margin depends on the type of applied spectra).

Still ongoing practical applications of the SMA (CDFM) approach as performed by Stevenson and Associates to evaluate the HCLPF seismic capacities of SDSEC on two plants, i.e. on the NPP Paks, Hungary (Units 3&4), and on the NPP V2 Bohunice, Slovakia (Units 1&2) are summarized in Table 2.

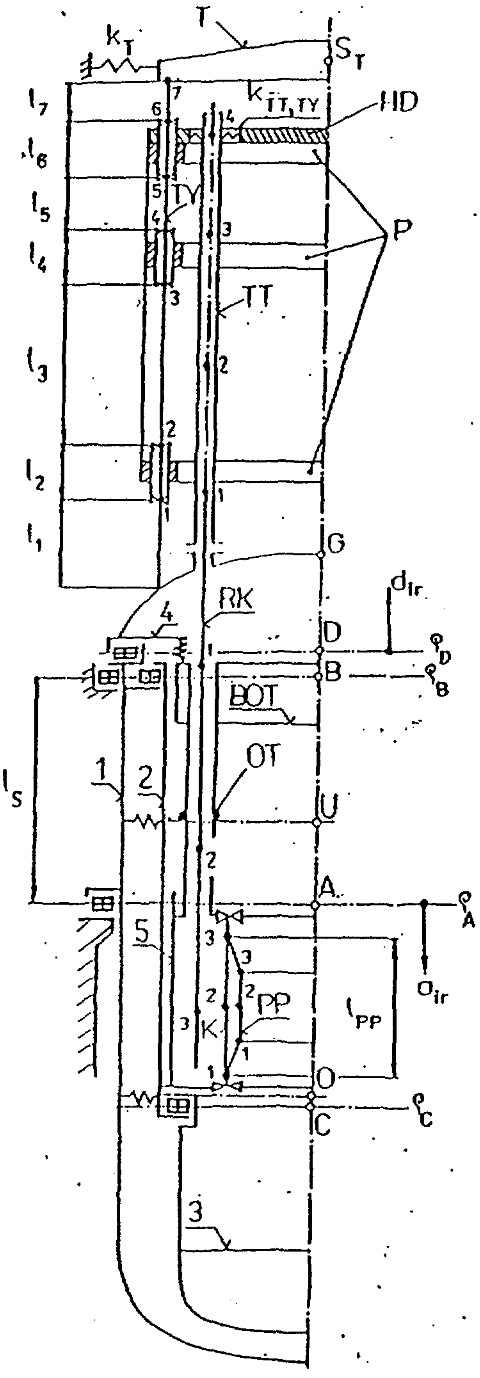
Table 2 Summary of Practical Applications of the SMA (CDFM) Approach as Used on the NPP Paks and NPP V2 Bohunice

Structures, Distribution Systems, Equipment Components	NPP Paks Units 3&4 1)	NPP V2 Units 1&2 2)
Structures of the Main Reactor Building		+
Structures of Other Buildings		+
Reactor Pressure Vessel and Internals	+	+
Class 1 Pipes	+	+
Primary Circuit Mechanical Componets and Pressurizer	+	+
Class 2 and 3 Large Bore Pipes	+	+
Tanks and Heat Exchangers	+ 3)	+ 3)
Small Bore Pipes and HVAC Ducts	+ 4)	+ 4)
Transportation Components	+ 5)	+ 5)

Notes:
1) **Based on preliminary ISRSs attached to the $PGA_{SME} = 0.30$ g.**
2) **Based on ISRSs attached to the $PGA_{SME} = 0.25$ g.**
3) **In combination with the GIP methodology.**
4) **Special non-calculation approaches.**
5) **Only stability of position is required during an earthquake.**

3. GENERIC IMPLEMENTATION PROCEDURE OF SQUG IN APPLICATION TO SEISMIC VERIFICATION OF EQUIPMENT COMPONENTS ON WWER-TYPE NPPs

The procedure titled as the Generic Implementation Procedure (GIP) has been prepared in the U.S.A. over a several year period to provide the detail technical approach, procedures, and documentation guidance which can be used to verify seismic adequacy of safe shutdown mechanical and electrical equipment namely on existing NPPs. The GIP-SQUG methodology is primarily a screening process. However, if safe shutdown equipment is classified as an outlier, more detail methods to verify its seismic adequacy may be used.



RIGID BODIES

1	RPV
2	core barrel (CB)
3	lower core barell
4	top head
5	secondary CB
BOT	upper core support shell and plate
HD	upper plate
T	traverse
P	ring

ELASTIC BODIES OF BEAM TYPE

OT	upper core support columm
K	hexagonal can of fuel element
PP	fuel rods
TT	CRDM housing
TY	traverse bars
RK	control rods

o	nodes
•	mass points
⊏⊐	coupling with compliance in y direction
⊞	coupling with compliance in x and y direction
—∿—	elastic coupling

Fig. 1 Analysis Model of the Reactor WWER 440-213 (NPPs Paks & V2)

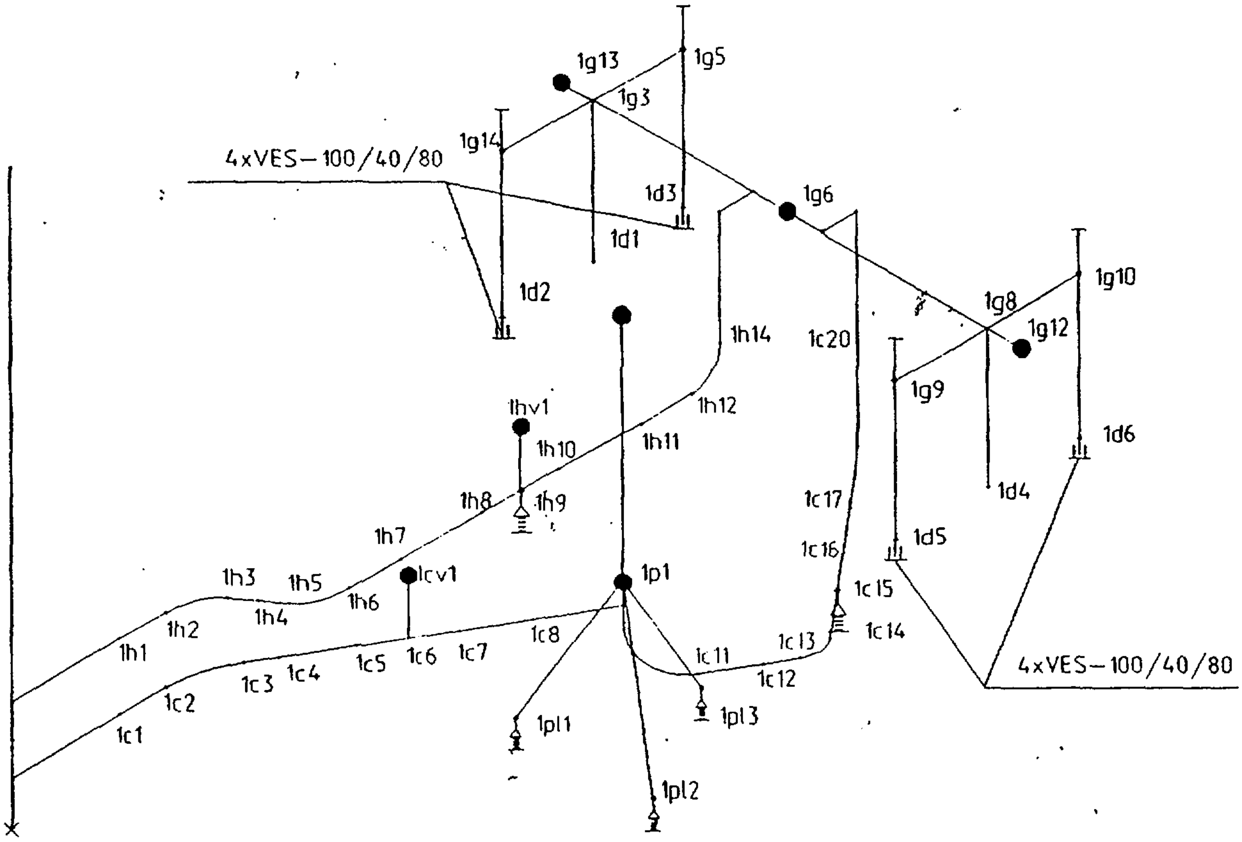


Fig. 2 Analysis Model of the Primary Loop Pipe System with the Steam Generator, the Main Cooling Pump and the Main Closing Valves (NPP V2)

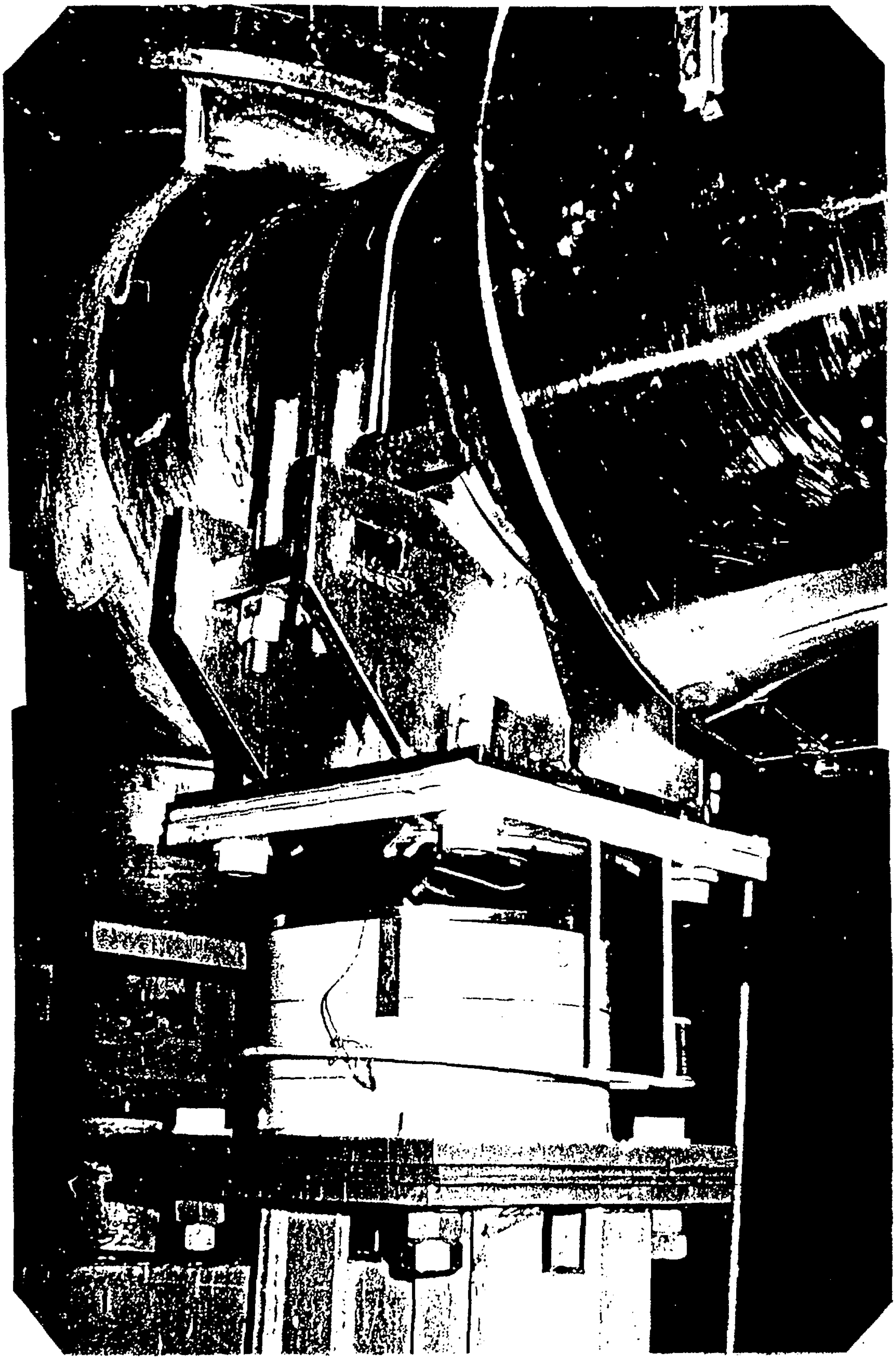


Fig. 3 Typical GERB Pipework Damper

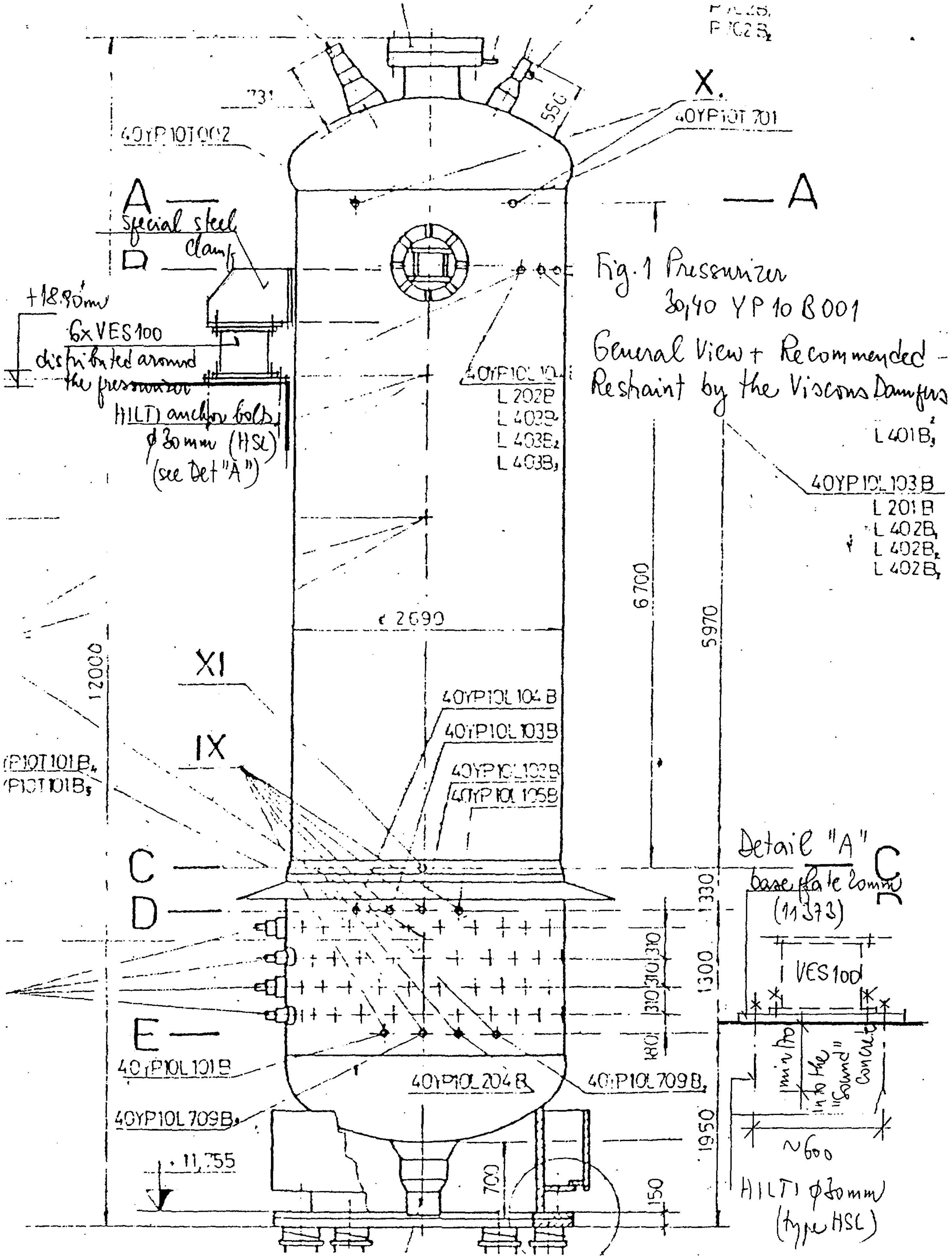


Fig. 4 Recommended Additional Lateral Bracing of the Pressurizer by the GERB Dampers (NPPs Paks & V2)

Generally, four major steps of this procedure are as follows:

- selection of Seismic Review Team (SRT),
- identification of safe shutdown equipment,
- screening verification and walkdowns,
- outlier identification and resolution

An engineering judgement is the major tool used by SRT during the screening verification and walkdowns to evaluate seismic adequacy of the equipment. The SRT should include system engineers, plant operation personnel, seismic capability engineers, and personnel to evaluate essential relays.

The mechanical and electrical equipment needed to achieve and maintain safe shutdown conditions are identified in two steps:

- the first step to define various alternative methods or paths which could be used to accomplish each of the four following main safe shutdown functions:

  -- reactor reactivity control,
  -- reactor coolant pressure control,
  -- reactor coolant invertory control,
  -- decay heat removal.

The second step is to identify the individual components of safe shutdown equipment and to develope the list of these components.

Basic criteria to verify seismic adequacy of an equipment item during the screening walkdown (see also the S&A expert system to be demonstrated on a notebook):

- seismic capacity greater than seismic demand (f.e. by comparison of the corresponding $ISRS_{SSE,\,SME}$ or $GRS_{SSE,\,SME}$ to the well known Bounding Spectrum (BS) or 1.5 times BS,
- similarity to the equipment in the seismic experience data bases (checking of caveats),
- adequate anchorage of equipment (anchorage calculations, or engineering judgement, based on walkdowns and also study of documentation),
- potential seismic interactions evaluated (mostly based on walkdowns).

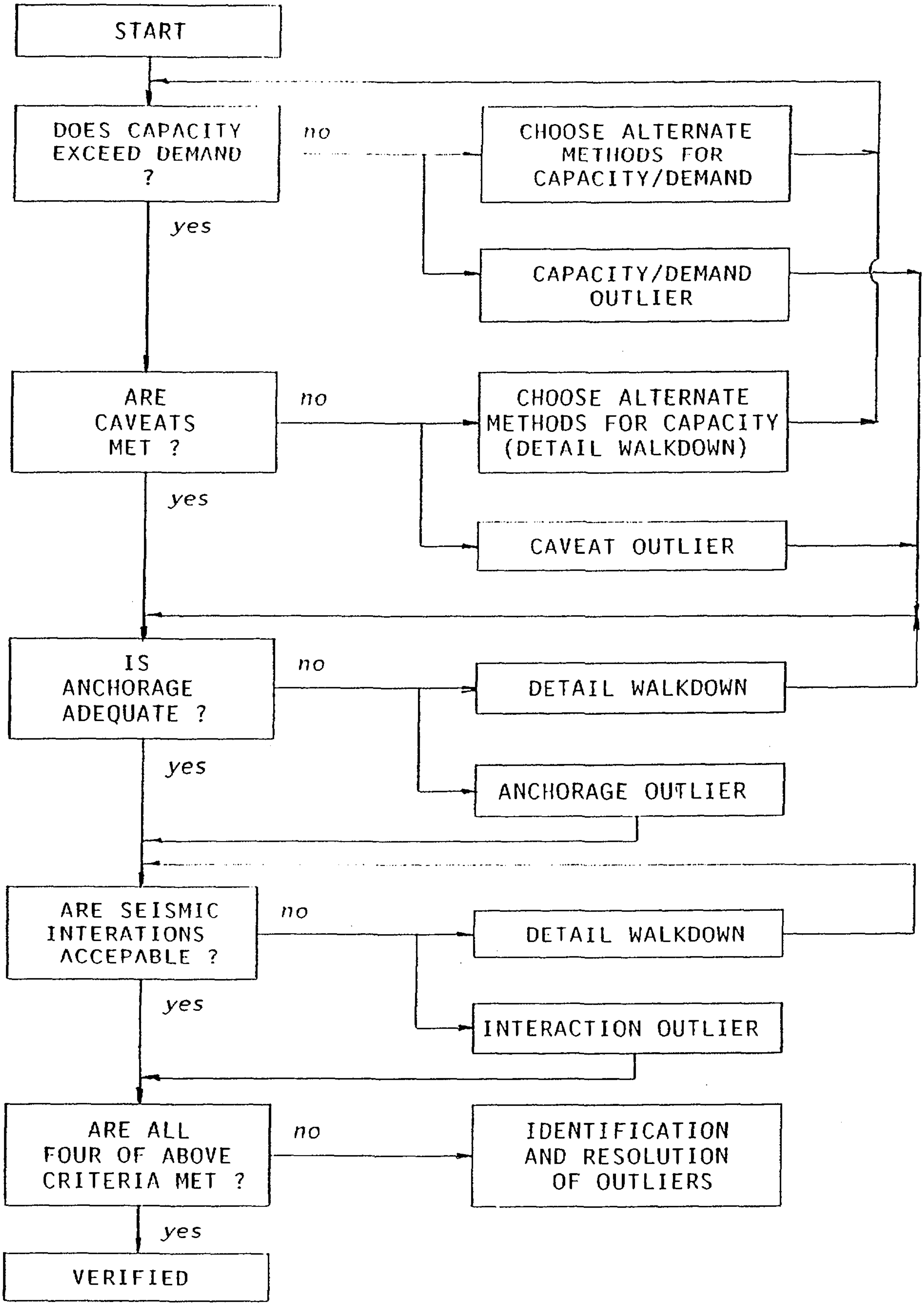


Fig. 5 Seismic Screening Verification and Walkdown Procedure as Assumed by the GIP-SQUG Methodology

Table 3 List of Equipment Classess in GIP and Their Extention

CLASS OF EQUIPMENT	AVAILABLE DATA	
1. Motor Control Centers	SQUG EE (BS)	GERS
2. Low Voltage Switchgears	SQUG EE (BS)	GERS
3. Medium Voltage Switchgears	SQUG EE (BS)	GERS
4. Transformers	SQUG EE (BS)	GERS
5. Horizontal Pumps	SQUG EE (BS)	
6. Vertical Pumps	SQUG EE (BS)	
7. Fluid-Operated Valves	SQUG EE (BS)	GERS
8. Motor-Operated and Solenoid-Operated Valves	SQUG EE (BS)	GERS
9. Fans	SQUG EE (BS)	
10. Air Handlers	SQUG EE (BS)	
11. Chillers	SQUG EE (BS)	
12. Air Compressors	SQUG EE (BS)	
13. Motor Generators	SQUG EE (BS)	
14. Distribution Panels	SQUG EE (BS)	GERS
15. Batteries on Racks	SQUG EE (BS)	GERS
16. Battery Chargers and Invertors	SQUG EE (BS)	GERS
17. Engine Generators	SQUG EE (BS)	
18. Instruments on Racks	SQUG EE (BS)	
19. Temperature Sensors	SQUG EE (BS)	
20. I&C Panels & Cabinets	SQUG EE (BS)	
ADDITIONAL CLASSES		
21. Relays, Switches, Transmitters		GERS
22. Electrical Penetrations		GERS
SPECIAL APPROACHES		
23. Cable Supporting Structures	Special Data Base	
24. Tanks and Heat Exchangers	Anchoring	
25. Hand Operated and Non-Return Clack Valves	Engineering Judgement	
26. Water and Air Filters	Engineering Judgement	

Notes: 1) SQUG EE means the Seismic Qualification Utility Group Earthquake Experience,

2) GERS means the Generic Equipment Ruggedness Spectra (they are an intellectual property of EPRI and cannot be used without their permission),

3) BS means the Bounding Spectrum,

4) classes 25 and 26 added by S&A for WWER-type plants.

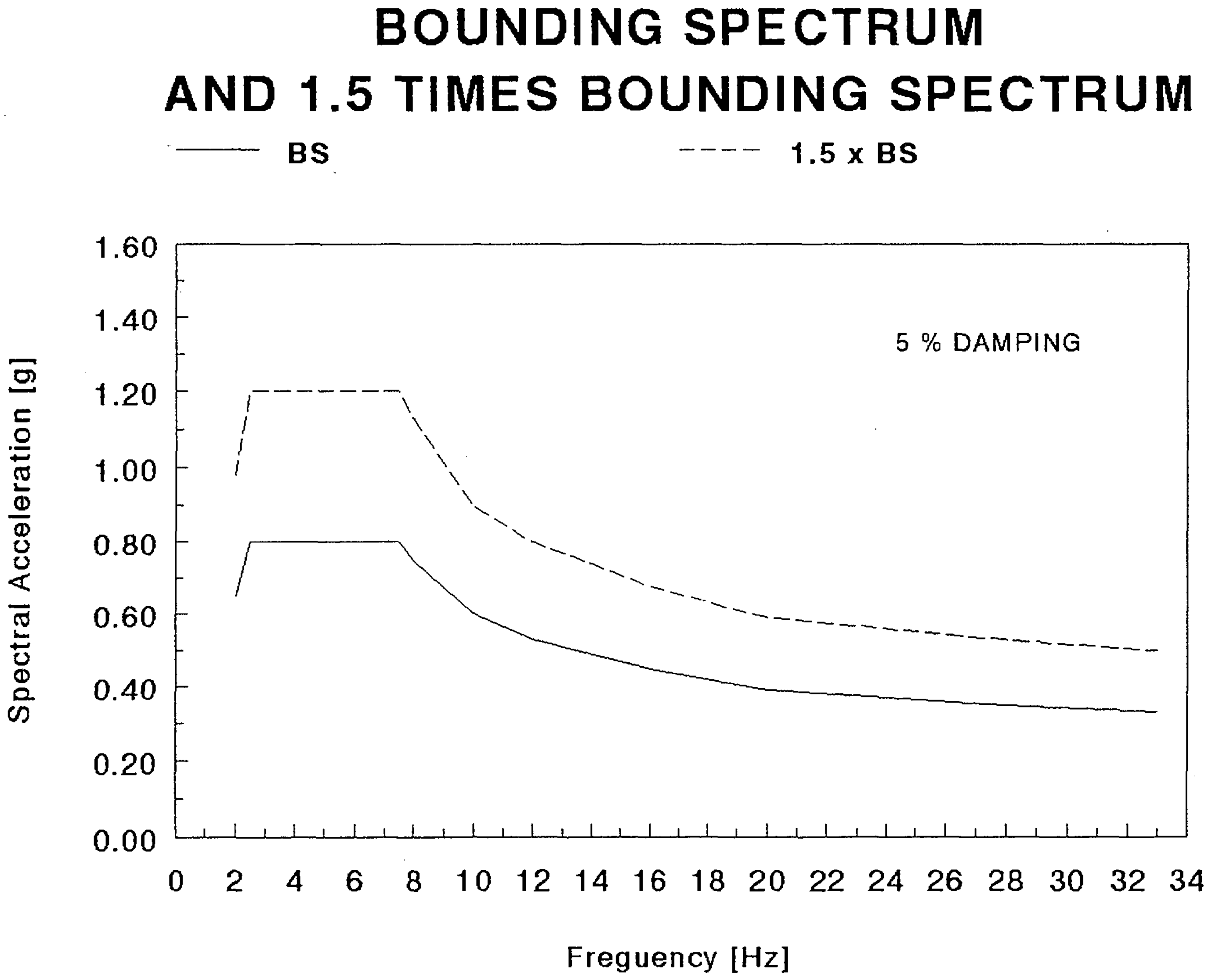


Fig. 6 Seismic Capacity Bounding Spectrum (0.33 g)

The results of the screening walkdown should be documented on the corresponding verification sheets (output results when the S&A expert system is used).

An outlier is defined as an item of the equipment which does not meet the screening criteria. Outliers may be shown to be adequate for given seismic effects by performing additional evaluations such as the seismic qualification techniques currently used for new NPPs. These additional or alternative methods should be documented.

With a number of caveats and exclusions for seismic inputs below the BS normalized to 0.3 g and in some cases 0.5 g for the PGA, it is unnecessary to perform explicit seismic analysis or test qualification of existing equipment in the equipment classess designated as earthquake experience data bases also for WWER type NPPs to demonstrate functionality during and after an earthquake. This conclusion is based (1) on earthquake experience data confirming that the equipment included within the given limitations is resistant enough to maintain functionality after an earthquake, and (2) that, the safe shutdown mechanical and electrical equipment components on the WWER type NPPs are, with some exclusions, generally similar to those installed on western NPPs.

The existing SQUG data base reasonably demonstrates the seismic ruggedness of existing equipment up to the seismic motion bounds (BS). This conclusion is based on earthquake experience data which confirm that the equipment included within the limitations is rugged enough to maintain functionality during and after an earthquake.

Much of the SQUG data base equipment as over 20 years old at the time of the earthquake exposure, and some of this equipment was located in reasonably high thermal and corrosive environments. Therefore, the data base does address the aspect of equipment aging. However, the data base equipment was not exposed to radiation, so the aging effects from radiation exposure on the equipment are beyond the scope of the reviewed data base.

Still ongoing practical applications of the GIP-SQUG approach as performed by Stevenson and Associates to verify seismic adequacy of mechanical and electrical equipment components on two plants, i.e. on the NPP Paks, Hungary (Units 3&4), and on the NPP V2, Bohunice, Slovakia (Units 1&2), are summarized in Table 4.

Table 4 Summary of GIP-SQUG Applications for the NPP Paks and NPP V2 Bohunice (performed by S&A)

Class of Equipment	NPP Paks Units 3&4[1)]	NPP V2 Units 1&2[2)]
1. Motor Control Centers		+[3)]
2. Low Voltage Switchgears		+[3)]
3. Medium Voltage Switchgears		+[3)]
4. Transformers		+
5. Horizontal Pumps	+	+
6. Vertical Pumps	+	+
7. Fluid-Operated Valves	+	+
8. Motor-Operated and Solenoid-Operated Valves	+	+
9. Fans	+	+
10. Air Handlers	+	+
11. Chillers	+	+
12. Air Compressors	+	+
13. Motor Generators		
14. Distribution Panels		+[3)]
15. Batteries on Racks		+
16. Battery Chargers and Invertors		+
17. Engine Generators	+	+
18. Instruments on Racks		
19. Temperature Sensors		
20. I&C Panels and Cabinets		+[3)]
21. Relays, Switches, Transmitters		
22. Electrical Penetrations		
23. Cable Supporting Structures		+[3)]
24. Tanks and Heat Exchangers	+[4)]	+[4)]
25. Hand-Operated and Non-Return Clack Valves	+	+
26. Water and Air Filters	+	+

Notes:
1) **On the base of preliminary ISRSs attached to the $PGA_{SME} = 0.30$ g.**
2) **On the base of ISRSs attached to the $PGA_{SME} = 0.25$ g.**
3) **Only for a limited scope of equipment items.**
4) **In combination with the SMA (CDFM) methodology.**

Table 5 Results of Verification of Seismic Adequacy for Selected Classes of Equipment Installed on the NPP V2 Jaslovské Bohunice (Unit 1)

Description	Horizontal Pumps[1]	Vertical Pumps	Ventilators
Total Number of Verified Items	21	18	5
Total Number of Equipment Types	8	2	3
Verified	8	6	
Outliers	0	12[2]	
Resolution of outliers, other recommended seismic upgradings	none	additional restraint of suction pipes, detail verification of anchorage	additional checking of drawings of supporting pedestals

Notes: 1) Small horizontal pumps in the dieselgenerator station are not included in this summary.

2) The main water supply pumps are classified as outliers due to long cantilever impeller shaft length and also due to confusing anchorage of their motors into the concrete floor below motors (missing documentation).

The following types of valves were verified on the NPP V2:

- **Hand Operated Valves (HOV) and Non-Return Clack Valves (NRCV),**
- **Pressure Relief Valves (PRV),**
- **Motor Operated Valves (MOV),**
- **Solenoid Operated Valves (SOV),**
- **Quick Acting Isolation Valves (QAIV, fluid operated).**

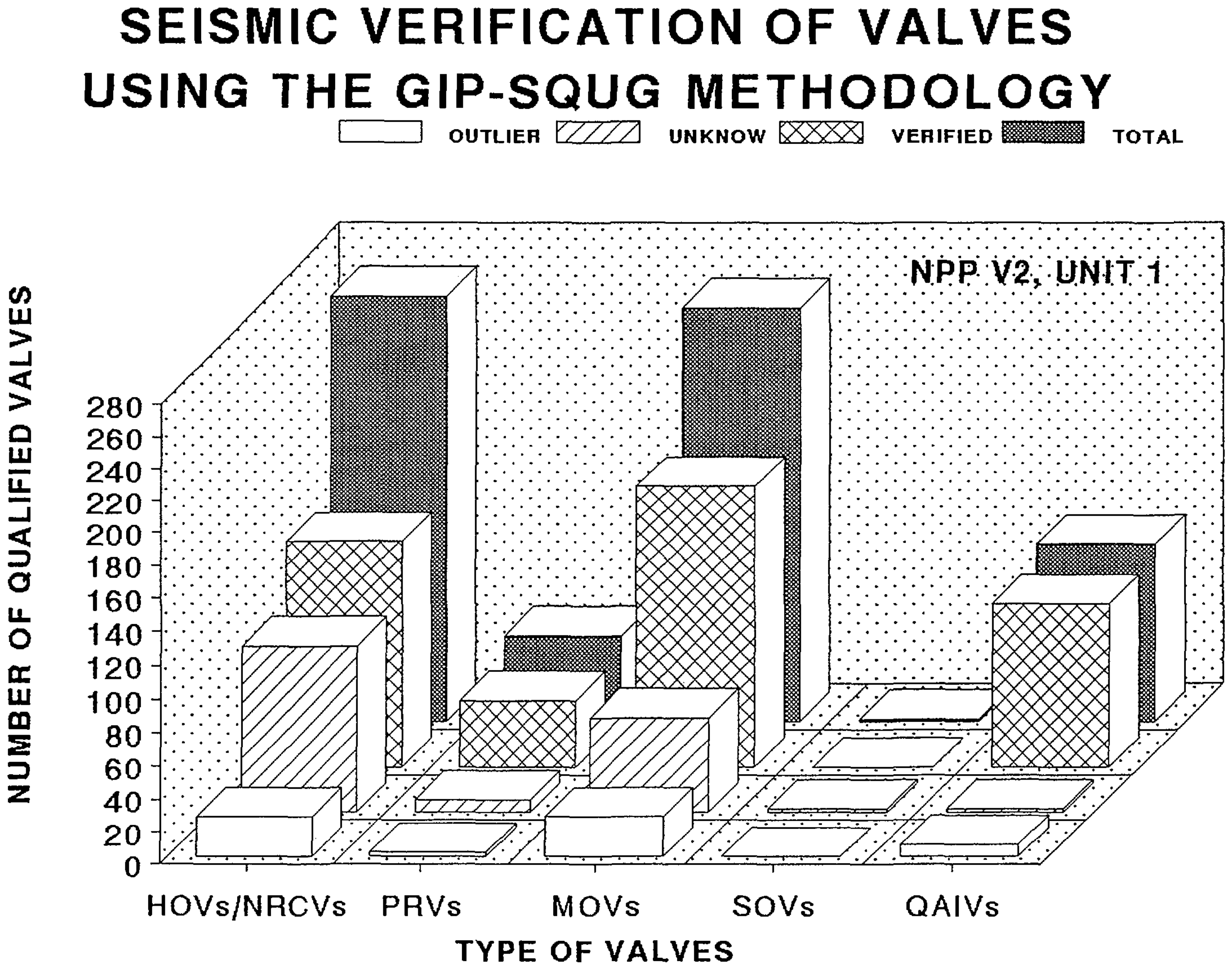


Fig. 7 Results of Seismic Verification of Valves - NPP V2

Outlier means herein that further investigations or replacement are necessary.
Unknown means herein that further investigations are necessary (missinig documentation, inspection impossible etc.).
Verified means herein that only additional checking of seismic interactions and flexibility of attached lines during the detail walkdown is recommended for those valves which were not inspected during the walkdown and are verified only on the base of ocumentation.

Table 6 Results of Verification of Seismic Adequacy for Selected Classes of Equipment Installed on the NPP Paks (Unit 3)

Description	Horizontal Pumps[1)]	Vertical Pumps[2)]	Ventilators
Total Number of Verified Items	27	6	26
Total Number of Equipment Types	10	1	11
Verified	15	0	13
Outliers	12[2)]	6[3)]	13[4)]
Resolution of outliers, other recommended seismic upgradings	seismic restraints of long unsupported attached pipes, detail investigations of anchorage of several pumps	motor probably unanchored into the concrete floor, additional investigation and anchorage necessary	additional stops to base isolated frames with free gaps, further detail investigation of seismic interactions

Notes:
1) **Small horizontal pumps in the dieselgenerator station are not included in this summary.**
2) **Some of these pumps are classified as outliers due to their long unsupported attached pipes and also due to unavailable anchorage details (missing documentation).**
3) **These pumps are classified as outliers due their probably unanchored motors (missing documentation).**
4) **Some of these ventilators are classified as outliers due to their evidently flexible base isolation devices. Easy fixing by means of the special steel restraints with free gaps to compensate small operate vibrations is recommended.**

4. ANCHORAGE OF EQUIPMENT

The presence of proper anchorage is perhaps the most important aspect of seismic performance of equipment. Adequate strength of equipment anchorage can be determined by several methods. Design procedures for equipment anchorage using the CDFM based capacity criteria can be used to evaluate existing anchorages. Alternatively, the procedure which has been developed within the GIP (SQUG) methodology can be also applied for these purposes. Generally, the four main steps for evaluation of seismic adequacy of equipment anchorage include:

- anchorage installation inspection,
- anchorage capacity determination,
- seismic demand determination,
- comparison of capacity to demand.

A check of the following equipment anchorage attributes should be made:

- equipment characteristics,
- type, size, and location of anchors,
- installation adequacy,
- embedment lengths,
- gap at threaded anchors,
- spacing between anchors and edge distances ,
- concrete strength and condition, crack locations and sizes,
- essential relays in cabinets,
- equipment base stiffness and prying action,
- equipment base strength and structural load path,
- embedment steel and pads.

The allowable capacity of anchors is obtained by multiplying the nominal allowable capacity by the following reduction factors:

- reduction factor for the type of expansion anchors,
- reduction factor for a short embedment length,
- reduction factor for closely spaced anchors,
- reduction factor for near edge anchors,
- reduction factor for low strength concrete,
- reduction factor for cracked concrete,
- reduction factor for expansion anchors securing equipment with essential relays.

The following five steps are usually done to determine the loads applied to the anchors by the seismic demand imposed on the item of equipment:

- determine the appropriate input seismic accelerations for the item of equipment for each three directions of motion,
- determine the seismic inertial equipment loads for each of the three directions of motion,
- determine seismic inertial anchor loads by calculating the various load components for each direction of motion,
- calculate the combined seismic loads on each anchor from each of the three directions of seismic motion and then combine the load components from these three directions using theSRSS rule or the rule „100% + 40% + 40%",
- calculate the total anchor load on each anchor by adding the combined seismic loads to the equipment deadweight loads and any other loads acting under NOC.

The last step in evaluation the seismic adequacy of equipment anchorage is to compare the seismic capacity of the anchors to the total anchor loads using the appropriate shear-tension interaction formulation. The nominal allowable capacities of various anchors may be obtained from the following sources:

- standards and guides for design of conventional cast-in-place anchor bolts, or embedded steel anchors,
- manufacturer's average test failure loads divided by a factor of safety which should be equal at least of 3.0 and 4.0 for ductile (i.e. tensile of the bolt) and brittle failure modes (i.e concrete cone failure) respectively - for expansion anchor bolts,
- test results using the justifiable safety factors.

Grouted-in-place J-type anchor bolts are often used for anchorage of heavy mechanical equipment components as heat exchangers, pumps etc. on WWER-type NPPs. Their realistic pullout and shear nominal allowable capacities depend on the quality of their concrete grouting which may vary from the case to case. Table 7 presents the nominal allowable capacities of these anchor bolts obtained on the basis of the Soviet instruction SN 471-75 originally prescribed for anchorage by such bolts on the WWER type NPPs. Neverless, these pullout capacities were additionally reduced by a factor 0.3 to take into account sometimes undefined quality and performance of their grouting. This factor was derived on the basis of experience and results of several tests performed on the plants during the last time.

Table 7 Nominal allowable pullout and shear capacities of the grouted-in-place J - type anchor bolts

Diameter of the anchor bolt [mm]	Pullout capacity [kN]	Shear capacity [kN]	Minimum embedment [mm]	Minimum spacing [mm]	Minimum edge length [mm]
12	9.00	13.00	500	50	100
16	13.80	23.00	670	50	140
20	21.00	35.00	850	60	175
24	33.00	55.00	1000	75	210
30	54.00	90.00	1260	90	265

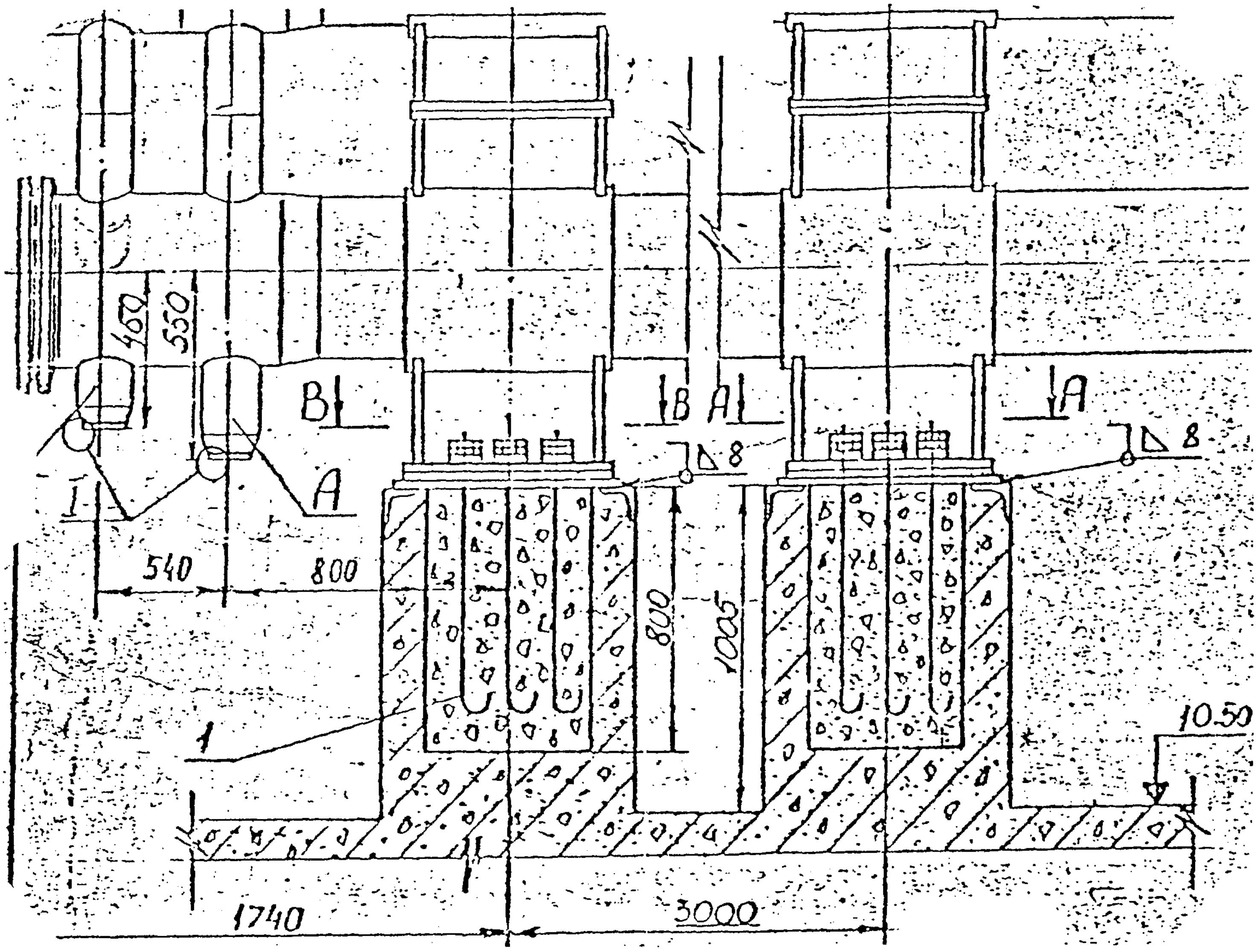


Fig. 8 Anchorage of a Typical Heat Exchanger by Means of the Grouted-in-Place J Bolts into the Concrete Pedestal with Problematic Reinforcement

5. SEISMIC INTERACTIONS, VERIFICATION OF SEISMIC ADEQUACY OF SMALL BORE PIPES AND BURIED PIPES

Seismic interactions which could affect the performance of the seismic safety-related SDSEC during an earthquake must be identified during the walkdowns. These interactions include:

- falling, i.e. an impact and damage of a safety-related item due to structural integrity failure of a safety-non-related item,
- proximity, i.e. a condition when two items are close enough together that their seismic displacements may result in impact,
- spray and flood which can result from failure of piping, tanks and vessels which are not properly anchored or supported.

A procedure and supporting information for verification of seismic adequacy of small bore pipes has been prepared by Stevenson and Associates on the basis of recent investigations. The main steps of this procedure are:

- check applicability conditions,
- check deadweight and lateral support spacing,
- check axial supports for straight pipe runs,
- check support loads and evaluate these supports incl. their anchorage, if necessary.

Applicability conditions:

- material should be carbon and/or stainless steel usually used for pipes on NPPs,
- NPS up to 60 mm for Class 1 pipes regardless to the working temperature and internal pressure,
- NPS up to 100 mm for Class 2 and 3 pipes regardless to the working temperature and internal pressure,
- NPS up to 200 mm for Class 2 and 3 pipes when the working temperature is less than 60°C and internal pressure is no more than 15 MPa,
- butt and socket welded and also threaded and flanged joits,
- light or medium-weight (up to 50% of the pipe weight incl. fluid), otherwise the effect of more heavy insulation shall be expressed by the equivalent pipe span length,
- fluid can be water, fuel, oil, air, gas, steam,

- the inertia effect of non-supported valves shall be expressed by the equivalent reduced pipe span,
- in general, the deadweight support spacing should meet the ASME BPVC Section III, Subsection NF, Table NF-3611-1 recommendations (small exceedance acceptable, if an average support spacing is satisfied),
- seismic anchor movement evaluated separately using the approximate formula for checking the first lateral support span of the branch pipe attached to the main pipe or the lateral support span of the pipe attached to separate buildings or equipment,
- axial supports shall be provided for pipe runs longer than twice of the maximum deadweight support spacing (the requirement may be satisfied by a lateral support near to the end of the straight run).

The maximum lateral support spacing for small bore pipes are given for three PGA_{SSE} = 0.1, 0.2, and 0.3 g, for NPS from 25 to 200 mm, for welded, threaded and flanged pipe joints, for elevations below 15 m and up to 30 m above grade, and for several different allowable pipe seismic displacements. These values are summarized in tables not presented herein. They have been extracted from the results of seismic + deadweight analysis of more than 100 small bore pipe segments and are based also on a number of other important investigations. Several formulas have also been extracted from these sources for approximate evaluation of support loads of small bore pipes. Also recommendations for additional pipe supports, if necessary, are given depending on the temperature and size of the pipe.

During earthquakes, a buried pipeline can experience significant loading as a result of large relative displacements of the ground along its length. Large ground movements can occure due to the following effects:

- faulting,
- liquefaction,
- lateral spreading,
- landslides and slope failures.

Large relative displacements can also occur in the connections of the buried pipes into the building structures. These connections should be designed to be completely flexible. Results of several studies show that dynamic amplification does not play an important role in the response of buried pipelines. The combination od\f a restrained system and the presence of high radial damping characteristics of the surrounding soil causes that stresses and strains due to amplification effects are less than those from small relative pipeline-soil displacements computed using maximum ground strain extimates. Therefore, when it is possible to suppose, that no large ground movements caused by effects described above will take a place, only the static response of buried pipelines subjected to the passage of seismic waves are considered. It is well/known that the critical places of a such buried pipeline subjected to seismic wave propagation effects are their elbows. The formulas to calculate a buried pipe with 90° elbow when subjected to a wave-propagation effects have been presented by a number of authors (O'Rourke, Novak). The major difficulties in applying of these formulas consist in estimation the apparent propagation speed of the seismic ground excitation. Peak ground accelerations and velocities are caused by a mixture of compression, shear, and Rayleigh waves, and wave velicities are a function of their travel path through deeper and higher volocity material. Although it is usually impossible to predict which type of wave will predominate, a general rule is to assume that structures located within 2 to 5 depths of an earthquake are affected by compression and shear waves (body waves), while for those beyond 5 focal depths, Raleyigh waves (surface waves) will tend to be more significant.

6. SEISMIC RESPONSE AND CAPACITY OF VERTICAL CYLINDRICAL TANKS

A seismic analysis of vertical cylindrical liquid storage tanks usually consists of two phases:

- seismic response analysis (based mostly on works of Housner, Haroun, and Veletsos),
- seismic capacity assessment (based mostly on works of Kennedy, Manos, and other investigators).

Flat bottom vertical cylindrical liquid storage tanks have sometimes failed with loss of their content during strong earthquakes. For tanks with relatively thin walls and for tanks with minimum or no anchorage, failures have often been associated with rupture of the tank wall near its connection to the bottom, due to excessive tank wall buckling of bolt stretching and excessive bottom uplift. Both these failure modes are primarily due to seismic overturning moment at the tank base due to impulsive mode liquid pressure on the tank wall. Another common failure mode has been breakage of piping connected to the tank. Breakage of a pipe between the tank wall and shutoff valve is one of the most prelevant causes of loss of liquid from a storage tank. Other failure modes which are of much lesser importance are: distortion of the tank bottom near the tank side wall due to a foundations failure under the tank bottom, tank sliding, excessive hoop tensile stresses due to hydrodynamic pressures on the tank wall, and damage of the roof and internal attachements due to liquid sloshing and insufficient freeboard height.

The following phenomena are estimated in the first phase:

- the fundamental horizontal, vertical and sloshing frequencies of the tank-liquid system with or without consideration of tank-foundation interaction,
- the response spectral accelerations for these frequencies, taken from the 5% and 0.5% damped horizontal and vertical response spectra given at the tank base (5% for the impulsive response components, 0.5% for the sloshing response),
- the impulsive mode base shear, moment, and hydrodynamic pressure, which represent the effect of the part of the liquid that may be considered to move in synchronism with the tank structure as a rigidly attached mass,
- the convective (sloshing) mode base shear, moment, hydrodynamic pressure, and theoretical sloshing height, which represent the action of the part of the liquid near the free surface that experiences sloshing motions,
- the hydrodynamic pressure caused by the vertical component of seismic motion,
- the combined seismic base shear, overturning moment, static liquid pressure and total pressure both near the tank bottom, seismic liquid pressure at the tank bottom, and pressure at the tank bottom which loads the tank foundation.

These responses are then used in the second part for evaluation of tank seismic capacities:

- the combined overturning base moment determined in the tank shell immediately above the tank bottom is compared to the nominal overturning tank moment capacity which is governed by a combination of shell buckling (elephant and diamond modes), liquid hold-down capacity, and anchor yielding of failure and generally governs the seismic the seismic capacity of the tank,

- the combined base shear is compared to the nominal sliding shear tank capacity which only seldomly controls the seismic capacity of the tank,
- the total liquid pressure near the tank bottom is compared to the hoop membrane capacity of the tank shell which essentially never governs the seismic capacity of a properly designed tank,
- the fluid sloshing height is compared to the freeboard height above the top of the liquid to estimate whether roof damage is likely.

For tanks with minimum anchorage and for unanchored tanks, the hold-down forces resulting from fluid pressure acting on the tank bottom contribute significantly to the overturning moment capacity of the tank. For anchored tanks, it is recommended that the small displacement theory should be used to compute the liquid hold-down forces.

Stevenson and Associates developed two PC programs TANKV and TANKV (M) for seismic evaluation of large vertical single and also multi-cylindrical flat bottom liquid storage tanks.

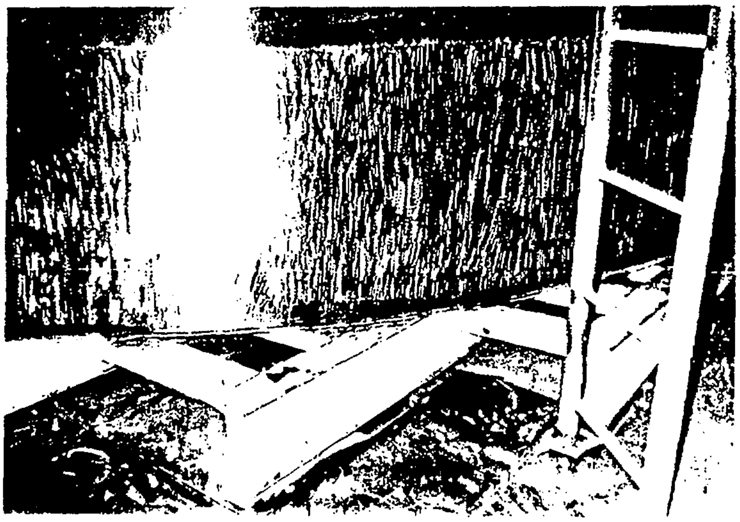


Fig. 9 Typical Unanchored Large Multi-Cylindrical Vertical Tank Made of Stainless Steel and Supported by the Grid Made of Carbon Steel (on all WWER- 440 Type NPPs)