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SEISMIC RE-EVALUATION CRITERIA FOR BOHUNICE V1 RECONSTRUCTION

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Abstract

Bohunice V1 in Slovakia is a Russian designed two unit WWER 440, Model 230 Pressurized Water Reactor. The plant was not originally designed for earthquake. Subsequent and ongoing reassessments now confirm that the seismic hazard at the site is significant. EBO, the plant owner has contracted with a consortium lead by Siemens AG (REKON) to do major reconstruction of the plant to significantly enhance its safety systems by the addition of new systems and the upgrading of existing systems. As part of the reconstruction, a complete seismic assessment and upgrading is required for existing safety relevant structures, systems and components. It is not practical to conduct this reassessment and upgrading using criteria applied to new design of nuclear power plants. Alternate criteria may be used to achieve adequate safety goals. Utilities in the U.S. have faced several seismic issues with operating NPPs and to resolve these issues, alternate criteria have been developed which are much more cost effective than use of criteria for new design. These alternate criteria incorporate the knowledge obtained from investigation of the performance of equipment in major earthquakes and include provisions for structures and passive equipment to deform beyond the yield point, yet still provide their essential function. IAEA has incorporated features of these alternate criteria into draft Technical Guidelines for application to Bohunice V1 and V2.

REKON has developed plant specific criteria and procedures for the Bohunice V1 reconstruction that incorporate major features of the U.S. developed alternate criteria, comply to local codes and which envelop the draft IAEA Technical Guidelines. Included in these criteria and procedures are comprehensive walkdown screening criteria for equipment, piping, HVAC and cable raceways, analytical criteria which include inelastic energy absorption factors defined on an element basis and testing criteria which include specific guidance on interpretation of existing single axis, single frequency testing and on amplification factors for electrical cabinets.

1. INTRODUCTION

Bohunice V1 in Slovakia consists of a two unit WWER 440, Model 230 Pressurized Water Reactor. Commercial operation of Unit 1 began in 1979 and Unit 2 in 1981. No specific seismic provisions were incorporated into the original design basis. Later reassessment of the potential seismic hazard for the site resulted in an assignment of MSK intensity 8.0. This correlates approximately to 0.25g peak ground acceleration.

Some seismic upgrading was performed in the early 1990s as part of an initial safety upgrading program. The ground motion input at that time was defined as a suite of eight natural earthquake records scaled to 0.25g pga. Results of the responses to these records were then enveloped. Using the enveloped results (spectra and structural loads), structural upgrades were carried out on the main reactor building complex, the primary circuit, some essential piping, and some electrical and control cabinets.

As a condition of continued operation, a major reconstruction project (REKON) is being carried out by a consortium led by Siemens AG. In this reconstruction project, new equipment and structures are integrated with existing equipment and structures to comprise a highly upgraded, substantially safer, power system.

In the international community, it is recognized that for upgrading existing NPPs, it is not practical nor necessary to seismically qualify all essential structures and components to current standards used for new design. Adequate safety goals may be achieved by applying alternate approaches. These alternate approaches utilize seismic experience, testing experience and analytical techniques that allow for response of ductile SSCs beyond the elastic limit.

In the U.S., several seismic reevaluation issues have surfaced over the past twenty years and approaches alternate to new design criteria have been developed to resolve these issues. The oldest U.S. NPPs, which had little or no seismic design, were partially evaluated and upgraded using criteria that demonstrated the ability of ductile structural systems to perform adequately when stressed beyond the elastic limit. Generic Safety Issue USI A-46 addressed the operability of equipment in approximately two-thirds of the operating NPPs in the U.S. which had incomplete or outdated seismic qualifications. A Generic Implementation Procedure (GIP), Reference 2, that utilizes a combination of seismic and testing experience and well-defined analytical procedures for evaluation of anchorage and selected components, was developed in support of the resolution of USI A-46. The GIP covers twenty generic classes of components plus cable raceways, tanks and heat exchangers. Application of the GIP is considered to be equivalent to a design basis qualification and is being employed in the REKON Project where applicable.

As a part of the U.S. severe accident policy, Individual Plant Examination of External Events (IPEEE) has been performed on all operating NPPs using either Seismic Probabilistic Risk Assessment or Seismic Margins Assessment methodology.

For items not covered by the GIP such as piping and HVAC, procedures similar to the seismic margins approach, Reference 3, are utilized. The seismic margins approach is a deterministic methodology, similar to design methodology, that focuses on demonstrating a High Confidence of Low Probability of Failure (HCLPF). HCLPF is defined mathematically as 95% confidence of less than 5% probability of failure.

For structures, an additional methodology developed for U.S. Department of Energy facilities, Reference 4, and based on performance goals, is utilized for evaluation and upgrading of existing structures. Use of appropriate performance goal criteria results in the establishment of a HCLPF.

The REKON Project has developed a series of technical criteria, Table 1, that incorporates the appropriate features of the GIP, Seismic Margins, DOE Criteria, local design codes, and U.S. and Western European codes. The criteria apply to design of new SSCs as well as evaluation and upgrading of existing SSCs.

The fundamental features of the REKON criteria envelop draft "IAEA Technical Guidelines for Re-Evaluation Program of Bohunice NPP-Units V1-V2," Reference 5, whereas the details are developed specifically for the V1 REKON Project.

Table 1: Technical Documents

NPP BOHUNICE V1, PROJECT-SPECIFICATION

Zuordnung von Referenz-Nr. zu Berichts-Nr. und Doku-Kennzeichen Bohunice

Basic-Reports

Ref.-Nr.	KWU-Berichtsnr.	.Doku-Kennzeichen Bohunice	Titel
0-1	NDM5/96/E1382	REKOV1/SER/ST/0001/NDM5	Introduction
0-2	NDM5/96/E1383	REKOV1/SER/ST/0002/NDM5	Work Plan
0-3	NDA2/96/E240	REKOV1/SER/ST/0003/NDA2	SQDP Part A: Civil Structures
0-4	NDM5/96/E2043	REKOV1/SER/ST/0004/NDM5	SQDP Part B: Mechanical and Electrical Components
0-5	NDM5/96/E1384	REKOV1/SER/ST/0005/NDM5	SQDP Part B1: Walkdown Criteria
0-6	NLE/96/E	REKOV1/SER/ST/0006/NLE	SQDP Part B2: Test Qualification
0-7	NDM5/96/E2044	REKOV1/SER/ST/0007/NDM5	SQDP Part B3: Analytical Verification of Mechanical and Electrical Components

Attachments

Ref.-Nr.	KWU-Berichtsnr.	Doku-Kennzeichen Bohunice	Titel
A-1	NDM5/96/E1221	REKOV1/EBS/ST/0003/NDM5	Interim Review Level Earthquake
A-2			Technical Guideline IAEA
A-3	NDM5/95/E1113a		Basic Engineering Report
A-4	NDA2/96/E0523	REKOV1/EBS/ST/0004/NDA2	Spectra Main Building Complex
A-5		REKOV1/EBS/ST/0005/NDA2	Spectra Diesel Building
A-6	NDA2/96/E102	REKOV1/EBS/ST/0001/NDA2	Spectra SHN Building and Canal
A-7	NDM5/96/E	REKOV1/SER/ST/0008/NDM5	Piping Evaluation Guideline (PEG)
A-8	NDM5/96/E1385	REKOV1/SER/ST/0009/NDM5	SC IIA-Criteria
A-9	NDA2/96/E291	REKOV1/SER/ST/0010/NDA2	Anchorage Verification Criteria (AVC)
A-10	NDM5/96/E1388	REKOV1/SER/ST/0011/NDM5	Cable Tray Criteria (CTC)
A-11	NDA3/96/E	REKOV1/SER/ST/0012/NDA3	Piping Support Criteria (PSC)
A-12	NDM5/96/E1387	REKOV1/SER/ST/0013/NDM5	HVAC Duct Criteria

The seismic reevaluation and upgrading portion of the REKON Project consists of the following steps:

1. Establish an Interim Review Level Earthquake (iRLE). The iRLE selected for the Reconstruction Project, Reference 6, is considered to be equivalent to an S2 design basis earthquake as defined in Reference 1.

2. Develop in-structure response spectra and structural loads for the iRLE. The procedures used follow the U.S. practice for design as specified in NUREG-0800, Reference 7.

3. Develop a safe shutdown equipment list of structures, systems and components necessary for safe shutdown and mitigation of the design basis accident. The methodology used is an expansion of the guidelines in References 2 and 3.

4. Perform a walkdown and apply the Generic Implementation Procedure screening criteria, Reference 2, to 20 generic classes of essential components plus tanks, heat exchangers and cable raceways. This is considered to be equivalent to design basis criteria.

5. For SSCs not covered by the GIP, apply alternate screening criteria similar to the seismic margins assessment criteria of Reference 3, to demonstrate that the HCLPF is equal to or greater than the iRLE. This approach is equivalent to or envelopes the guidelines in Reference 5.

6. Perform analyses of SSCs that are not screened out during and subsequent to the walkdown using seismic margins approaches.

7. Perform tests as required to verify seismic adequacy of existing components. This is considered to be equivalent to design basis qualification.

8. Design seismic upgrades as required. The upgrades will be designed using the appropriate criteria from items 4 or 5.

The above approach to evaluation and upgrade design is considered to equal or exceed the IAEA guidelines summarized in Reference 5. A flow chart of the process is shown in Figure 1.

2. *SEISMIC INPUT MOTION*

Studies by Russian and local scientists determined that the site could be subjected to an earthquake of MSK 8 intensity. This relates approximately to a 0.25g peak ground acceleration but no specific ground motion spectral shape is defined. In the initial seismic adequacy studies and upgrading, a suite of eight natural earthquake records scaled to 0.25g were used to compute responses. These responses were then enveloped. The natural records tended to produce narrow banded low frequency, high amplification ground motion spectra.

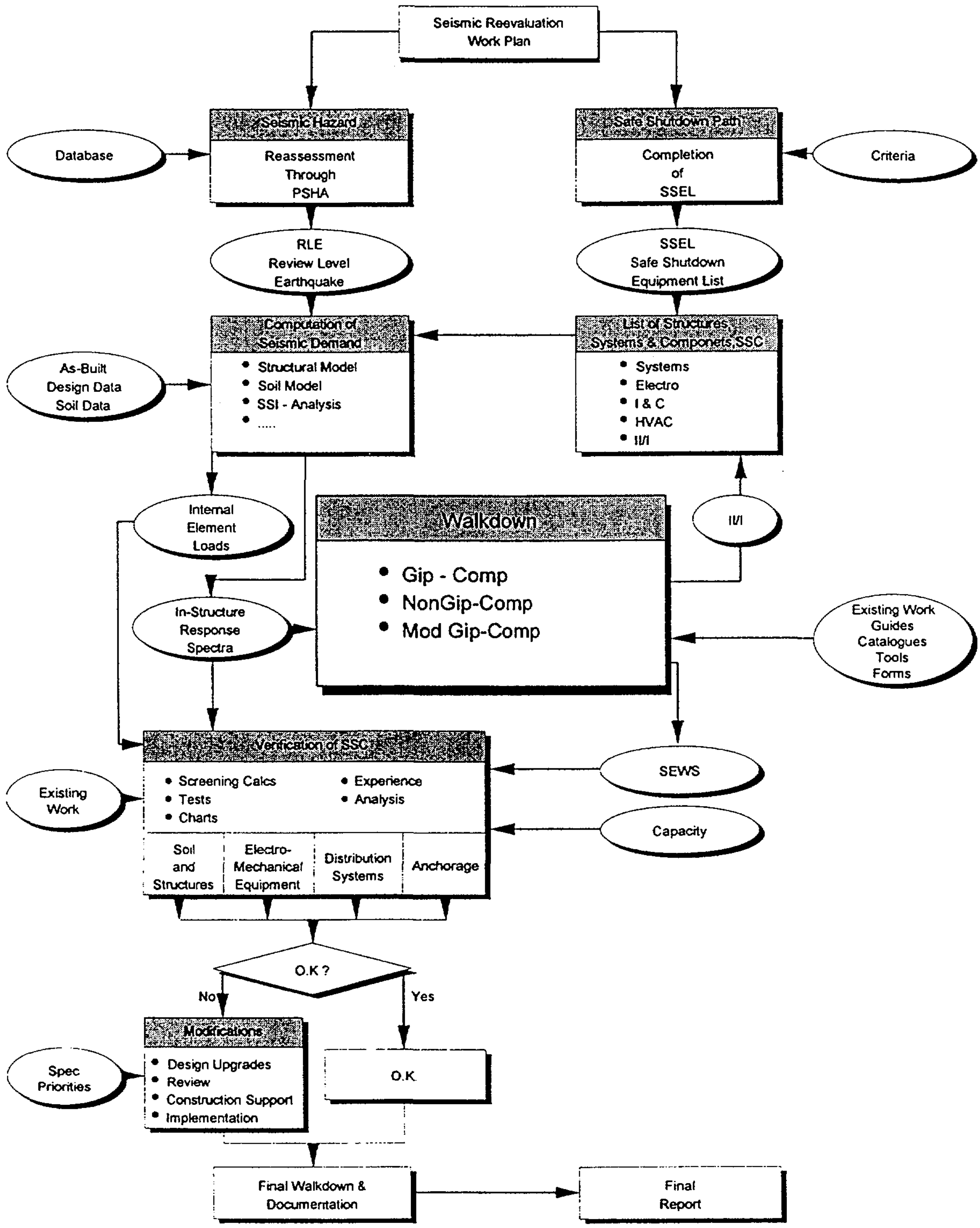

Figure 1: Flowchart for Seismic Verification of SSCs

A review of the site seismicity was conducted in 1990, Reference 8. This review included the development of an 84th percentile deterministic ground motion spectrum for the site and a probabilistic prediction of the peak ground acceleration. Results of this study indicated that the peak ground acceleration should likely be higher than 0.25g, but that the amplification of the pga at low frequency, which dominate the response of the main reactor complex, was less than resulted from the enveloping of the response to eight natural earthquake records.

In support of the long-term reconstruction of Bohunice V1 and further seismic assessment of the V2 units, the Slovakian Academy of Science Geophysical Institute, SAV, has been commissioned to conduct a detailed seismic hazard investigation for the Bohunice site. This study is ongoing. In the interim, an earthquake ground motion had to be selected as the basis for the seismic reevaluations and upgrades to be performed in the REKON Project. Using available seismotectonic data, a new study was conducted, Reference 6, to develop uniform hazard spectra for the site and to select an interim review level earthquake, iRLE, for use in the REKON Project. The goal in establishing an iRLE was to define a standard broad banded spectral shape that enveloped the best estimate of the 1E-4/yr 84th percentile site-specific spectrum.

The iRLE selected is based upon a USNRC Regulatory Guide 1.60 spectral shape anchored to 0.25g, but with the pga being further increased to 0.3g. The spectrum from 9 Hz to 33 Hz is then blended in. The resulting spectrum approximates an 84th percentile uniform hazard spectrum which may be inferred from Reference 6 and the deterministic 84th percentile spectra developed in Reference 8. This spectrum is shown in Figure 2. It is important to note that application of the GIP seismic experience-based screening criteria requires that the 5% damped spectral acceleration from about 2 to 8 Hz be enveloped by a seismic experience-based bounding spectrum which has a spectral acceleration of 0.8g in this frequency range. This is the frequency range considered to be most important in reevaluation of SSCs. As can be observed from Figure 2, the iRLE is less than 0.8g between 2 and 8 Hz, thus the GIP seismic experience-based screening criteria are applicable, providing that all other GIP criteria are met.

3. SAFE SHUTDOWN EQUIPMENT LIST

IAEA Technical Guidelines, Reference 5, for development of a Safe Shutdown Equipment List (SSEL) are patterned after the U.S. Seismic Qualification Utility Group (SQUG) GIP, Reference 2 and USNRC Individual Plant Examination for External Events (IPEEE), Reference 12, wherein a minimum set of systems and their components must be verified for seismic adequacy to achieve a safe shutdown and maintain the plant in a safe condition for up to 72 hours. Safe shutdown is defined as either hot or cold shutdown. This is achieved by:

- reactivity control
- reactor coolant system pressure control
- reactor coolant system inventory control
- reactor decay heat removal

In the U.S. IPEEE program, Reference 12, it is also required that one primary path and one redundant path be verified to achieve the above essential functions. It is also required that the capability to mitigate a small LOCA and containment isolation and cooling be verified.

In the reconstruction concept for Bohunice V1 the scope of seismic qualification follows these guidelines and in addition includes the mitigation of the design basis accident and the cooling of spent fuel. In addition, it is required to provide reliable cooling of the reactor to achieve cold shutdown.

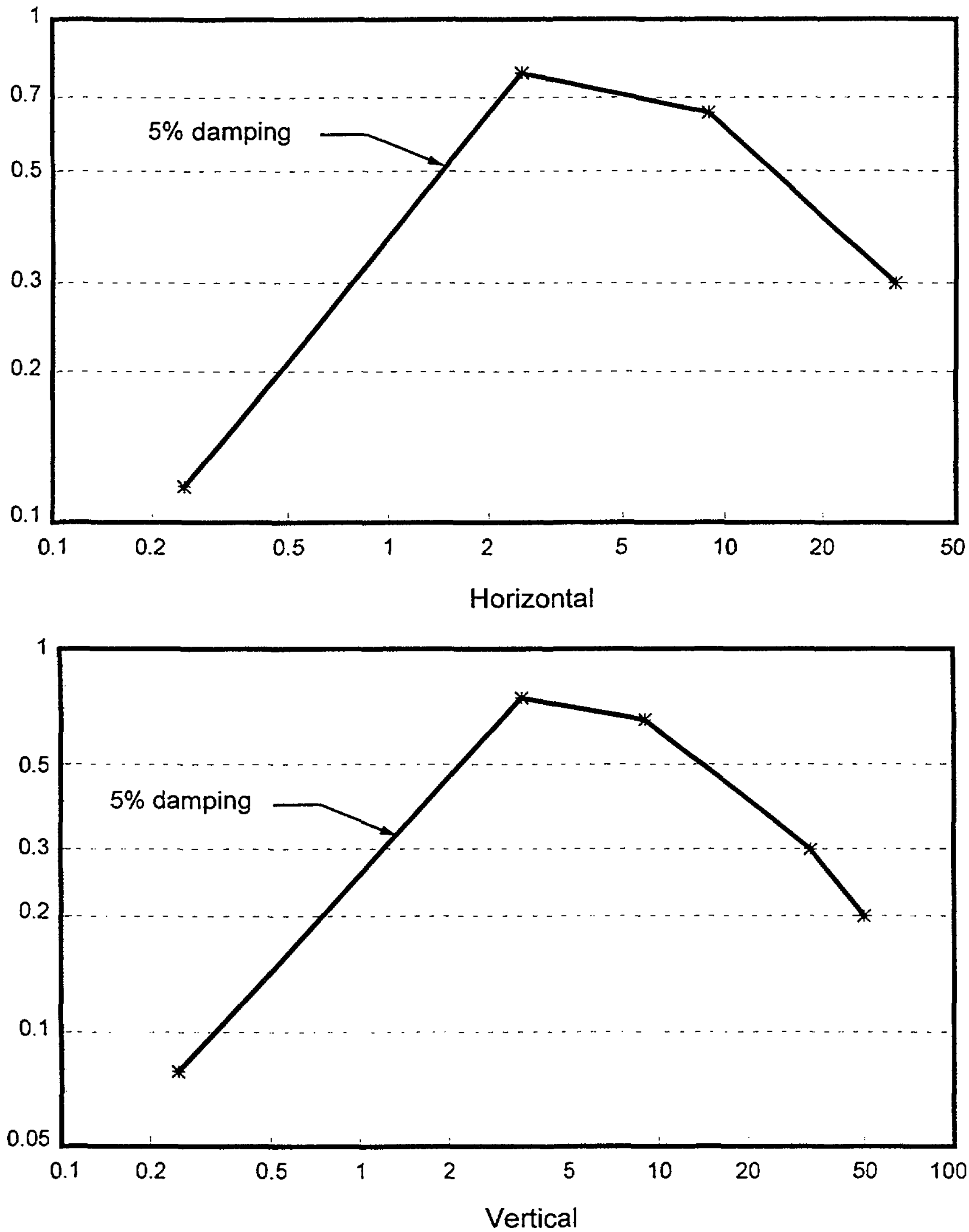

Figure 2: Interim Review Level Earthquake for Bohunice

Because of the many safety deficiencies in the WWER 440-230 design relative to Western Standards, considerable reconfiguration of the plant mechanical, electrical and I&C systems is required. In the case if emergency feedwater and service water, complete new systems are being constructed for which no essential elements are located in vulnerable areas such as the turbine hall. Many electrical systems and their cabling are being replaced or relocated to provide complete separation for fire and other hazards.

Reactivity control is provide by control rod insertion which is achieved by gravity. Control of boron concentration in the primary coolant is utilized for finer adjustment of reactivity during cool down. As is common on many Western PWRs, there is no separate emergency boration system to mitigate ATWS in the event that control rods cannot be inserted.

Pressure control in the emergency power mode is achieved by the power operated relief valves on the pressurizer. Pressurizer heaters are not essential for pressure control since the objective is to reduce pressure and not increase pressure.

Inventory control is achieved through the high pressure safety injection pumps. These pumps are also used for the early mitigation of the design basis accident which is a primary coolant break of 32mm diameter. The existing positive displacement makeup pumps are not essential for the safe shutdown scenario.

Decay heat removal to hot shutdown is achieved by release of steam to the atmosphere through new power operated steam dump valves and cooling of the steam generators by means of the new super emergency feedwater system. While it is feasible to cool the reactor by feed and bleed of the primary system by means of the pressurizer power operated relief valves and the high pressure emergency feedwater system, this is only considered as a last resort method of removing heat from the primary system.

The WWER 440-230's do not incorporate a containment that can confine the release of a large LOCA. A rectangular shaped, reinforced concrete confinement is designed to withstand the design basis accident which is a 32mm diameter primary coolant line break. The design pressure for the confinement is 1 bar.

Confinement cooling to prevent pressure of greater than 1 bar is achieved by means of the confinement spray system. Isolation of all confinement penetrations must be demonstrated through two isolation valves. In addition, the structural stability of piping past the second isolation valve must be demonstrated to an anchor point or through sufficient pipe supports that restrain all important degrees of freedom of the piping.

Spent fuel cooling is achieved via the spent fuel pool heat exchanger which is cooled by the new service water system.

The systems described above that provide the basic functions all require support systems and I&C to monitor and control the essential processes.

The safe shutdown equipment list incorporates all components, piping, cabling and HVAC ducting in the systems that perform the basic functions and in their essential support systems.

4. CIVIL STRUCTURES

Seismic category 1 (SC1) structures to be reassessed and upgraded if necessary are the main reactor building complex and the diesel generator building. Other SC1 buildings are either new additions, are being completely rebuilt or replaced. Structures that are not SC1, but whose failure could affect the functionality of SC1 structures and equipment are categorized as SC2A and include the ventilation stack, a radwaste building and a bridge connecting the auxiliary and reactor buildings. The criteria described herein are for SC1 structures which must be assessed and upgraded. Those structures that are SC2A are evaluated and upgraded per the Slovakian National Building Code, Reference 9.

Modeling: Finite element models are utilized in the evaluation and upgrade design of SC1 structures. Building models are to be constructed of beam and plate elements. The main reactor building complex consists of a concrete confinement structure and steel-framed reactor building superstructure, electrical galleries, ventilation hall and turbine building. All structures of the main building complex are interconnected, but have individual foundations. Thus, the finite element model is required to account for soil-structure interaction of these independent foundations, which in some cases are strip footings. There are many non load bearing unreinforced masonry walls and concrete panels in the main building complex which are not capable of carrying lateral structural loads arising from the iRLE, thus they must be modeled as mass only. Material properties used in the modeling are to be standard handbook properties from building codes and vendor catalogs.

The diesel generator building consists of steel framing and load-bearing unreinforced masonry walls. In this case, the stiffness of the masonry walls must be included in the model.

Input Motion: Analysis of the main reactor building complex is conducted using time history input. Artificial time histories for the three directions of input motion must result in spectra that envelop the iRLE horizontal and vertical spectra at 5% damping and must be statistically independent. Time history analysis is utilized for development of spectra and loads. For the simpler diesel generator building, in-structure response spectra are not needed and response spectrum modal analysis is sufficient for computing structural loads and for purposes of designing upgrades.

Soil-Structure-Interaction: For the reactor building complex, soil structure interaction effects must be properly accounted for using state-of-the-art methods that address embedment effects and the independent foundation input motion. Strain compatible shear modulus and damping must be employed. To account for uncertainty in soil properties, three cases are to be analyzed using the best estimate soil properties and maximum and minimum soil modulus properties. The maximum and minimum modulus are to be taken as two times and one half of the best-estimate case. For the much simpler diesel generator building, it is conservative and adequate to ignore SSI effects and use a fixed-base model of the structure above grade level and conduct response spectrum modal analysis to develop loads.

Damping: Damping to be considered in the analysis includes that due to hysteric energy losses in the structural and soil and radiation damping in the soil. Structural damping to be used in the analysis, whether for developing response spectra or loads in members, are provided in Table 2. Soil damping is determined from the soil characteristics and, in accordance with U.S. practice, Reference 7, it is not limited as long as realistic soil profiles are used or calculations are conducted in the frequency domain.

Development of Spectra: Response spectra are to be developed from the three independent soil stiffness cases and then smoothed and broadened not less than 10% so that a single spectrum for each of the three orthogonal directions envelopes the broadened individual soil stiffness cases. If the maximum and minimum soil cases produce a frequency range of greater than plus and minus 15%, no broadening is necessary.

Strength: Design code ultimate capacity equations shall be used to determine the allowable response of the structural elements. Code ultimate capacity may be determined from U.S., German or Eurocodes.

Table 2: Damping Values D in % of Critical Damping

Type of Structures	Damping Value D (%)
Welded aluminum structures	4
Welded and friction-bolted steel structures	4
Bearing-bolted steel structures	7
Reinforced concrete structures	7

Notes:

(1) These values are appropriate for linear analysis and should not be used for non-linear analysis where hysteritic energy dissipations is directly considered.

(2) Lower damping values may be appropriate for development of response spectra if the overall structural demand is less than about 1/2 of yield.

Ductility: The extent to which structures may be loaded beyond code ultimate capacity is determined on an element basis rather than a global basis. Ductility factors, $F\mu$, shown in Table 3 may be used to reduce the calculated elastic inertia response of structural elements. These factors are derived from Reference 4 and when applied in combination with code ultimate capacity equations, a HCLPF is achieved.

Load Combination: Response to the iRLE shall be combined with concurrent static and dynamic loads in accordance with:

$$1.0\,(DL + LL + T) + 1.0\ iRLE_i/F\mu + 1.0\ R_{SL} < U$$

where:

DL = Dead Load
LL = Live Load
T = Restraint of Thermal Expansion
$iRLE_i$ = Seismic Inertia Load
R_{SL} = Other earthquake induced loads such as differential motion and systems interaction effects. The design basis accident is not postulated to occur simultaneously with the iRLE.
$F\mu$ = Element ductility factor per Table 3
U = Ultimate code capacity

Non-permanent loads that counteract the effects of seismic loading shall not be included in the load combination.

Limitation factors on concurrent loads are:

0.25 for LL
0.3 for Snow load
0.0 for working loads of hoists and cranes

5. MECHANICAL AND ELECTRICAL COMPONENTS

Mechanical and electrical components may be evaluated by performing a detailed walkdown and screening of components using seismic experience-based screening criteria,

Table 3: Inelastic Energy Absorption Factors, Fμ

	Fμ Value
Steel braced frames	
- Beams	1.60
- Tension-compression diagonal braces	1.40
- Tension-only diagonal braces, chevron, V, and K bracing	1.20
- Columns	1.00
Concrete braced frames or concrete/steel frame systems	1.40
- Tension-compression diagonal braces	1.20
- Columns	1.00
Ordinary steel moment frames	
- Beams	1.50
- Columns in flexure	1.50
- Columns in axial compression or shear	1.00
Ordinary concrete moment frames	
- Beams	1.20
- Columns in flexure	1.20
- Columns in axial compression or shear	1.00
Reinforced concrete shear walls	
- In-plane flexure	1.40
- In-plane shear	1.20
- Out-of-plane flexure	1.40
- Out-of-plane shear	1.00
Connections for all structural systems	
- Assure connection stronger than members by 20%	1.00

Connections - For all structural systems, the connections are typically governed by less ductile failure modes than the attached members. As a result, connections must be capable of withstanding the lesser of (1) the strength of the connecting members; (2) the member force corresponding to Fμ of unity; or (3) the maximum forces that can be transmitted through the connection by the structural system.

analysis, testing or a combination of these methods. Components which must be verified are categorized as SC1A, SC1B, SC1C and SC2A. SC1A components are those that must function during or after the earthquake. SC1B components must survive the earthquake without loss of pressure boundary. SC1C components must only maintain their stability and SC2A components are nonessential components whose failure could impede the function of SC1 components. The emphasis for verification of seismic adequacy is on walkdown and screening where applicable. This methodology is generally applicable to all categories except the case of SC1A components which must function during the strong motion shaking. In cases where screening cannot be accomplished, selected analyses or tests must be conducted to verify seismic adequacy.

Verification by Walkdown and Screening: The GIP, Reference 2, is utilized to guide the walkdown and screening of components. The GIP covers 20 generic classes of equipment and the screening criteria contained in the GIP are based for the most part on the successful performance of equipment in strong motion seismic events. The seismic experience database that forms the basis for the GIP screening criteria is primarily for U.S. commercial grade equipment, but some Western Europe and Asian data is included. In order to apply the GIP screening criteria to equipment manufactured in Eastern Europe and the former Soviet Union, the engineers performing the walkdowns and screening must be experienced in not only the application of the GIP, but also in the background of the data which served as the basis for the GIP. This background and training are necessary as a condition for demonstrating the applicability of the GIP and for making screening judgments.

The walkdown screening per the GIP criteria requires fundamentally that:

- The equipment is represented in the data base. Note that absolute representation is not necessary but similarity of important features must be demonstrated.
- Anchorage must be verified. Alternate anchorage verification criteria have been formulated for the REKON Project to specifically account for the anchorage configurations used.
- GIP criteria for capacity vs. demand must be satisfied. This requires the floor response spectra are bounded by 1.5 times the seismic experience based SQUG bounding spectrum or that the Ground Motion Spectrum is enveloped by the SQUG bounding spectrum. For most components, the later criteria requires that the component must be demonstrated to have a natural frequency greater than 8Hz.
- Relays within the component must meet specific relay screening criteria.
- Components must be free of seismic induced interactions (falling of objects onto the component, impact, spray, etc.)

All components which do not meet the screening are outliers and require alternate methods to demonstrate seismic adequacy. Note that in almost all cases, the relay screening is not applicable and relays must be addressed separately even if the enclosures meet all of the screens.

Verification by Analysis: For the most part, the seismic adequacy verification does not require detailed analysis and the analytical verification is focused on anchorage capacity. The GIP provides detailed guidance on evaluation of anchorage with emphasis on expansion anchors. In general, the original anchorage of mechanical and electrical equipment at Bohunice did not include expansion anchors. Many components were unanchored and must be anchored, in which case expansion anchors are often used and the GIP is used as guidance in sizing expansion anchors. Often details of the existing anchorage cannot be verified and new anchorage must be designed.

Outliers that do not meet the GIP walkdown screening criteria may be resolved by analysis. Analysis is generally performed to assess a strength issue or define a displacement. In general, analysis cannot be reliably conducted to verify function of electro-mechanical devices subjected to dynamic load. If analysis is performed a variety of methods may be used which, in order of increasing complexity, include:

- Static analysis with the coefficient being defined as the peak of the response spectrum at the attachment point for flexible systems or the zero period acceleration for rigid systems.

- Response spectrum modal analysis.
- Linear time history analysis
- Non-linear time history analysis.

Damping values applicable to seismic response of component are listed in Table 4.

If components are evaluated by analysis, applicable code equations are utilized to assess capacity. Codes of different countries and for different types of components differ slightly, but, in general, for the same failure modes in components and supports the allowable stresses are similar. U.S. ASME and German KTA standards are applied where applicable. Ductility factors, $F\mu$, may be applied to ductile components where structural capacity is the failure mode of concern. Ductility factors may generally not be applied to components if deformations are critical to function.

Table 4:
Damping Values for Mechanical and Electrical Components
(percentages of the critical damping)

Structures and Components	Damping Value
Welded steel structures (support structures)	4.0%
Bolted steel structures (support structures)	7.0%
Tanks, vessels, heat exchangers	4.0%
Pumps	3.0%
Valves	3.0%
Instrument cabinets and racks	3.0%
Piping	4.0%
HVAC ducts	7.0%
Cable trays <50% loaded	10.0%
Cable trays ≥50% loaded	15.0%
Sloshing liquid	0.5%

Ductility factors, $F\mu$, for components are listed in Table 5.

Load combinations applicable to components vary with the type of component or support. Seismic inertia loads are combined with normal operating loads such as dead weight and internal pressure. Any operating load that is present more than 2% of the time must also be included in the load combination.

For pressure boundary components, the applicable load combination is:

$$1.0\ DL + 1.0\ LL + 1.0\ P + iRLE/F\mu < \text{ASME Level D or KTA allowable stress}$$

For component supports the applicable load combination is:

$$1.0\ DL+1.0\ LL+1.0\ T+(iRLEi^2 + IRLEm^2)^{1/2}/F\mu < \text{ASME Level D or equiv. KTA}$$

where:

$iRLE_m$ is seismic anchor motion loading and the other terms are as defined in Section 4.

Note that for non-ductile elements of supports, $F\mu$ is 1.0.

For non-pressure components such as electrical enclosures, the structural criteria of Section 4 is to be used.

Testing: In general testing is limited to electro-mechanical devices such as relays, motor contactors and breakers. Testing should comply to recognized national standards such as KTA 2201.4, Reference 10, or IEEE 344, Reference 11. In general, multi-axial, multi-frequency testing should be conducted, but single-axis, single-frequency tests are acceptable under certain qualifying conditions.

Existing test data are to be evaluated relative to criteria in current standards and the requirements derived for the specific location. Major requirements for seismic verification by test are:

Test Seismic Input Motion: The seismic input is defined by a Test Response Spectrum (TRS) applicable at the location of the specimen mounting (in-cabinet, floor, wall, etc.). The TRS must envelop the Required Response Spectrum (RRS) defined at the

Table 5: Ductility Energy Absorption Ratio Values, $F\mu$

Components and Supports	Structural Ductility Energy Absorption Ratio $F\mu$
Passive mechanical and electrical components:	
Ductile material	1.50
Non-ductile material	1.00
Passive mechanical and electrical component supports:	
Steel frames	2.00
Steel skirts, saddles, etc.	1.50
Active mechanical and electrical components including supports	1.00
Instrument cabinets and racks including supports	1.00
Pipes fabricated of steel:	
Butt welded	1.50
Socket welded or bolted flange	1.50
Threaded	1.00
Piping supports made of steel:	
Rigid supports (hangers, columns)	1.25
Framework	2.00
HVAC ducts, including supports	1.50
Cable trays including supports	1.50
Steel substructures (welded or bolted)	
Columns	1.00
Beam members	2.00
Connection members	1.00

mounting location. The actual input motion of the shake table must result in a response spectrum that is equal to or exceeds the RRS in all frequency ranges of interest. If the input motion is single frequency, the envelope of the spectra resulting from the single frequency inputs must envelop the RRS for all frequencies above the fundamental frequency. See Figure 3 as an example of enveloping of single frequency spectra. If the response investigation demonstrates that the dynamic response is primarily in a single mode, then single-frequency testing is acceptable without a penalty. If response is multimode, the envelope of the single frequency TRS must be reduced by $\sqrt{2}$ before comparing to the RRS.

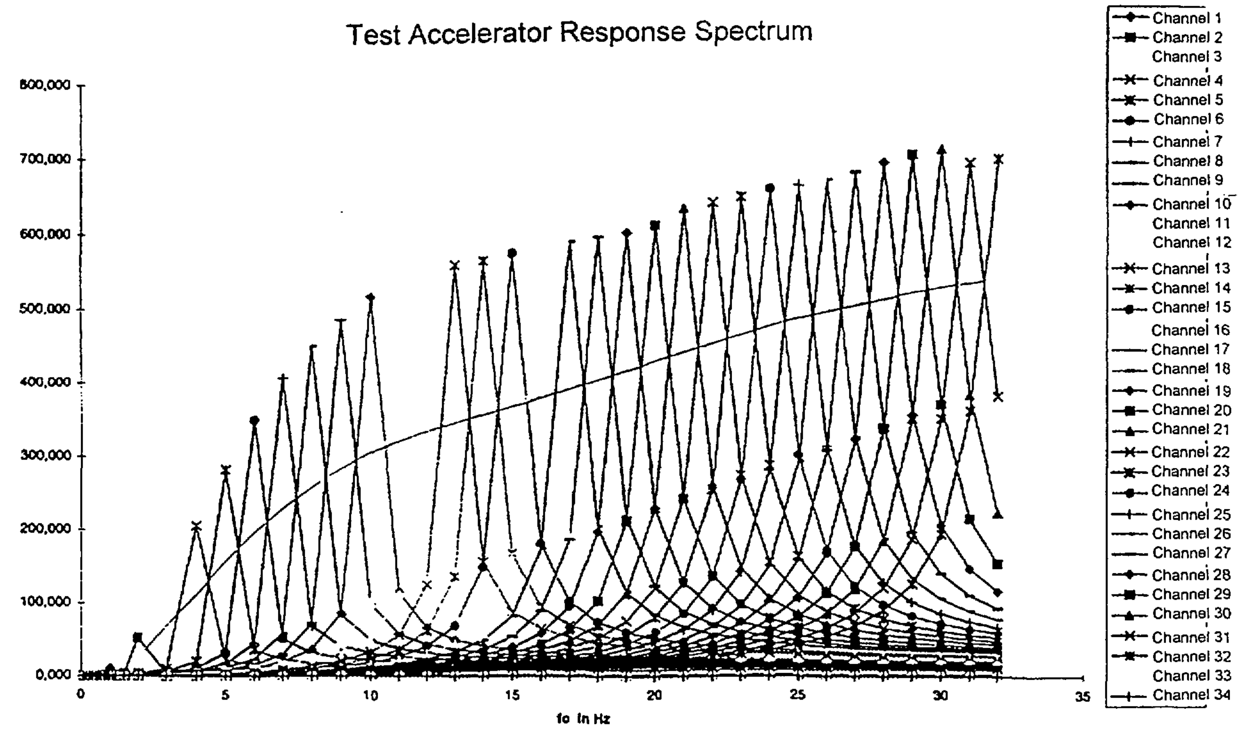

Figure 3: Enveloping of Single Frequency TRS

If testing is single axis, and it can be reasonable demonstrated by response investigations or by geometric arguments that there is very limited coupling between directional responses or that the component function is only sensitive to a single direction response, then the single axis test TRS is acceptable for comparison to the RRS for each axis. Otherwise, the single direction response must be reduced before comparing to the RRS. The reduction should be either $\sqrt{2}$ if the response is sensitive to two directional input or $\sqrt{3}$ if sensitive to three directional input.

Monitoring: If electrical functions are critical during the shaking, then the essential functions must be monitored during the test. In the case of devices such as relays that may be in different states during normal operation, each state must be tested and monitored. If there are no active functions to be performed during the time frame of the earthquake, then it is only necessary to verify that the component is functional after the earthquake.

Combinations of Analysis and Test: In many instances it is necessary to test devices such a relays for function, but it may not be necessary to test the entire cabinet enclosure. Typically, transmissibilities will be developed from the floor to the device by analysis, in-situ testing or by use of generic amplifications derived from experience as provided in the GIP. In the case of generic amplifications, some modifications have been made to the GIP guidance to reflect stiffening that has been conducted on flexible panels to which relays are mounted. Panels have been stiffened to a point that amplifications greater than 3.0 are not postulated.

6. DISTRIBUTION SYSTEMS

For distribution systems like piping, cable trays and HVAC ducts a combination of detailed walkdown using experience-based screening criteria and selected analysis is applied for evaluation. Selecting of the appropriate procedure depends mainly on the complexity of the system. Screening criteria have been developed in previous seismic reevaluation projects in various European plants and were modified for the specific issues at Bohunice.

Piping and Piping Supports: It is common practice that piping systems are designed or reevaluated either by detailed finite element analysis or by simplified methods like support span charts. In new design the use of simplified methods is usually restricted to small bore piping while the rest is verified by analysis, which leads to an extensive amount of computer calculations.

With the general experience that piping systems are very rugged under seismic loads, even if they have not specifically been designed to seismic criteria, it is judged to be acceptable to increase the scope of piping systems to be evaluated by simplified method.

Due to experience gained in various reevaluation projects in Germany and Western Europe, the use of detailed analysis for Bohunice piping systems is limited to:

- Reactor coolant system
- High pressure systems with design temperature > 100 C
- Selected system sections with extremely complex layout

All other piping, including all systems or system sections which are classified as SC2A, will be evaluated with simplified screening criteria.

Verification by Analysis: For those systems, where analysis is required the response spectrum modal analysis method is to be used with applicable code equations and stress values. Modeling, decoupling and system properties are done in accordance with international standards like U.S. ASME and German KTA. Stress intensification factors are used in accordance with the same codes, provided that they represent the geometric configuration. A damping value of 4% is specified for all diameters whereas higher values may be accepted if they are justified.

The load combination for piping analysis is specified as:

Pressure + deadload + earthquake loads < ASME or KTA Level D allowable stress

Earthquake load is defined as the inertia loading from the iRLE.

Where structural capacity will exceed allowables a ductility factor of 1.5 may be applied to represent non-linear behavior of the system, however, in accordance with Table 5, a factor of 1.0 is applied to nonductile joints.

Verification by Walkdown and Screening: The method which is used for most of the piping systems is a combination of seismic experience and a variety of generic calculations representing typical piping layouts and arrangements.

The screening criteria are focused to satisfy the three major aspects for verification of seismic adequacy of piping systems which are:

- Vertical ad horizontal piping support spacing
- Flexibility check and expansion length for anchor movements (thermal and seismic)
- Support loads for verification of substructures and anchoring

The screening criteria for the above parameters are set up in tables and nomographs for easy use in walkdown screening

The engineers performing the walkdown must be trained not only in the application of these criteria but also must be able to verify the construction quality of the piping arrangement. In cases of non-applicability of the criteria, the criteria may be modified according to the individual situation or supplemented by some simple analysis.

The walkdown staff further has to have extensive knowledge in system operation parameters such as normal and transient conditions to assure that all credible load combinations are addressed and that seismic upgrades will not cause adverse affects to the operational requirements.

Verification of Piping Supports: To assure seismic resistance of piping systems, piping supports and their anchoring is more relevant than the pressure piping itself. Experience gained in various seismic evaluation tasks show, that for piping supports, the most critical parts are either the anchoring, certain features of some of the standard support items or the welds, but in a very few cases the steel structures. The focus is on the non-ductile portions of the supports.

The acceptance of capacity of piping systems for seismic loads depends mainly on the supports performing the right function and having a continuous load path.

Most existing piping supports are standard designs and construction and the development of screening and walkdown criteria take into account the specific detail. To verify integrity of piping supports by walkdown and screening a set of criteria were set up which address the:

- Functional performance of the pipe support substructure
- Capacity of the most critical items
- Type and quality of welding

Due to similarity of piping supports and standard configurations not every support has to be evaluated, only a sampling of typical construction.

Guidance for individual modification of the screening criteria, especially for quality discrepancies in welding, are provided. A simple assessment procedure was established taking into account geometric aspects as well as fabrication parameters like welding undercut, holes or gaps.

For piping supports for which the simplified procedure is not applicable, due to complex geometry or loading, static analyses are performed to verify seismic adequacy. The analyses are conducted in accordance with current international standards like ASME or German DIN or Eurocode and are performed with standard computer tools.

Where necessary and applicable, ductility factors Fu, as listed in Table 5, may be used.

Assessment of HVAC Ducts: Essential HVAC ducting at Bohunice V1 is constructed of either folded seam or welded seam sheet metal. In both cases, longitudinal connections are made by bolted flanges. The folded seam ducting is thinner, thus potentially more vulnerable to seismic inertia loading, plus has a much less robust design of the connection flanges.

Failure modes to be considered in the assessment are buckling of the ducting, opening of the folded seams, attachment of the ducting to the flanges and the pressure integrity of the bolted flange joint.

Evaluation of the failure modes by analysis is difficult and uncertain. Fortunately, Siemens has a large database of HVAC ducting tests which includes data for ducting which is very similar in design and construction. From these test data it was determined that the critical failure mode for both cases is opening of the bolted flange joints, thus compromising the pressure retention capability of the ducting. Opening of the flanges does not, however, result in instability or collapses of the ducting systems.

Test results provide the bending moment capacity of the ducting flange joint. Given this moment capacity, span spacing for vertical and horizontal supports can be determined. In determining the allowable span spacing the peak of the 7% damped floor spectrum is used as the seismic demand. Seven percent damping is the acceptable value from the REKON standard and is obtained from KTA standards for NPP design. By using the peak of the spectrum for demand, the eigenfrequency of the HVAC and support system does not have to be calculated or controlled.

Support loads from seismic inertia are defined as the peak 7% damped spectral acceleration times the tributary weight of the ducting. For vertical support spacing, dead load is added to the tributary seismic load.

Existing supports are generally inadequate and new supports must be added. The new supports are standardized designs sized to carry the tributary loading derived from the governing span spacing. In almost all cases, the supports are welded to existing structural elements. Where support attachment to the structures is by expansion anchors, manufacturers allowable loading is used to size the expansion anchors.

The span spacing and support screening criteria are summarized in tables for easy use in walkdown screening and placement of new supports.

Cable Raceways: Existing cable raceways are in general evaluated in accordance with the criteria in the GIP with some modifications to accommodate unique features of cable raceways and their supports at Bohunice. Most existing raceways do not pass the GIP screening, thus the walkdown screening of cable raceways is focused primarily on modifying the raceway support system to comply with the GIP. In many cases, new supports and their anchorage are designed to standard strength criteria utilizing the damping values in Table 4 and ductility factors in Table 5.

Many new routings of cables necessitate complete new design of raceway systems. These new system raceway designs have been done to existing KTA standards and do not utilize the more liberal seismic experience based GIP criteria.

7. *SYSTEMS INTERACTIONS*

Seismic-induced systems interactions may be spatial or systematic. Spatial interactions result from a failure or deflection of a SC2 item which may impair the function of an SC1 item by falling on it, impacting it or spraying it. These types of interactions are usually identified during the walkdown and screening phase. The most common of these interaction sources at Bohunice are the numerous unreinforced masonry walls and concrete panels which are weakly attached to the steel structural members. Systematic interactions might consist of failures of a pipe or heat exchanger that is not safety related, but is not isolated from an essential system. This can also occur in electrical systems where a short in a non safety circuit is not isolated from an essential circuit. These types of interactions are usually identified from reviews of flow diagrams and circuit diagrams.

The criteria for evaluation and upgrading of potential systems interactions sources is flexible to the extent that it must only be demonstrated that the interaction cannot occur. Use of the Slovakian Building code, Reference 9, for structural type interaction sources is acceptable and consistent with international guidelines, Reference 1. Other methods, such as energy methods suggested in Reference 5 are acceptable as is engineering judgment based on seismic experience. Often it is convenient and not a cost penalty to upgrade anchorage for potential systems interaction sources using the SCI criteria summarized in this paper. In other cases, such as for a large structure which is an interaction source, use of the local building code for upgrades is the most prudent approach. The engineering effort vs. the hardware cost must be considered in making upgrades to alleviate potential interactions.

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