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Seismic Verification Methods for Structures and Equipment of VVER-Type and RBMK-Type NPPs (Summary of Experiences)

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ABSTRACT

The main verification methods for structures and equipment of already existing VVER-type and RBMK-type NPPs are briefly described in this paper. In this connection the following aspects are discussed: fundamental seismic safety assessment principles for VVER/RBMK-type NPPs (seismic safety assessment procedure, typical work plan for seismic safety assessment of existing NPPs, SMA (HCLPF) calculations, modified GIP (GIP-VVER) procedure, similarity of VVER/RBMK equipment to that included in the SQUG databases and seismic interactions.

KEY WORDS: seismic, seismic adequacy, seismic evaluation, seismic re-evaluation, seismic design, seismic qualification, seismic safety, VVER-type, RBMK-type, seismic margin assessment, HCLPF, GIP, GIP-VVER

INTRODUCTION

The seismic safety of already existing NPPs was recognized as one of the most important safety issues due to almost no or insufficient original seismic design and qualification of these NPPs and their structures and equipment in particular. Therefore, the main objective of the seismic re-evaluation and re-qualification program of existing NPPs, and VVER/RBMK-type NPPs in particular, is currently to enhance the seismic safety of these plants to the level generally accepted by the international community and in compliance with the currently valid standards and recognized practice, information and data available to date. Such a program has usually two important phases:

- the seismic safety assessment of the plant (structures and equipment) with identification of corrective measures, if required,
- the design and implementation of these upgrading measures.

The basic idea is to carry out a refined review of the original design and state of structures and equipment „as built or as mounted“ to identify the real safety margins of these structures and equipment and the possibility to use such initial conservatism to guarantee an adequate safety margin, as far as possible, even to a new seismic conditions.

(a) The seismic safety assessment should use conservatism in a very careful way. An extensive use of conservative assumptions in a re-evaluation or re-qualification phase can easily lead to the conclusion of very expensive or an unfeasible upgrading program.

(b) The seismic re-evaluation and re-qualification program should adopt a safety margin policy to avoid that a high conservatism in the seismic task gives the illusion of high safety margin in the overall plant design. The limited residual life of the plant should also be considered.

(c) On the other side, the higher design-based conservatism should always be used for all newly designed and newly installed structures, equipment and also for any physical modifications of the already existing structures and equipment.

The main codes, standards and guidelines primarily used for seismic re-evaluation and re-qualification of existing NPPs are:

IAEA:	50-SG-S1, 50-SG-D15, NS-G-3.3 (draft No. 302), ND-G-1x (draft No. 304), TECDOC-1333,
ASCE:	4-86, 4-98,
ASME:	BPVC Section III, Division 1 (1992 ed.), and QME-1-1994,
Russian:	PNAE G-1-011-89, PNAE G-5-006-87, PNAE G-7-002-86, OTT-87,
IEC:	980-89, 255-21-3
IEEE:	Std 344-1987, Std 382-1982, Std 382-1996
Specific:	SQUG GIP, GIP-VVER, DOE Seismic Evaluation Procedure
National:	for capacity evaluation of concrete and steel structures.

FUNDAMENTAL SEISMIC SAFETY ASSESSMENT PRINCIPLES FOR VVER/RBMK NPPs

Seismic Safety Assessment Procedure

The Review Level of Earthquake (RLE) is a level of extreme ground motion that should nave a very low probability of being exceeded during the plant lifetime and represents the maximum level of ground motion to be used for re-evaluation and re-qualification purposes. For the probability of exceedance, a typical value of 10^{-4} /year is used for RLE which should equal or exceed the IAEA SL-2 level earthquake including the minimum requirement of 0.1 g Peak Ground Acceleration (PGA).

In a case of an earthquake, the NPP should be capable to shutdown the reactor, monitor its critical parameters, maintain the reactor in a stable shutdown conditions, remove residual heat for at least 3 days and also control the radiation conditions keeping the dose limits for the plant personnel and population. The existing levels of defense in depth should be preserved.

The main functions associated with the VVER/RBMK-type reactor to be assured during and after the RLE are as follows:

- reactivity control,
- reactor coolant system pressure control,
- reactor coolant system inventory control,
- reactor residual heat removal.

The following special acceptability conditions are typical for seismic re-evaluation and re-qualification of already existing NPPs, and VVER/RBMK-type in particular:

- initial plant status before the RLE: normal power operation,
- plant status after RLE: safe stable cold shutdown conditions,
- no electrical power, no make-up water and other media (e.g. diesel oil) for safety system operation available from external sources during 3 days after the initiating event,
- no other external event such as fire, flood, tornado, sabotage, etc. takes place simultaneously with an earthquake,
- earthquake induced internal fires and floods and other seismic interactions affecting the safety functions should be avoided,
- any internal accidental failures are not postulated to be concurrent with the RLE, neither LOCA, nor HELB takes place simultaneously with the earthquake, however the rupture of small bore pipes, as a consequence of the earthquake, should be considered, unless their qualification and reinforcement do not exclude such possibility.

It is also widely acknowledged that the general redundancy level (for instance, 3x100% for VVER-type NPPs) is respected by the seismic safety assessment procedure.

In the selection of Structures, Systems and Components (SSC) for the safety functions, the single failure criterion is applied. The single failure occurs independently of the RLE and it includes the consequential failures from the postulated one. The active single failure is postulated to occur at any time during the sequence of RLE. Single failures in electrical systems are active failures. The passive single failures may occur may occur only in long phase of the RLE sequence. Only one single failure is postulated per systems, even in the case of safety systems for twin units. In the case of common safety systems of twin units, an active single failure is postulated for an each unit.

The technology of the cooling down and continuous heat removal of the reactor is determined in such a way that the possible less amount of coolant lost due to small pipe breaks, if any, remains inside the hermetic area only. The consequences of small pipe breaks are investigated from both limit dose aspects and hermetic area integrity aspects. Whenever possible, the cool-down and heat removal methods are selected to do not cause excess loads of the hermetic are, e.g. the secondary bleed and feed instead of the primary one.

In order to assure the cooling of the spent fuel in the cooling pool, the cooling and re-filling systems of the cooling pool are seismically re-qualified and upgraded if necessary. Of course, the structural integrity of the cooling pool when subjected to RLE is also evaluated using the same criteria as for the structural integrity of the hermetic area.

The main source of the radioactive releases is the reactor, and consequently, the releases are dominantly determined by the activity released from the primary circuit to the hermetic area following the earthquakes, and the integrity of the hermetic area. Radioactivity might be released also from the non-reinforced volumes of the auxiliary building containing the radioactive waste liquids and other materials inside the auxiliary building. The structural integrity of that part of the auxiliary building is an important safety issue.

In general, the method of the reactor shutdown (manual, automatic), the shutdown criteria (acceleration level, Cumulative Absolute Velocity - CAV), the technology of the cool-down and residual heat removal, the way of the system isolation, the pre-earthquake preparedness and the post-earthquake actions form a harmonized set of assumptions, methods and procedures titled usually as the „Seismic Scenario of the NPP“.

Typical Work Plan for the Seismic Safety Assessment of Existing NPPs

Generally, the seismic re-evaluation and re-qualification of an each equipment component or an each distribution system consists of the following three main steps:

- evaluation of the seismic margin capacity of equipment as built,
- assignment of the relevant seismic upgrading measures, if necessary,
- evaluation of the seismic margin capacity of upgraded equipment.

The Seismic Margin Assessment (SMA) is used to determine the High Confidence Low Probability of Failure (HCLPF) seismic margin capacity of components and systems (as built and also when upgraded) in combination with the Generic Implementation Procedure (GIP) or the modified GIP called as GIP-VVER (typically for active mechanical and electrical equipment components). It is, of course, assumed, that the evaluated equipment components and distribution systems were properly designed against all non-seismic loads and effects. The methods typically used to evaluate seismic adequacy of structures and equipment of existing NPPs are as follows:

(a) **seismic analyses** based on the Seismic Margin Assessment (SMA) methodology (for building structures, main pipelines, main mechanical components (primary circuit pressure components, other pressure vessels, tanks, heat exchangers, pumps, anchorage of equipment),

(b) **qualification by earthquake experience** using the GIP or GIP-VVER procedure (for active mechanical, electrical and I&C equipment components, cable supporting structures, small bore and cold large bore pipes, HVAC ducts, verification of seismic adequacy of equipment as mounted),

(c) **qualification by seismic tests** (relays and similar devices sensitive to shocks and vibrations, some types of valve actuators, sensors, transmitters, reactor control rod drive systems etc).

Special emphasis should be devoted to the following important phenomena:

(a) in relation to building structures

- proper consideration of structural ductility,
- soil-structure interaction
- evaluation of liquefaction potential and soil capacity,
- seismic adequacy of structural joints and connections,
- seismic adequacy of non-bearing masonry walls,
- structural seismic interactions,
- potential seismic interactions (pushing) of near-by buildings,

(b) in relation to pipelines and equipment components

- functionality of active equipment components (mechanical, electrical, I&C),
- seismic adequacy (capacity, proper function) of equipment component and pipe supports,
- seismic adequacy (capacity) of essential equipment component nozzles,
- anchorage of pipe and equipment component supports (capacity),
- equipment seismic interactions (falling, proximity, spray and flooding).

SMA (HCLPF) CALCULATIONS

Table 1 Background of the Conservative Deterministic Failure Margin (CDFM) SMA Approach

Load combinations	Normal Operating Conditions+ Seismic Margin Earthquake
Ground response spectrum	84% non-exceedance probability
Damping	Median values (less conservative than design values)
Modeling of structures and equipment	Best estimation (median) + uncertainty variation in frequency
Soil-structure interaction	Best estimation + parameter variation
Material strength	Code specified minimum strength or 95% exceedance actual strength if test data available
Capacity equations	Code ultimate strength for concrete and steel structures, Service Level D (ASME BPVC Section III) or functional limits
Inelastic energy absorption (ductility)	Use ductility factors for non-brittle failure modes and linear analysis, or perform nonlinear analysis and go to 95% exceedance ductility levels
In-Structure (floor) response spectra generation	Use frequency shifting rather than peak broadening to account for uncertainty

MODIFIED GIP (GIP-VVER) PROCEDURE

The purpose of this section is to briefly describe the modified GIP titled as GIP-VVER which was created and can be used to verify seismic adequacy of the selected classes of the most important to safety mechanical and electrical equipment and also distribution systems of operating or constructed VVER-type NPPs, namely VVER-440/213, VVER 1000 type NPPs and also RBMK-type NPPs.

The procedure GIP-VVER has been prepared using the following background:

- public available information contained in SSRAP, GIP, U.S. DOE, LLNL and MCEER documents,
- information extracted from the documents prepared in a frame of the IAEA Benchmark Study for the Seismic Analysis and Testing of WWER-Type Nuclear Power Plants,
- information extracted form the results of available seismic tests performed mostly in Czech Republic during the last about 15 years, collected systematically and studied by S&A-CZ,
- experience taken from various many seismic walkdowns, evaluations and analyses of VVER-type NPPs equipment performed by S&A-CZ during the last eight years for these NPPs located in Czech, Slovakia and Hungary,
- information extracted from other related papers and documents.

The scope of equipment covered by the current version of the GIP-VVER procedure includes, similarly as the original GIP, the following twenty classes of mechanical and electrical equipment:

(1) Motor Control Centers
(2) Low Voltage Switchgears
(3) Medium Voltage Switchgears
(4) Transformers
(5) Horizontal Pumps
(6) Vertical Pumps
(7) Fluid-Operated Valves
(8) Motor-Operated and Solenoid-Operated Valves
(9) Fans (ventilators)
(10) Air Handlers
(11) Chillers
(12) Air Compressors
(13) Motor Generators
(13) Engine Generators
(14) Distribution Panels
(15) Batteries on Racks
(16) Battery Chargers and Inverters
(17) Instruments on Racks
(18) Temperature Sensors
(19) I&C Panels and Cabinets

European and particularly VVER-type relays, switches, transmitters and electric penetrations are significantly different from those included into the original GIP databases. These two classes of equipment are not included into the GIP-VVER procedure and their seismic verification shall be based on testing. In addition to twenty classes listed above, the GIP-VVER procedure also includes guidelines for simplified analytical seismic evaluation of the following classes of equipment:

(23) Cable Supporting Structures (based mainly on the EPRI methodology) ,
(24) Tanks, Heat Exchanger, Filters (based mainly on the documents).
(25) Pipelines and HVAC Ducts (based on the public available documents).

GIP-VVER also includes two special guidelines to verify adequacy of anchorage and seismic adequacy of non-bearing masonry walls.

The GIP-VVER is as well as the GIP or the DOE GIP primarily a screening and walkdown procedure. However, if an equipment item is classified as an outlier, rigorous approaches as testing on shaking table, deep study of input data, sophisticated analysis etc. may be used to verify its seismic adequacy. Generally, four major steps of this procedure when applied evaluation of seismic adequacy of classes of equipment identified above are as follows:

- selection of Seismic Review Team (SRT)
- identification of equipment the seismic adequacy shall be evaluated and set-up the Seismic Equipment List (SEL),
- screening verification and walkdowns,
- outlier identification and resolution.

An engineering judgment 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, experienced and professionally trained seismic capacity engineers, and also personnel to identify and evaluate essential relays. The basic criteria to verify seismic adequacy of an equipment item during the screening walkdown are :

- seismic capacity greater than seismic demand (by comparison of the corresponding $\mathrm{ISRS}_{\mathrm{RLE(SL2,\ SSE)}}$ (In-Structure Response Spectrum) or $\mathrm{GRS}_{\mathrm{RLE\ (SL2,\ SSE)}}$ (Ground Response Spectrum) to the Bounding Spectrum (BS),
- similarity to the equipment in the seismic experience data bases (checking of caveats, based on walkdown and information available from documentation),
- adequate anchorage of equipment (calculations or engineering judgment, based on walkdowns and information available from documentation),
- potential seismic interactions evaluated (based on walkdowns).

The GIP-VVER procedure uses two bounding spectra (BS):

(a) BS attached to PGA = 0.33 g (the same as introduced by SSRAP and used by GIP),
(b) BS attached to PGA = 0.50 g (1.5 times SSRAP BS) for selected VVER equipment classes (evidently rugged).

The following sheets are used for seismic verification and walkdowns:

- Seismic Verification Data Sheet (SVDS)
- Seismic Evaluation Work Sheets (SEWS)
- Seismic Walkdown Sheet (SWS)
- Outlier Seismic Verification Sheet (OSVS)

SIMILARITY OF VVER/RBMK-TYPE EQUIPMENT TO THAT INCLUDED IN THE SQUG DATABASES

Similarity of VVER/RBMK-type equipment to equipment included in the SQUG databases is the most important keystone of practical application of the GIP-VVER procedure. Generally, the principal of similarity is based upon comparison of equipment dynamic and physical characteristics. The procedure to establish similarity within an each equipment class includes the following comparisons:

- most probable modes of malfunction (based on recognized behavior of all critical devices) ,
- predominant resonant and critical frequencies and mode shapes,
- critical damping,

- most important physical equipment characteristics:
  - -- *equipment size, mass and position (vertical, horizontal, inclined etc.),*
  - -- *general making, quality of making, age of equipment,*
  - -- *location of the center of gravity, presence and location of cantilevered parts,*
  - -- *implementation of heavy and / or moving internal parts,*
  - -- *implementation of supports and anchorage,*
  - -- *implementation of attached lines, substructures, devices etc.*
  - -- *presence of devices (mechanical or electrical) sensitive to vibrations and shocks.*

SEISMIC INTERACTIONS

The four seismic interaction effects that are considered are:

- <u>proximity</u> (impacts of adjacent equipment or structures on safety-related equipment due to their relative motion during an earthquake),
- <u>structural failure and falling</u> of overhead or adjacent structures, systems, or equipment components),
- <u>flexibility of attached lines and cables</u>,
- <u>flooding</u> due to earthquake induced failures of tanks or vessels.

Interaction examples typical for existing older NPPs (not only VVER-type) are as follows:

- unreinforced masonry walls adjacent to safety-related equipment may fall and impact safety-related equipment or cause loss of support of such equipment,
- fire extinguishers may fall and impact or roll into safety-related equipment,
- inadequately anchored or braced equipment as vessels, tanks, heat exchangers, cabinets etc. may overturn, slide and impact adjacent safety-related equipment,
- equipment carts, chains, air bottles, welding equipment etc. may roll into, slide, overturn, or otherwise impact safety-related equipment,
- storage cabinets, office cabinets, files, bookcases etc. located, for instance in control rooms, may fall and impact adjacent safety-related equipment,
- too flexible piping, cable trays, conduits, and HVAC ducts may deflect and impact adjacent safety-related equipment,
- anchor movement may cause breaks in nearby piping, cable trays, conduits, HVAC ducts etc. that may fall or deflect and impact adjacent safety-related equipment,
- emergency lights and lower ceiling panels can fall down and damage safety-related equipment,
- free crane hooks may bang safety-related equipment in their vicinity.

CONCLUSION

<u>The practical approaches described above have been used and still are used by S&A-CZ and also by S&A-RU for seismic re-evaluation and re-qualification of structures, equipment components and distribution systems installed on operating NPPs in several countries (Czech and Slovak Republics, Hungary, Russia).</u>

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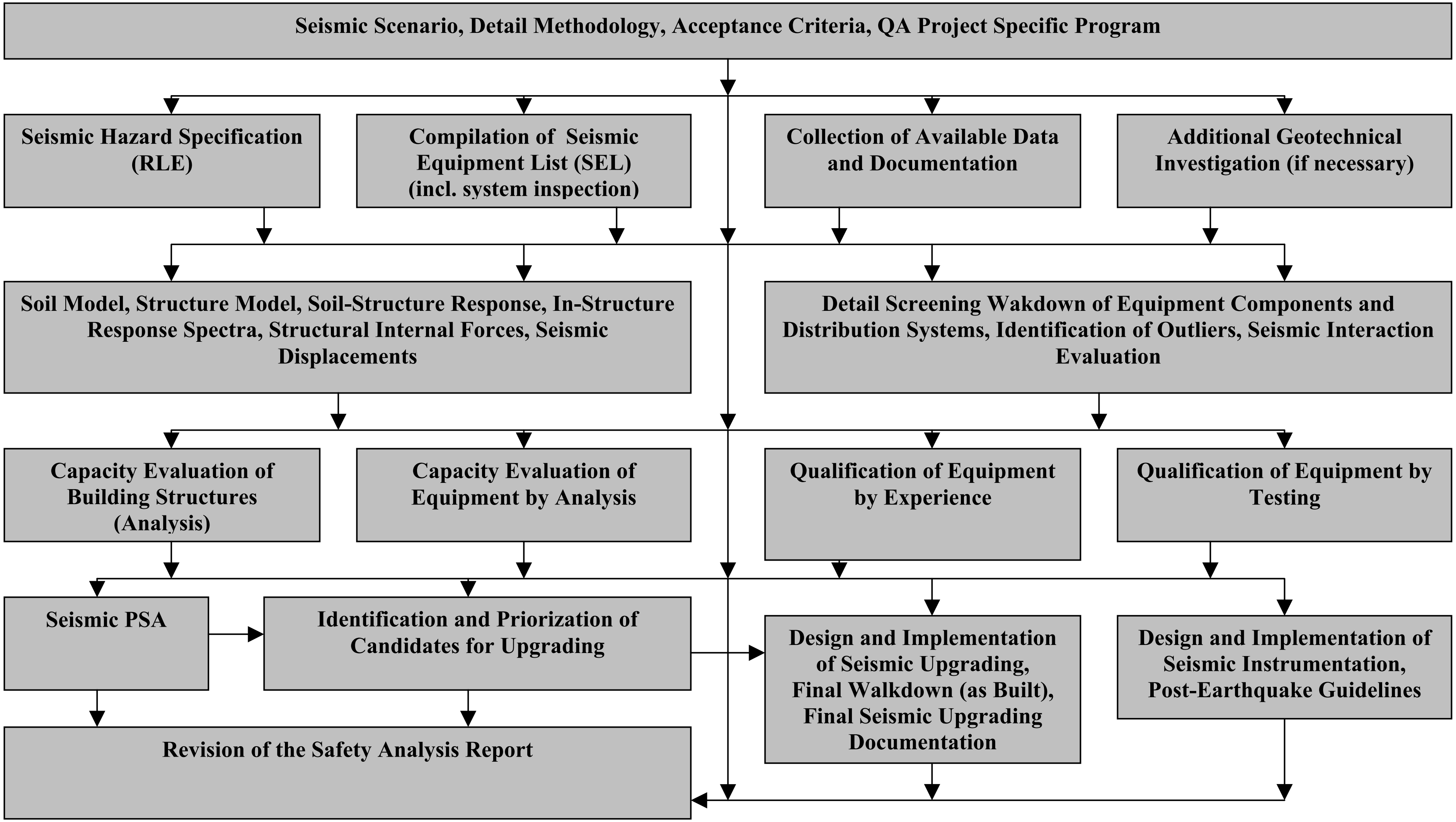

Figure 1 Typical Work Plan for the Seismic Safety Assessment of Existing NPPs