Some Results of the Low Power and Shutdown Seismic Risk Assessment for the Paks NPP

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Four VVER-440/V213 units each with 460-500 MW electrical capacity

Outline

- Introduction
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  - Seismic acceleration ranges
  - Failure modes and fragility
  - Baseline LPSD seismic PSA model
- Quantification
- Evaluation of Selected Seismic Upgrades
- Conclusions
<table>
<thead>
<tr>
<th>year</th>
<th>activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>First comprehensive level 1 PSA for internal initiators</td>
</tr>
<tr>
<td>1997</td>
<td>Unit specific level 1 PSA for internal initiators for all units</td>
</tr>
<tr>
<td>1997</td>
<td>Level 1 PSA for low power and shutdown status, internal initiators</td>
</tr>
<tr>
<td>1998-2001</td>
<td>Unit specific fire and flood level 1 PSA for all units (full power)</td>
</tr>
<tr>
<td>2007</td>
<td>Fire and flood level 1 PSA for one unit (low power and shutdown)</td>
</tr>
<tr>
<td>2002-2004</td>
<td>Level 1 PSA for spent fuel pool, internal initiators, fire and floods, all operational modes</td>
</tr>
<tr>
<td>2001-2004</td>
<td>Seismic PSA level 1 plus containment (full power)</td>
</tr>
<tr>
<td>2006</td>
<td>Seismic level 1 PSA (low power and shutdown)</td>
</tr>
</tbody>
</table>
During the design of VVER plants the seismic hazard of the sites was underestimated and safety aspects related to the external events were neglected.

The Paks site seismic hazard was also underestimated.

Units of the Paks NPP were not designed for any earthquake loads.

At the end of 1980s it was clear that seismic hazard of the site can be much greater, than it was assumed during the design.

We launched a comprehensive program for seismic assessment and upgrading of the plant years ago; the approach followed in the upgrade program was a combination of seismic margin assessment and the use of experience-based methods.

Preparation of the seismic PSA for the units was an integral and final part of the program.

The objective of the PSA study was to:

- determine the remaining risk of core damage due to seismic events
- identify the upgraded plant vulnerabilities to a strong seismic motion
- provide feedback to further seismic upgrades of the plant, if necessary

Quantitatively show the current level of plant safety with respect to the seismic hazard representative for the Paks site.
Seismicity of the Pannonian region
Seismic PSA - steps

- Assessment of seismic hazard
- Analysis of seismic response
- Assessment of failure modes and seismic fragility
- PSA model development for accident sequences from seismic events
- Quantification of core damage risk from earthquakes

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Picture is taken from GeoRisk 2000.
It was not practical to quantify the PSA models using continuous families of seismic hazard curves and associated equipment fragility distributions.

Seven acceleration ranges were selected to define seismic initiating events:

- Lower bound corresponds to the lowest seismic capacity for all structures and equipment.
- Upper bound is the highest acceleration evaluated in the seismic hazard analysis.

<table>
<thead>
<tr>
<th>Initiating Event</th>
<th>Acceleration Range (g)</th>
<th>IE Frequency (event/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEIS1</td>
<td>0.07 – 0.10</td>
<td>2.69·10⁻³</td>
</tr>
<tr>
<td>SEIS2</td>
<td>0.10 – 0.15</td>
<td>1.08·10⁻³</td>
</tr>
<tr>
<td>SEIS3</td>
<td>0.15 – 0.22</td>
<td>3.16·10⁻⁴</td>
</tr>
<tr>
<td>SEIS4</td>
<td>0.22 – 0.32</td>
<td>8.71·10⁻⁵</td>
</tr>
<tr>
<td>SEIS5</td>
<td>0.32 – 0.48</td>
<td>2.35·10⁻⁵</td>
</tr>
<tr>
<td>SEIS6</td>
<td>0.48 – 0.70</td>
<td>4.76·10⁻⁶</td>
</tr>
<tr>
<td>SEIS7</td>
<td>0.70 – 1.0</td>
<td>8.99·10⁻⁷</td>
</tr>
</tbody>
</table>
Most fragilities were developed during the full power seismic PSA

Extended for the LPSD study: a limited number of mechanical and I&C components, structures (e.g. cranes and support structures)

Fragilities determination: standard separation of variables approach, based on existing deterministic analyses conducted during seismic upgrades

It was not practical to perform fragility calculations or tests on all components modelled in PSA

Screening was applied, and generic fragilities were developed (used as surrogate elements) according to the criteria evolved in US IPEEE

- high screen level HCLPF= 0.41g pga
- low screen level HCLPF= 0.27g pga

The analysis of seismic response based on the results of finite element evaluations of structures and floor response spectra were calculated for practically all levels of interest within the buildings of safe shutdown components

Focus on consequences of liquefaction, non-ductile failure modes of steel structures and spatial systems interactions identified during plant walk-down
Selection and grouping of equipment failures that can be caused by an earthquake

Identification of transient initiating failures and additional system, system train and component level failures and degradations in each POS that can be caused by equipment failures within a seismic failure group

Development of functional event trees for single transient initiating failures

Development of a generic event tree in each POS for modelling plant responses to an earthquake with combinations of single and multiple transient initiating failures

Quantification of post-initiator human errors were revised to take an account of mental and physiological factors associated with a seismic event

Operator failure definitions and probabilities of the internal event PSA were used up to an acceleration level of 0.3 g unless operator intervention was assumed physically affected (hindered) by seismic failures

No credit was given to successful post-initiator action above this acceleration level
Model was developed using the Risk Spectrum PSA Professional computer code

For convoluting seismic hazard and seismic fragility curves a separate code was developed and used

Calculations performed by Risk Spectrum required a new type of calculation as compared to the internal event PSA: the conditional core damage probability was computed where the rare event approximation does not apply

The annual core damage probability from seismic initiating events that can occur during any of the low power and shutdown states is

$$3.82 \cdot 10^{-06}$$

Results are dominated by failures of untested (seismically non qualified) relays and cabinets (both electrical and I&C) and failure of the air compressor building
Distribution of Core Damage Risk between POSs

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Distribution of CDF between POSs

Leállás kezdete óta eltelt idő, óra

CDF (1/év)

CDF

Kumulatív CDP

POS_08
POS_09
POS_10
POS_11
POS_12
POS_13
POS_14
POS_15
POS_16-18
POS_17-21
POS_19-23
POS_22-23
POS_24
POS_01-02
POS_03-04
POS_05
POS_06
POS_07
POS_08
POS_09
POS_10
POS_11
POS_12
POS_13
POS_14
POS_15
POS_16-18
POS_17-21
POS_19-23
POS_22-23
POS_24

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<tr>
<th>Initiating Event</th>
<th>Acceleration Range (g)</th>
<th>IE Frequency (event/year)</th>
<th>Annual CDP $\Sigma 3.82 \cdot 10^{-06}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEIS1</td>
<td>0.07 – 0.10</td>
<td>2.66E-3</td>
<td>1.20E-08</td>
</tr>
<tr>
<td>SEIS2</td>
<td>0.10 – 0.15</td>
<td>1.08E-3</td>
<td>1.78E-07</td>
</tr>
<tr>
<td>SEIS3</td>
<td>0.15 – 0.22</td>
<td>3.16E-4</td>
<td>7.69E-07</td>
</tr>
<tr>
<td>SEIS4</td>
<td>0.22 – 0.32</td>
<td>8.71E-5</td>
<td>9.47E-07</td>
</tr>
<tr>
<td>SEIS5</td>
<td>0.32 – 0.48</td>
<td>2.35E-5</td>
<td>1.52E-06</td>
</tr>
<tr>
<td>SEIS6</td>
<td>0.48 – 0.70</td>
<td>4.76E-6</td>
<td>3.31E-07</td>
</tr>
<tr>
<td>SEIS7</td>
<td>0.70 – 1.00</td>
<td>8.99E-7</td>
<td>6.27E-08</td>
</tr>
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</table>
Progressive risk improvements evaluated that may be achieved from implementation of two potential seismic upgrades

**Upgrade 1:** untested relays and cabinets
- Increase the seismic capacities for untested relays, electrical and I&C cabinets that affect any equipment in the PSA models to at least the lower screening capacity.
- Correlated failures of all the untested relays and cabinets are assumed in the baseline PSA and a single element is used in the model to describe these correlated failures.
- To avoid simultaneous failure of untested relays and cabinets that would cause loss of offsite power, inadvertent closure of all steam generator isolation valves, inadvertent opening of all steam generator safety valves and failure of all feedwater systems as well as failure of emergency core cooling systems.

**Upgrade 2:** air compressor building
- Increase the structural capacity of the air compressor building.
- To avoid loss of high-pressure air that causes the steam generator isolation valves and the main steam header sectioning valves to close.
- Enable more reliable closed loop secondary side heat removal.

According to parametric studies significant risk reduction can be achieved by implementing these upgrades.
CDP for different initiating events

Annual CDP

- baseline CDF
- upgrades CDF

initiating event

SEIS1 SEIS2 SEIS3 SEIS4 SEIS5 SEIS6 SEIS7

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Conclusions

- Probabilistic safety assessment for seismic events has been carried out in the last stages of a comprehensive program on enhancing the seismic safety of the four VVER-440, type 213 reactors of the Paks NPP in Hungary.

- The seismic PSA was concerned with the quantification of core damage risk and with an evaluation of the effectiveness of the previously performed seismic upgrade.

- The initial analysis covered seismic events at full power operation and followed by a low power and shutdown seismic PSA.

- The analysis followed the traditional steps of a seismic PSA including: assessment of seismic hazard, development of seismic fragilities for safety related systems, structures and components, development of accident sequence models for seismic-induced plant transients, and computation of core damage risk.

- The results of the Paks LPSD seismic PSA show that earthquakes are an important contribution to LPSD core damage risk.

- Based on these results two upgrades have been conceptualized.

- According to parametric studies, significant risk reduction can be achieved by implementing these upgrades.