Seismic Risk Management of the Beznau Nuclear Plant

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1. INTRODUCTION

A probabilistic risk analysis (PRA) of the Beznau nuclear plant was accomplished by Pickard, Lowe and Garrick, Inc., and included an assessment of earthquake effects on plant safety. This paper describes the seismic risk analysis methodology and demonstrates its use in managing the seismic risk of the plant. Dominant seismic contributors to risk were identified. A reduction in risk level was effected after practical changes were made to the plant.

Nuclear power plant Beznau is a two-unit, 350-MWe plant. This plant is situated in Switzerland. It is owned and operated by Nordostschweizerische Kraftwerke AG.

The main elements of the seismic risk analysis were a seismic hazard evaluation, structure and component fragility analysis, plant logic analysis, and the risk quantification and plant improvements process. Each element is further discussed.

2. SEISMIC HAZARD ANALYSIS

The seismic hazard analysis performed by Basler & Hofmann, Zurich, had, as its goal, the prediction of the frequency of various peak ground accelerations at the site, considering historical information. Important parameters that were evaluated consisted of defining large zones of past earthquakes that could influence the seismicity at the Beznau site, predicting the magnitudes of future earthquakes and their frequency, and estimating the likely attenuation effects as a function of source distance and media characteristics between the sources and the Beznau site. Considering alternative interpretations of historical information, geology, and assumptions of the correct empirical relationships, 36 total possible combinations of source locations, maximum magnitudes, frequency-magnitude relationships, and attenuation relationships were evaluated, each combination having a different degree of certainty or confidence. The product of the seismic hazard analysis was a set of seismic hazard curves represented by a median and plus or minus 1 standard deviation, as seen in Figure 1.

It can be seen from the curves in Figure 1 that, at very low peak ground accelerations, say 0.05g, there is about one order of magnitude range of uncertainty in the annual frequency. (The safe shutdown earthquake used in the initial design was 0.12g.) At peak ground accelerations of about 0.4g, there are perhaps five orders of magnitude range in the predicted annual frequency of these accelerations.

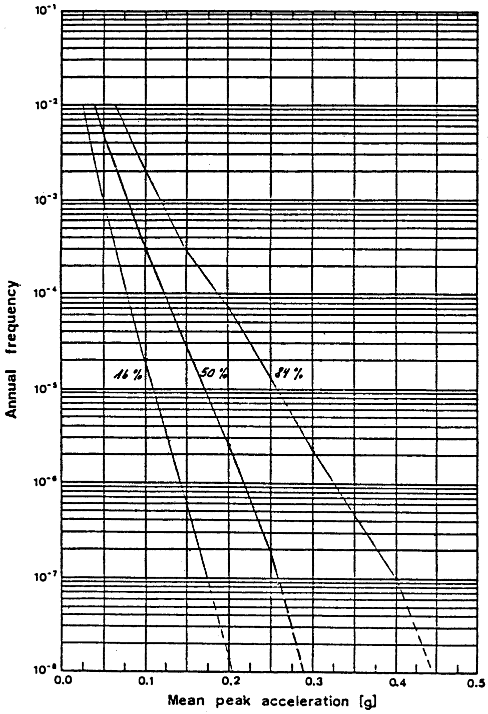

Figure 1. Final Seismic Hazard Functions for Nonexceedance Probability Levels of 16%, 50%, and 84%

3. FRAGILITY ANALYSIS

A seismic fragility analysis was performed by Structural Mechanics Associates, Newport Beach, California, for plant structures and components whose failure could affect the initiation or termination of accident scenarios. This analysis was performed to predict the probability that plant buildings and equipment of interest would fail at various levels of peak ground acceleration. The objective was to assess the failure margin of safety over the design basis. Parameters considered in this analysis fell into two groups: capacity and structural response. Factors affecting capacity were the actual strength of materials and inelastic energy absorption, or ductility. Factors affecting the evaluation of the response were the assumed site-specific peak ground response spectra and damping, the method of combining earthquake components, consideration of the soil-structure interaction, and the method of analysis and the modeling accuracy used in the design.

The ratio of best estimate values for each factor over values used in the design in accordance with regulatory guidelines was a ratio that, when multiplied by the safe shutdown earthquake acceleration used in design, provided an estimate of the peak ground acceleration at which component failure is predicated. Variability in that margin for each parameter was assumed to be logarithmic because data reasonably fit this type of distributions except in the tails of distributions. As a result, the acceleration capacity, a, can be expressed in terms of

$$a = \overset{\approx}{a} \exp(f' \beta_U)(f \beta_R) \qquad (1)$$

where

$\overset{\approx}{a}$ = median acceleration capacity.

f' = standard Gaussian distribution representing the variability of the acceleration capacity that, if additional information were available, the variability might be reduced.

β_U = a factor applied to f' to adjust the variability distribution, based on the level of available specific knowledge about the building or component.

f = the standard Gaussian distribution representing the random variability of the acceleration capacity due to earthquakes yielding the same acceleration at the site differing in energy content and duration, thus resulting in different effects on plant component capacities. For given accelerations, this is a variability that additional information would not affect.

β_R = a factor applied to f to adjust the distribution on the randomness for the evaluated parameters.

The fraction of earthquakes, $F_{(a)}$, resulting in acceleration a at the site is given by

$$F_{(a)} = \Phi\left(\frac{1}{\beta_C} \ln \frac{a}{\overset{\approx}{a}} \right) \tag{2}$$

where Φ is the standard Gaussian cumulative distribution and

$$\beta_C = \sqrt{\beta_R^2 + \beta_U^2} \tag{3}$$

A list of 21 of the initially most fragile components in the Beznau plant and their median acceleration capacity and variabilities is given in Table 1. Components with acceleration capacities greater than 1.0g are not listed because, as seen in Figure 1, even with uncertainty, at this acceleration there is essentially no chance of a component failing at a sufficiently high frequency to be of interest. The median acceleration capacity is also shown in the table for NANO, a major backfit to the plant currently in construction. This backfit is designed to increase the plant's safe shutdown capability after an external accident.

Table 1 (Page 1 of 2). Beznau Key Structures/Components for Seismic Analysis

Symbol	Structure/Equipment	Median Acceleration Capacity $\overset{\approx}{a}$(g)	Randomness Parameter β_R	Uncertainty Parameter β_u
①	Offsite Power	0.30	0.25	0.50
②	Motor Control Center for Component Cooling Water Raw Water Booster	0.32	0.44	0.43
③	Reactor Protection System	0.37	0.44	0.55
④	208/120V AC Instrumentation Bus	0.39	0.44	0.51
⑤	Control Building E Masonry Wall	0.39	0.48	0.49
⑥	Engineering Safeguards System Cabinets	0.41	0.44	0.63
⑦	Cable Trays	0.42	0.34	0.61
⑧	Condensate Storage Tank	0.43	0.54	0.65
⑨	Building D Shear Wall	0.44	0.31	0.41
⑩	Control Building E Shear Wall	0.45	0.33	0.41
⑪	125V DC Distribution Panel	0.46	0.45	0.57
⑫	380/200V Vital Bus	0.46	0.45	0.57
⑬	380V Motor Control Centers	0.46	0.45	0.57
⑭	Residual Heat Removal Heat Exchanger	0.50	0.34	0.58

Table 1 (Page 2 of 2). Beznau Key Structures/Components for Seismic Analysis

Symbol	Structure/Equipment	Median Acceleration Capacity $\tilde{\tilde{a}}$(g)	Randomness Parameter β_R	Uncertainty Parameter β_u
⑮	Primary Makeup Water Tank	0.50	0.60	0.60
⑯	Hydro Plant	0.50	0.44	0.52
⑰	Building a Shear Wall	0.59	0.36	0.40
⑱	6-kV/380V Transformers	0.60	0.30	0.45
⑲	8-kV Transformer	0.60	0.30	0.45
⑳	6-kV Switchgear	0.60	0.30	0.45
㉑	Diesel Generator Fan Control Cabinet	0.78	0.53	0.69
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4. PLANT LOGIC ANALYSIS

The plant logic analysis determines the consequence of various building and plant component failures. The approach used in the Beznau risk assessment relied on the logic expressed by event trees developed in the internal initiating events analysis. In these trees, the event tree top events are systems or recovery actions, each of which may have had to be modeled separately to reflect success or failure of its components. The likelihood of success or failure in moving along the various pathways through the top events defines a multitude of potential accident scenarios that, when quantified, give the frequency of each scenario. Summing those scenarios resulting in similar plant conditions gives the frequency of various plant damage states. Different plant damage states are a function of whether water has been injected into the vessel; if yes, whether the water was injected before or after the vessel meltdown, whether the containment cooling is available, and whether the containment is isolated. The sum of the plant damage state frequencies is the frequency of all core damage.

The first step in the logic analysis was to identify the components whose seismic failure could initiate an accident scenario. Given an earthquake, possible failure of such components determines the initiating event and thereby identifies the event tree, or trees, to be used in the seismic analysis. Many of the failures listed in Table 1 would cause a turbine or reactor trip, representing a transient-type initiating event. In this project, the general transient event tree sufficed for representing all of the initiating events and possible scenarios, provided that the possible seismic failures were added. Buildings, cable trays, and other passive plant components whose potential failure was not included in the internal initiating events models, but that might fail seismically, were added to the event trees.

Once the required event tree was identified, an impact table was developed to relate each component that could fail seismically to the failure of one, or more, top events in the event tree. In some cases, the seismic failure of more than one component could fail the same top event. Also, the component might fail from nonseismic causes. The top events were modeled to include the combinations of seismic and nonseismic equipment failures that would fail each top event.

5. QUANTIFICATION AND PLANT IMPROVEMENTS PROCESS

The initiating events in the event trees were discrete accelerations over the range of accelerations of interest, each acceleration having an annual frequency determined from the mean hazard curve. The lower bound discrete acceleration for this analysis was established by determining the lowest acceleration at which any component might fail. This was reasonably assumed to be the high confidence, low probability of failure (HCLPF) acceleration [acceleration at the 5th percentile of uncertainty (β_U) and the 5th percentile of random (β_R)

variability] of component fragilities. In the Beznau project, the discrete acceleration values were 0.05g (based on HCLPFs), 0.07g, 0.09g, and 0.125g to give greater definition in the higher frequency range, and 0.175g, 0.225g, and 0.325g.

The event tree quantification process began by using an event tree code, ETC, and MAXIMA, a code for linking the support and frontline trees and identifying dominant scenarios. A point estimate calculation was made of the frequency of each plant damage state. The event trees were executed for each discrete acceleration frequency that represented the initiating event frequency. The frequency of like seismically initiated plant damage states (PDS) was added from all such event tree executions. After elimination of insignificant PDSs and scenarios (those with very low frequency), consideration was given to potential plant improvements in order to reduce seismic risk.

It was found that, referring to Table 1, the failure of ④, the 208/120V AC instrumentation bus, causes a plant trip and was assumed to also lead to a loss of operator control and core damage. Also, failure of component ⑬, the 380V motor control centers, results in a plant trip and a loss of equipment control, leading to core damage. Loss of the reactor protection and safeguards actuation cabinets would be caused by the failure of ⑤, the control building masonry wall. Also, the wall's failure or failure of ⑪, the 125V distribution panel, results in a plant trip and a loss of DC power and control, also leading to core damage. Failure of component ⑦, cable trays, would lead to a plant trip and a loss of both AC and DC power, resulting in core damage.

Using the information generated in the study, risk management actions such as externally reinforcing the unreinforced masonry wall, bracing of the pertinent cable trays, improving the anchorage of the selected electrical cabinets, etc., were taken.

These actions resulted in a reduction of seismically initiated core damage frequency from $3X10^{-4}$ to $4X10^{-5}$ per year; hence, a reduction of factor of 10. This improvement was carried out at a modest cost when compared with the risk reduction. This was done to cover the period until NANO, the safe shutdown facility now under construction, is completed.

The analysis was expanded to assess the seismic risk, including the NANO installation. The result of the requantification with NANO that was included with the plant improvements showed seismically initiated core damage mean frequency to be further reduced to about $1X10^{-6}$ per year.

This paper presented the seismic risk analysis used in the Beznau PRA and its application to a risk management function. The approach enabled the disassembly of the analysis to take place easily, providing for the identification of major contributors and for the evaluation of the potential reduction in damage frequencies if these contributors were to be strengthened.