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SEISMIC STRESS TEST OF KOEBERG NPP

Darryn McCormick[1], Alexey Berkovsky[2], Tomás Trejbal[3], Thaabit Rylands[4]

[1]Engineer, Nuclear Structural Engineering, Cape Town, South Africa (darryn@nucse.com)
[2]Principal, CKTI-Vibroseism, Saint Petersburg, Russia
[3]Chief Engineer, Rizzo Associates Czech a. s., Plzeň, Czech Republic
[4]Director, Nuclear Structural Engineering, Cape Town, South Africa

ABSTRACT

This paper presents the methodology, technology, and special considerations that were applied in the seismic stress test of Koeberg Nuclear Power Plant in South Africa. This seismic stress test was undertaken in response to the events at Fukushima Daiichi on 11 March 2011 and was set with a review level earthquake of 0.5g zero period ground acceleration. Special considerations that had to be taken into account during the assessment included that the nuclear island of Koeberg is seismically isolated.

INTRODUCTION

This paper discusses the seismic stress test assessment undertaken for Koeberg Nuclear Power Plant (KNPP) in South Africa. KNPP is the only nuclear power station on the African continent and consists of two pressurized water reactors (PWR) of French design (2x900 MW). The plant was designed and constructed in the 1970's and 1980's with the first unit being synchronized to the grid on 4 April 1984. The design basis earthquake for KNPP consisted of spectra with a 0.3g zero period ground acceleration (ZPGA). The stress test was undertaken with an international team, with members from South Africa, Russia, Czech Republic, United States of America and the United Kingdom.

PURPOSE

Following the events at Fukushima Daiichi Nuclear Power Plant on 11 March 2011 the International Atomic Energy Agency and South African government agreed to undertake a stress test of KNPP to identify areas of improvement for the plant. A component of this work was the seismic reassessment of various critical structures, systems and components (SSC) against a review level earthquake (RLE) beyond the original design basis. This RLE was defined at 0.5g ZPGA.

This paper presents the various technologies and methodologies applied in the seismic assessment of the SSC used to highlight any seismic deficiencies of the plant.

METHODOLOGY AND TECHNOLOGY

The seismic aspect of the stress test of KNPP used the seismic margin assessment approach in the evaluation of the list of SSC. Some elements of the seismic fragility approach were utilized, particularly in the evaluation of structures. The reference documents used as the basis for the assessment of the list of SSC consisted of EPRI NP-6041-SL (1991) and the Department of Energy DoE/EH-0545 (1997), with provisions of the SQUG Generic Implementation Procedure (GIP) (1990) also applied. Different technologies were applied in different areas to achieve results.

Overview

An overview of the implemented methodology is shown in Figure 1. This process is a summary of that indicated in the various reference documents for the seismic margin approach.

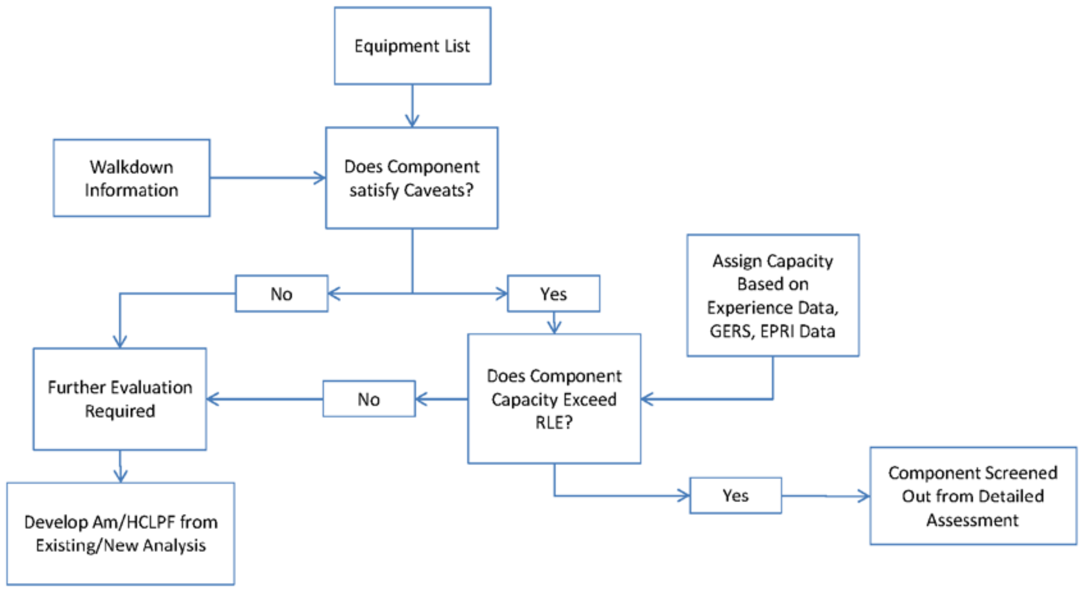

Figure 1: Approach used in Seismic Margin Assessment Methodology for Individual Components

SEISMIC EVALUATION WALKDOWNS

A significant aspect in the assessment of electrical and mechanical components was the use of seismic evaluation walkdowns and screening. These were used to aggressively screen out components that are seismically rugged and to identify areas that required further analysis and assessment. A typical representation of the approach used in the assessment of whether a component was screened out or not is shown in Figure 2. This approach is typical of those suggested in the codes of practice. Screening in this context is based on identifying whether a component had any concerns, and whether an in-depth assessment of the component was necessary. Due to the high RLE, where information was available, all components had some level of further evaluation applied.

A unique aspect in the applied approach was that, while components were still grouped together, as far as possible all components were inspected and reviewed in depth. This was made possible with two unique methods used in the assessment. The first was that technicians were given the list of SSC's prior to the walkdowns and were tasked with locating all of these components beforehand. These technicians formed part of the seismic walkdown team, using their knowledge of the plant and unique knowledge of the components on the list to guide the rest of the team. This significantly reduced the level of effort required during the walkdowns to locate and identify components. This has the additional benefit of reducing the amount of time spent in areas with high levels of radiation.

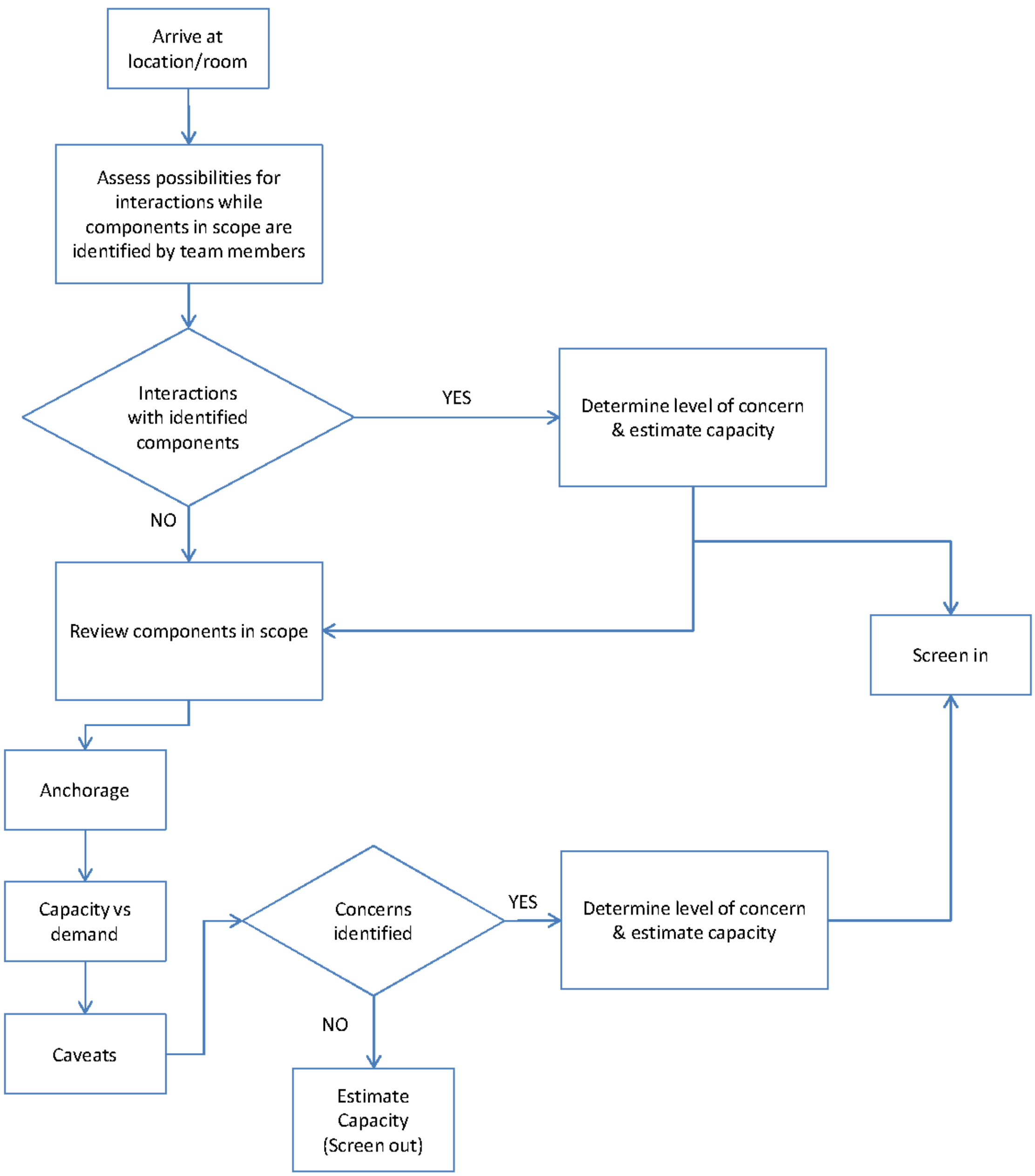

Figure 2: Walkdown Screening Methodology

The second unique tool was in the processing of the collected information from the walkdowns. The walkdown teams were familiarized with the caveats defined in the reference documents and during the walkdowns specifically focused on identifying outliers or areas of concern. Only with these components were detailed remarks made, concerns clearly identified and documented. Components that could be screened out were assigned a high confidence low probability of failure (HCLPF) value where possible and signed off. After the walkdowns the processing of the components with concerns was carried out. A Microsoft Access database had been prepared with unique tools that facilitated the filling out of the GIP questionnaires, linking of photographs to specific components and assigning of HCLPF's.

Components and groups of components were assigned various statuses depending on what the seismic walkdown team identified on the plant. These statuses along with the number of groups components assigned this status are shown in Table 1.

Table 1: Summary of Walkdown Results

Walkdown Status	Description	Number of Groups of Components
OK	Components are ok with no concerns identified	1637
Analysis and Testing	Components that cannot be assessed by walkdown or the walkdown teams estimate capacity below the RLE	91
Easy Fixes	Components that can be repaired quickly and easily without significant effort or redesign	149
Not Easy Fixes	Components that require a more in depth repair or redesign to improve capacity	6
Not Accessible	Components that were not accessible during the walkdowns (due to radiation levels or similar)	86
Total Number of Groups		1969

ANALYTICAL REVIEW

Using the results from the walkdowns and the SSEL an analytical review was undertaken on various SSC.

The first group of components that was reviewed was those identified during the walkdowns that required further Analysis and Testing. These were either components where the HCLPF capacity from the walkdowns was below that of the RLE, or components that cannot be assessed by walkdowns (tanks as an example).

Noting the high RLE, significant effort was put into the analytical review and a large scope of equipment was assessed. Where available, existing documentation was identified and used in the assessment of the equipment. Fortunately there are significant quantities of information available from the design of the plant, allowing for the determination of HCLPF capacity from this. Various approaches were used in the determination of HCLPF values, based on the principles of EPRI NP-6041-SL (1991), depending on the information that was available.

Tanks

Various tanks were identified as part of the SSEL, as possible sources of cooling water for the plant in the case of an event. Finite Element Models of tanks were developed in the analysis package Strand7 and analyzed against floor response spectra developed from the RLE. The principles of loading combinations and soil structure interaction presented in ASCE 4-98 (2000) were used. These models included fluid in the tank and accounted for sloshing effects.

Other Large Components

Typically, manufacturer test and qualification reports or KNPP design specifications and reports were used to determine the HCLPF's for large components. Where possible, conservatisms in the calculations were removed following the principles presented in EPRI NP-6041-SL (1991). Components that fell within the caveats of the Generic Implementation Procedure and the Generic Equipment Ruggedness Spectra (GERS) were assessed using the GERS.

Structures

Critical structural elements on the nuclear island of KNPP were assessed using recommendations presented in EPRI NP-6041-SL (1991). Conservative deterministic failure margin (CDFM) values of the critical structural elements or groups of elements were determined in orthogonal directions for different levels of the structures. Flexural and shear capacities of the various elements were determined according to ACI 349-01 (2001). This was carried out for slabs and for shear walls.

A complimentary fragility analysis of the structures on the nuclear island was also undertaken, yielding similar results to the CDFM method. Safety related structures off the nuclear island were assessed using the fragility principles presented in EPRI TR-103959 (1994) and EPRI 1002988 (2002).

SPECIAL CONSIDERATIONS

Two aspects of the seismic margin assessment required particular and in-depth consideration. The first of these was the base isolation of KNPP. This consists of neoprene rubber springs with a friction couple between the springs and soffit of the nuclear island raft. This allows both shaking and sliding of the structure.

The combined shaking and sliding of the nuclear island introduces a non-linear relationship in the accelerations of the structures, particularly in the horizontal direction. As such, the vertical design floor response spectra could be linearly scaled to the new RLE, but the horizontal spectra could not.

To accommodate the non-linearity of the horizontal accelerations and to further understand the influence of the base isolation, the original stick model used in the design of the plant was redeveloped and a sensitivity analysis undertaken with ground motions of various ZPGA's. This exercise in itself yielded further complications relating to modelling and analysis approaches, assumptions and finite element method codes. The various parameters in the modelling were calibrated to the design basis stick model to yield similar floor response spectra to the design spectra. Differences in the analysis codes and methodologies between the original design and the sensitivity study resulted in some small inconsistencies with the spectra.

The results of the sensitivity study confirm that vertical floor response spectra can be linearly scaled and indicated that the linear scaling of horizontal spectra would be conservative, particularly for higher frequencies.

A final consideration of the base isolation is differential movement between the nuclear island and the surrounding ground and adjacent structures. On this concern, during the seismic walkdowns, services that cross over the gap between the island and the rest of the plant were confirmed to be appropriately designed (with sufficient slack in cabling or similar) to accommodate the differential movement. Impact between the nuclear island and the surrounding ground was also considered in the stick model.

As has already been mentioned, due to the high RLE it was necessary to extend the review of SSC to confirm seismic capacities of many components that were deemed OK from the walkdowns. The scaled vertical spectra from the 0.3g design basis earthquake to the 0.5g RLE was beyond the reference spectrum at several frequencies, supporting the need for more in-depth assessment of the various classes of components. This provided further validation to the walkdown results.

This approach required significant effort in locating and interpreting design documentation, along with processing the information to determine HCLPF's.

CONCLUSIONS

The seismic stress test of Koeberg Nuclear Power Plant required the combined efforts of several experts from around the world. A combination of the various methodologies available for the seismic reassessment of nuclear facilities was applied to accommodate the particular requirements of KNPP.

Overall KNPP was found to be seismically robust and well designed, with some areas for attention and improvement that were highlighted.

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