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Content

1. Introduction

It is generally recognized that well designed industrial facilities, especially nuclear power plants, have an inherent capability to resist earthquakes. This is supported by the experience of seismic events at other nuclear power plants, where there have been no failures experienced of safeguard systems, even in events that have exceeded the original seismic design base. However due to developments in seismic hazard analysis and techniques, reassessment of original studies and seismic analyses of plants have been undertaken worldwide. For Koeberg NPS, the Safety Re-assessment II identified the need for re-assessment and this was again emphasised by the Fukushima Daiichi disaster.

This document outlines the strategy Eskom will adopt to demonstrate that from a seismic hazard perspective the existing plant is safe, and that future enhancements are implemented appropriately. The intent is to initially perform an interim review and justification aligned to US/EPRI methodology. This will be followed by a PSHA, performed in accordance with the enhanced SSHAC level 2 guidelines, and then a seismic PSA to evaluate the overall seismic impact on the plant.

2. Supporting Clauses

2.1 Scope

2.1.1 Purpose

The purpose of this strategy document is to outline the Koeberg approach to the update of the seismic hazard for Koeberg. It takes into account recent developments in seismic hazard analysis as well as the response to the Fukushima event.

The four objectives of the strategy are to:

1. Provide an interim justification of the robustness of the Koeberg plant and identify any significant enhancements required;
2. To characterise the seismic ground motion response, and return periods, using the latest Probabilistic Seismic Hazard Assessment (PSHA) methodology, and develop the associated in-structure floor motion response spectra;
3. To quantify the revised seismic risk by performing a seismic PSA; and
4. To provide design guidance regarding new plant change, where these plant change need to withstand or mitigate design extension condition seismic events.

As the SSHAC studies may take a couple of years to develop, a phased approach will be employed.

2.1.2 Applicability

This document applies to Koeberg Nuclear Power Station and associated facilities located on the Duynefontein site.

2.1.3 Effective date

This document is effective from the authorisation date.

2.2 Normative/Informative References

2.2.1 Normative

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[5] EPRI Technical Report 3002004396, High Frequency Program: Application Guidance for Functional Confirmation and Fragility Evaluation, July 2015.

[6] EPRI Technical Report 3002000706, High Frequency Program: Phase 1 Seismic Test Summary, Sep 2013.

[7] EPRI Technical Report, High Frequency Program: High Frequency Testing Summary, Sep 2014.

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[9] EPRI Report 1014833, “Applicability of the Generic Equipment Ruggedness Spectra (GERS) for Internationally Manufactured Equipment, March 2007.

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[12] ESKOM Report no. 240-121010217, Design Extension Related Guidance for Modifications and Equipment – Seismic, Oct 2018.

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2.2.2 Informative

[21] US-NRC, GI-199, "Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States on Existing Plants", Sept, 2010.

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[30] Paul C. Rizzo Associates, Report No 07-3835-01, "Definition of Design Ground Motion for the PBMR Demonstration Power Plant", Rev 0, 2008.

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[37] US-NRC, NUREG/CR 6372, “Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts”, 2016.

[38] US-NRC, NUREG-2117, “Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies”, Rev.1, 2012

[39] US-NRC, NUREG-2213, “Updated Implementation Guidelines for SSHAC Hazard Studies”, 2018.

[40] EPRI Report 1014833, “Applicability of the Generic Equipment Ruggedness Spectra (GERS) for Internationally Manufactured Equipment”, Final Report, March 2007.

[41] IAEA, SRS No. 103. “Methodologies for Seismic Safety Evaluation of Existing Nuclear Installations”, 2020.

[42] DSG-318-033, “Specification for the Seismic Qualification of Electrical and Mechanical Equipment”, Rev 2, 2016.

2.3 Definitions

Definition	**Explanation**
Design Basis Earthquake *or* Safe Shutdown Earthquake (SSE)	A design basis earthquake is a commonly employed term for the SSE: that earthquake for which safety related structures, systems and components are designed to remain functional. SSEs are commonly characterized by a standardized spectral shape anchored to a “peak ground acceleration” value.
Expedited Seismic Evaluation Process	An approach developed by EPRI, working with experts from within the nuclear industry, with the intent of identifying reasonable measures that can be employed to accomplish an effective seismic evaluation in an expedient manner. More specifically, the approach was designed to constitute a specific path to focus the initial industry efforts on short term evaluations that would lead to prompt modifications to some of the most important components that could improve plant seismic safety.
Ground Acceleration	Acceleration at the ground surface produced by seismic waves, typically expressed in unit of g (i.e. gravitational acceleration)
Ground Motion Response Spectra	A representation of the anticipated site-specific seismic vibrational ground motion response. Site-specific ground motion response spectra are typically characterized by horizontal and vertical response spectra, determined as free-field motions on the ground surface or as free-field outcrop motions on the uppermost in-situ competent material using performance based procedures.
Floor Motion Response Spectra	A representation of the anticipated site-specific seismic vibrational floor motion response, or in-structure response. They are typically characterized by both horizontal and vertical response spectra, anchored at specific floors of a facility on a site.
High Confidence of Low Probability of Failure	A measure of seismic margin. In seismic risk assessment, this is defined as the earthquake motion level at which there is a high confidence (95%) of a low probability (at most 5%) of failure.

Definition	Explanation
Individual Plant Examination of External Events	An external events assessment requested by the US-NRC for all US based Nuclear Power Plants. The five external events assessed include: 1. Seismic Events 2. Internal Fires 3. High Winds and Tornadoes 4. External Floods 5. Transportation and Nearby Facility Accidents
NTTF Recommendation 2.1	US-NRC Near-term Task Force (NTTF) requested Seismic and Flood Hazard Re-evaluations, in response to the Fukushima accident.
NTTF Recommendation 2.3	US-NRC Near-term Task Force (NTTF) requested Seismic and Flood Walk-downs, in response to the Fukushima accident.
Practically Eliminated	The possibility of certain conditions occurring is considered to have been practically eliminated if it is physically impossible for the conditions to occur or if the conditions can be considered with a high degree of confidence to be extremely unlikely to arise
Probabilistic Seismic Hazard Analysis	A probabilistic method to derive the natural seismically induced ground motion behaviour of a site or location, considering seismic source, ground motion and local site response characteristics. It estimates ground motions with a specified probability of exceedance, with detailed consideration of uncertainties.
Response Spectrum	A plot of the maximum response (acceleration, velocity, or displacement) of a family of idealized single-degree-of-freedom damped oscillators as a function of natural frequencies of the oscillators for a given damping value. The response spectrum is calculated for a specified vibratory motion input at the oscillators' supports.
Review Level Earthquake	It is the intensity of the Earthquake at the site (quantified in PGA), that is reviewed against in a Seismic Margin Assessment.
Safety Goal	Basic and limiting safety goal required to ensure safety, provided by the NNR in PP-0014
Seismic Capacity	Seismic Capacity relates to how a structure or equipment will behave under earthquake loading. It provides an estimate of how large the maximum inelastic load the structure can withstand before failure occurs.
Seismic Demand	Seismic Demand relates to the seismic characteristics of a location in the plant, usually consider at the mounting point of a particular piece of equipment. This takes into consideration the seismic characteristics of a location, the plant foundations and the plants structural response. Each region of the world has their special characteristic regarding the ground acceleration that amplifies with different value of amplification that depends on the soil condition at that particular region. (e.g. soft, medium, or hard soil type). In most of the current seismic design codes, seismic demand is given as a form of Response Spectrum where the design acceleration over the spectrum of vibrational frequencies is provided. This typically represented by a GMRS or a FMRS.

Definition	Explanation
Seismic Hazard	Any physical phenomenon, such as ground motion or ground failure, that is associated with an earthquake and may produce adverse effects on human activities (such as posing a risk to a nuclear facility).
Seismic Hazard Analysis	Seismic Hazard Analysis defines the natural seismically induced ground motion behaviour of a site or location, considering seismic source, ground motion and local site response characteristics
Seismic Margin	A measure of the seismic capacity of a structure or equipment. The difference between a SSC's HCLPF capacity and its seismic design basis (i.e. safe shutdown earthquake, SSE).
Seismic Margin Assessment	An assessment to determine the overall ability of a nuclear power plant to properly shut-down for a selected beyond design basis earthquake, through the assessment the HCLPF capacities of the structures, systems, and components required to shut-down the plant.
Seismic Risk	The risk (frequency of occurrence multiplied by its consequence) of severe accidents at a nuclear power plant that are initiated by earthquakes. A severe accident is an accident that causes core damage and, possibly, a subsequent release of radioactive materials to the environment. Several risk metrics may be used to express seismic risk, such as seismic core-damage frequency and seismic large early release frequency.
SSHAC Study	A study to characterise the Seismic Ground Motion Hazard for a site, performed in accordance with the methodology developed by the Senior Seismic Hazard Analysis Committee.
Seismic PSA	A probabilistic methodology to quantify the risk that a facility poses due to potential seismic hazards. Simplistically, it quantifies the risk based on the frequency of a seismic event and the facilities ruggedness to handle such an event.
Target Safety Goal	A surrogate safety goal (more stringent than the safety goal) required for additional margin of safety or conservatism above the safety goal, provided by the NNR in PP-0014

2.4 Abbreviations

Abbreviation	Explanation
ANS	American Nuclear Society
ASME	The American Society of Mechanical Engineers
CDFM	Conservative Deterministic Failure Method
CEUS	Central Eastern United States
DB	Design Base
DEC	Design Extension Conditions
DSSR	Duynefontein Site Safety Report
EE-SRA	External Events Safety Reassessment
ESEL	Expedited Seismic Equipment List
ESEP	Expedited Seismic Evaluation Process
ELAP	Extended Loss of all AC Power
EPRI	Electric Power Research Institute
GERS	Generic Equipment Ruggedness Spectra
GMRS	Ground Motion Response Spectra
FMRS	Floor Motion Response Spectra
HCLPF	High Confidence of Low Probability of Failure
IPEEE	Individual Pant Examination of External Events
ISRS	In-structure Response Spectra
ISG	US-NRC Interim Safety Guide
LTO	Long Term Operation
LUHS	Loss of Ultimate Heat Sink
NNR	National Nuclear Regulator
NTTF	Near-term Task Force (post Fukushima)
PBMR	Pebble Bed Modular Reactor
PGA	Peak Ground Acceleration
PHGA	Peak Horizontal Ground Acceleration
PSA	Probabilistic Safety Analysis
PSR	Periodic Safety Review
PSHA	Probabilistic Seismic Hazard Analysis
RLE	Review Level Earthquake
SAR	Safety Analysis Report
SBO	Station Blackout

Abbreviation	Explanation
SLOCA	Small Break Loss of Coolant Accident
SMA	Seismic Margin Assessment
SSC	Systems, Structures and Components
SSE	Safe Shutdown Earthquake
SSHAC	Senior Seismic Hazard Analysis Committee
SPSA	Seismic Probabilistic Safety Assessment
UHRS	Uniform Hazard Response Spectrum
US-NRC	United States National Regulatory Commission

2.5 Roles and Responsibilities

Nuclear Engineering is responsible for the overall seismic strategy.

Nuclear Siting Studies (NSS) is responsible for the development of the sites GMRS and hazard curves, using the SSHAC methodology, and updating the SSR.

Deterministic and Probabilistic Safety Analysis (DPSA) is responsible for developing the Seismic PSA.

Design Engineering is responsible for the compliance to the updated requirements, and confirming that all SR equipment comply with the updated floor motion response spectra (FMRS).

Design Engineering is responsible for updating the SAR.

2.6 Process for Monitoring

N/A

2.7 Related/Supporting Documents

Seismic studies and evaluations and their supporting documents, previously performed for the Koeberg site, applicable regulatory requirements, and seismic related EPRI reports and guidance.

3. Seismic Re-evaluation Strategy

The seismic re-evaluation strategy is to perform two seismic evaluations to provide confidence that the plant is safe from a seismic point of view, while the SSHAC study is being performed, and once the SSHAC study is completed. It also provides direction regarding specifying the seismic criteria for those modifications that are specifically required to mitigate a seismic DEC event.

The strategy is to adopt, as far as possible, an internationally accepted methodology that has been previously implemented successfully. Based on a review of international literature, including IAEA SRS No. 103, it was decided to adopt a seismic evaluation approach based on the EPRI developed Seismic Evaluation guidance [3].

The strategy, where possible, will take credit for previous seismic hazard studies completed for the site, or region. The strategy takes into consideration that an enhanced SSHAC level 2 seismic hazard study for the Duynefontein site is still in progress, and will take credit for its results as, and when, they become available.

3.1 Background

Koeberg was originally designed to 0.3g horizontal PGA using the Newmark-Hall Seismic Response Spectrum. This was based on Dames and Moore studies conducted in the late 1970s and early 1980s. The studies were specific to the Duynefontein site, used a Newmark-Hall spectrum that is based on Western US data. However, due to recent international developments in this field the Newmark-Hall spectrum are no longer considered representative of most hard-rock sites, and hence not completely representative of the Duynefontein site condition.

Subsequent to the original Dames and Moore seismic studies, the Council of Geosciences (CGS) performed a seismic hazard study in 2006, but the methodology was not deemed acceptable by the NNR. While this study was applicable to the Duynefontein site, and used latest available geo-technical data, the seismic hazard methodology was not aligned to state-of-the-art international practices. The current state-of-the-art had moved to a PSHA approach, using the SSHAC process as documented in NUREG/CR 6372, with recommended implementation guidance, as documented in NUREG-2117 and NUREG-2213.

A modern PSHA was conducted for the Duynefontein site as part of the PBMR demonstration project, in 2008, now often referred to as the Rizzo study. This PSHA study did consider the latest geo-technical data but did not follow SSHAC guidance, and, was not originally intended to serve any purpose other than to support the initial design demonstration of the PBMR. Criticism of the study is that it does not adequately treat epistemic uncertainties.

A SSHAC level 3 PHSA study has been performed for the potential new nuclear site at Thyspunt, in the Eastern Cape, near Port Elizabeth, and has been reviewed by the NNR.

As part of the external events Safety Re-assessment (EE-SRA) a seismic evaluation (i.e. stress test) was performed in 2011 on the Koeberg plant, for seismic events beyond the original seismic design of the plant, in order to identify potential seismic issues and cliff edge effects. The seismic stress test adopted a methodology based on a Seismic Margin Assessment (SMA), and reviewed numerous critical safety systems for their seismic capability (robustness) against a review level earthquake (RLE) of 0.5g. It was a reduced scope SMA to verify plant safety functions and to identify plant seismic vulnerabilities. The assessment was based on scaled Newmark-Hall Spectra on the then existing, mitigation system of an Extended Loss of all AC Power (ELAP) and Loss of Ultimate Heat-Sink (LUHS). Both Design Bases (DB) and Design Extension Conditions (DEC) seismic vulnerabilities and equipment with low seismic margins were identified. The seismic design of the plant was demonstrated to be generally seismically robust against a design base seismic event, and most SSCs, which were part of the original seismic design, having significant seismic margin.

3.2 NNR Regulations and Guides

There are three Regulatory Documents that are currently applicable to seismic evaluations:

- NNR RD-0024, "*Requirements of Risk Assessments and Compliance with Principle Safety Criteria for Nuclear Installations*" [16]
- NNR RG-0019, "*Interim Guidance on Safety Assessments of Nuclear Facilities*" [15], and
- NNR PP-0014, *External Events for Nuclear Installations*" [17].

NNR requirements document RD-0024 "*Requirements of Risk Assessments and Compliance with Principle Safety Criteria for Nuclear Installations*" [16] provides the NNR requirements on the assessment of nuclear installations against their Principle Safety Criteria including risk criteria, applicable to both worker and member of the public. It provides quantitative risk criteria that the installation should meet, which includes the risk contribution of both internal and external events, including seismic events.

RG-0019, "*Interim Guidance on Safety Assessments of Nuclear Facilities*" [15] provide the nuclear regulator general guidance on the documented evidence that are acceptable to the NNR on safety assessments, including changes to the current licencing basis, such as licence-binding documentation, and changes to any aspect to the safety envelop. It provides wide coverage of safety assessment aspects that should be considered in safety assessments, including the assessment of design extension conditions (DEC), but does not explicitly have requirements that are specifically related with seismic assessments.

The NNR position paper PP-0014 "*Considerations of External Events for New Nuclear Installations*" [17] outlines the NNR position on the characterization of external events and selection of design basis parameters required for ensuring the robust design of nuclear installations against external events and to meet NNR defined safety goals. It is applicable to both new nuclear installation as well as existing nuclear installations, when updating design basis hazard levels for external events.

NNR PP-0014 specifies that a site-specific probabilistic seismic hazard assessment (PSHA) study should be used to quantify the ground motion hazard due to the seismicity of the site and the surrounding region using one of a number of evaluation methods accepted for industry practice such as the Senior Seismic Hazard Analysis Committee (SSHAC) process [13], the performance-based approach [29], etc. The investigations should be consistent with the safety standard issued by the IAEA for acceptable seismic hazard evaluation practices [14]. It specifies that the method must be probabilistic in nature and should take into account both aleatory and epistemic uncertainties, and uniform hazard response spectra (UHRS) should be developed for the site, from which a site Ground Motion Response Spectrum should be developed.

NNR PP-0014 explicitly states that the ultimate objective is to demonstrate through PSA results that the Safety Goals do not compromise the annual fatality and dose limits specified in RD-0024. PP-0014 has derived the following probabilistic Safety Goals (SG), for typical PSA risk metrics, such as core damage frequency and large early releases, from the NNR Principle Safety Criteria, defined in RD-0024 that can be used for external hazards. In order to deal with cliff edge effect, additional Target Safety Goals (TSG) have been developed. An additional Safety Goal for Operating Basis Events is also provided, which is consistent with local seismic requirements for industrial structures. It indicates that PSA can be used to assess compliance to these NNR derived safety goals for external events, as provided in Table A.

	Risk Measures	Safety Goals	Target Safety Goals
Operating Base Events		$SG_{OBEE} = 2x10^{-4}$ /yr	
Level 1 PSA	Core Damage Frequency	$SG_{CDF} = 10^{-5}$ /yr	$SG_{CDF} = 5x10^{-6}$ /yr
Level 2 PSA	Large Early Release Frequency	$SG_{LERF} = 10^{-6}$ /yr	$TSG_{LERF} < 10^{-6}$ /yr

Table A: *NNR PP-0014 Safety and Target Safety Goals for External Events*

The site-specific hazard level selected as a design basis is not expected to fall below the hazard level used in the national code for the appropriate class of the building, facility or structure, taking into account the area of location. However, if the site-specific hazard level chosen as a design basis does fall below the national hazard level, a conservative assumption shall be made that the site-specific hazard level is at least equal to the hazard level used in the national code or national hazard map for the appropriate class of the building, facility or structure.

PP-0014 specifically derives Safety Goals for seismic events, based on the qualitative description of acceptable performance for Seismic Category 1 SSCs in a nuclear installation, so as not to exceed an elastic limit state of behaviour. Thus, the definition of unacceptable performance is the 'onset of significant inelastic deformation'. The qualitative measure represented by 'onset of significant inelastic deformation' means that inconsequential and localized inelastic deformation constitutes acceptable performance.

The target performance goal for the frequency of onset of significant inelastic deformation (P_{FOSID}) used for seismic design may be defined by $P_{FOSID} = SG_{CDF}$. In addition to fulfilling the performance goal for seismic-induced core damage, the design may be demonstrated to achieve the following performance goal for seismic induced large early release frequency (P_{SLERF}), where $P_{SLERF} = SG_{LERF}$.

	Risk Measures	Safety Goals	Target Safety Goals
Operating Base Earthquake Ground Motion (OBEGM)		$P_{OBEGM} = 2x10^{-4}$ /yr	
Level 1 Seismic PSA	Core Damage Frequency	$P_{FOSID} = 10^{-5}$ /yr	$P_{SCDF} = 5x10^{-6}$ /yr
Level 2 Seismic PSA	Large Early Release Frequency	$P_{SLERF} = 10^{-6}$ /yr	

Table B: *NNR PP-0014 Safety Goal and Target Safety Goal for Seismic Events*

In summary, PP-0014 provides explicit seismic safety and target safety goals for a seismic PSA, providing clear criteria regarding what the NNR regards as acceptable.

3.3 International Experience

3.3.1 US Experience

Since the Late 1970's seismic re-evaluation has been a topic of focus for the US-NRC. There has been on-going seismic developments, regulatory positions, scientific studies and site evaluations.

In the late 1980's unresolved safety issue A-46 was initiated to verify the seismic adequacy of mechanical and electrical equipment in many older plants, whose construction permit application pre-dated 1972. In 1984, US-NRC formed an 'expert panel on the quantification of seismic margin', which issued technical guidance and advise on the subject of seismic margins of NPP's, including reports and an approach to the quantification of seismic margins in NPP's, trial studies, technical guidance and advice on the subject.

In 1988 the US-NRC initially requested that all US plants conduct an internal event PSA, referred to as Internal Plant Evaluations (IPE) for internally initiated events only. In early 1990, US-NRC initiated Internal Plant Evaluations for External Events (IPEEE) of which seismic was one of the major external events, and all plants either conducted a seismic PSA or a seismic margin assessment, in response. In the late eighties and early nineties, two seismic hazards studies, were conducted by EPRI (1989), and Lawrence Livermore National Laboratory (LLNL)(1994) for the Central Eastern United States (CEUS) region, where numerous nuclear power plants are situated. There were significant discrepancies in the outcomes of these studies, looking at the same region. The divergent results of these two studies, led to the establishment of a "Senior Seismic Hazard Analysis Committee (SSHAC)", which was tasked with resolving the discrepancies in approach and outcomes between these studies, and recommend ways of improving the state of the art PSHA. The committee culminated in the formulation of the first SSHAC guidelines in 1997 (NUREG/CR-6372), which have since been supplemented with the publication of US-NRC SSHAC guidance in NUREG-2117 (2012) and NUREG-2213 (2019).

Extensive seismic evaluations were conducted in the US in response the Fukushima NTTF recommendations 2.1 & 2.3, issued in 2011. GI-199 was issued in 2010 in response to latest seismic studies conducted in the Central Eastern United States (CEUS) that indicated that the seismicity of the region had been previously underestimated. However, GI-199 was subsequently subsumed into NTTF Recommendation 2.1 which was released in response to the Fukushima accident.

In order to address NTTF recommendation 2.1, EPRI developed the EPRI Seismic Evaluation Guidelines [3], in 2013. The objective of this Seismic Evaluation Guidance is to provide guidance on the performance of plant seismic evaluations, and in particular those intended to satisfy the requirements of US-NRC NTTF Recommendation 2.1: Seismic. It is intended primarily for use by all U.S. nuclear power plants to address the requirements of NTTF Recommendation 2.1: Seismic. Its primary value is that it provided an approach that has been reviewed with the US-NRC, and can be applied by plants to provide a uniform and acceptable industry response. The guidance related to seismic evaluations is of value for any seismic risk assessment.

EPRI has also developed an augmented approach [4], referred to as the Expedited Seismic Evaluation Process (ESEP), which expedites the more important aspects, to provide a level of confidence in the plant seismic robustness and safety, while the remaining evaluation were being performed. The ESEP approach provides an option to scale of the SSE GMRS to perform the evaluation, and limits the assessment to the equipment required for SBO, as this covers the most likely accident sequence following a seismic event. This approach was accepted by the NRC in order to expedite the seismic evaluation in the US, and allow for continued efforts to respond to the NTTF.

3.3.2 IAEA

The IAEA has recently released IAEA SRS No. 103. “Methodologies for Seismic Safety Evaluation of Existing Nuclear Installations” [31]. It provides guidance on methodologies to perform seismic evaluations of existing nuclear power plants. The purpose of a seismic evaluation is to identify and assess the seismic margins built into the original design of the facility, taking credit for them in an updated seismic safety assessment, and where necessary to determine any upgrading actions to obtain the desired safety level. This report is predominantly based on the seismic evaluation methodologies and processes developed in the USA, and have been used in both Europe and Asia.

It introduces three possible methods of performing seismic assessment, namely seismic margin analysis (SMA), Seismic PSA (SPSA) or seismic design reconstitution. However, it focuses on the first two assessment methods as in most countries seismic design reconstitution is considered unnecessary, as it is typically used when the perception of the seismic hazard has increased significantly, as has occurred in Japan.

It is however generally recognized that well designed industrial facilities, especially nuclear power plants, have an inherent capability to resist earthquakes larger than the earthquake considered in their original design. Conservatisms are compounded through the seismic analysis and the design chain. This inherent capability, or robustness, is usually described in terms of the ‘seismic design margin’”. This existing seismic margin is one basis for the development and implementation of the SMA and SPSA methodologies, which successfully address many seismic issues that arise

It then predominantly describes the two seismic assessment techniques, namely seismic margin analysis and seismic PSAs, with a high level description of how to undertake them. It emphasises that the most significant difference is in the system analysis, with the seismic PSA being able to produce result that can be compared to regulatory limits, or risk based safety goals.

The publication does highlight that it needs to be emphasized that there has so far been no failure of a high hazard resistant designed nuclear power plant SSCs for actual earthquake shaking motions up to twice the DBE PGA.

The IAEA bases much of their supported seismic evaluation methodologies on the development that has taken place in the US, and supports the fact that either SMA and Seismic PSAs are the most pragmatic and effective tools to assess the seismic capability of a nuclear installation.

3.3.3 French experience

The practice in France is to re-evaluate the design basis periodically. When the seismic design basis is modified all the seismically classified SSCs are verified, the design margins are credited (e.g. using inelastic energy absorption factors) and the analysis detail is graduated according to the importance of the SSCs in the seismic scenarios.

EDF have conducted seismic PSAs for certain plants, such as St Alban, following the EPRI methodology for seismic PSA. These are then adapted to other sites, to account for site unique features. The St Alban seismic PSA focuses on full power, only calculates CDF, and does not consider consequential (induced) hazards.

EDF have been developing the seismic PSAs for their plants, which will consider shutdown plant states, and include consequential hazards. They apply the EPRI seismic PSA implementation guide as the primary reference, with a few adaptations to meet EDF practice and the expectations of the French regulator, and are consistent with the IAEA and ASME standards.

3.4 Koeberg Seismic Re-evaluation Strategy

The seismic re-evaluation strategy is to provide confidence that the Koeberg plant is safe from a seismic point-of-view and complies with regulatory requirements. Initially, an interim seismic evaluation strategy will be performed and once the SSHAC study is completed a final seismic re-evaluation performed. The final re-evaluation will include updating the FMRS, confirming equipment compliance to updated seismic requirements and quantifying the seismic risk using a seismic PSA.

The interim strategy is based on USA methodology employed for the resolution of NTTF recommendation 2.1, while the more detailed seismic PSAs, seismic margin assessments and the high frequency test program were still not fully developed. This interim guidance, referred to as the expedited seismic evaluation process (ESEP), was developed by EPRI and accepted by the US-NRC, and applied in the USA. The Koeberg strategy is to emulate this approach as close as practically possible for the South African situation.

The strategy is to adopt internationally accepted methodologies that have been previously implemented successfully. Based on a review of international literature, including IAEA SRS No 103, it was decided to adopt an approach based on EPRI developed Seismic Evaluation guidance. This approach makes use of the SSHAC methodology to establish an acceptable GMRS. The GMRS will be used as input to a plant model to update the FMRS and thereby establish updated seismic requirements for installed plant equipment.

In order to quantify the risk that seismic activity poses to the plant, and meets NNR regulatory criteria, a seismic PSA is to be undertaken. A general overview of the proposed seismic re-evaluation strategy is provided in Figure 1.

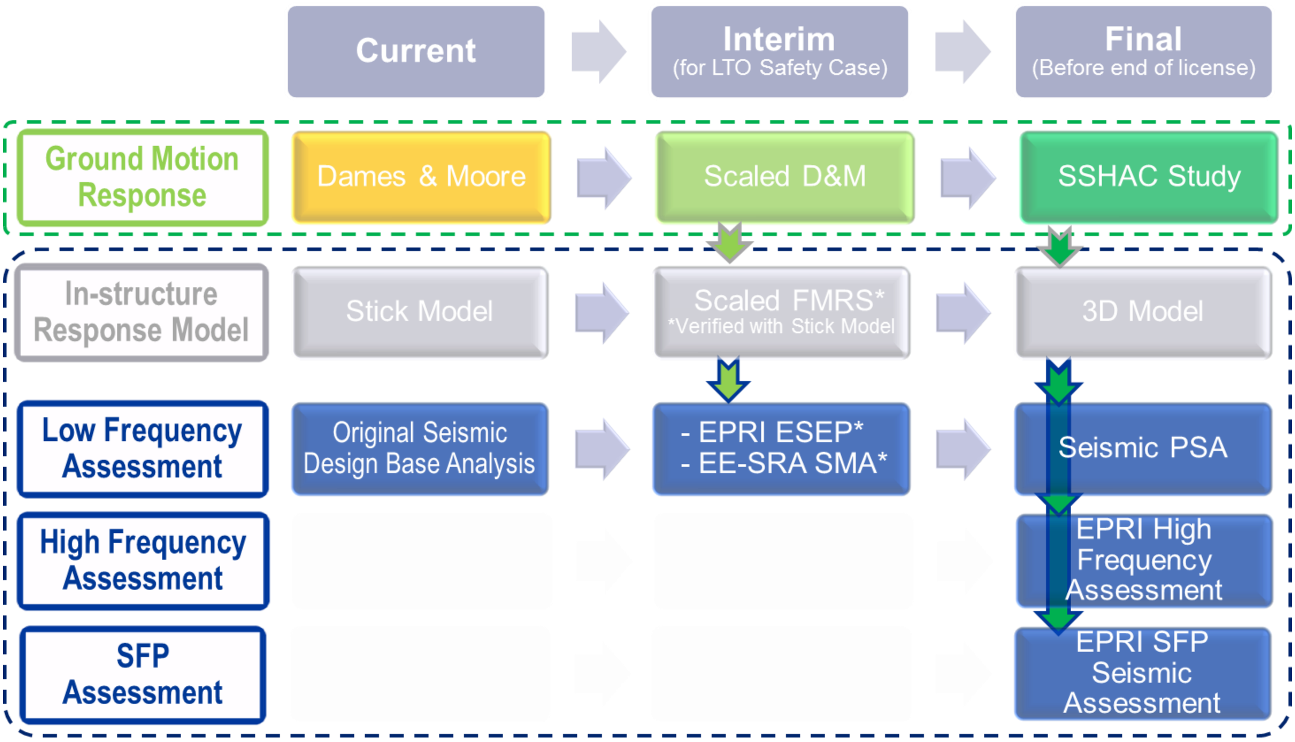

Figure 1: Overview of Interfacing of Seismic Re-evaluation Strategy

To provide guidance for design changes and new plant creation that are required to withstand or mitigate design extension condition seismic events, directives will be stipulated in this strategy.

3.4.1 Interim Seismic Evaluation

While the enhance SSHAC level 2 study is underway an interim re-evaluation will be performed based on EPRI expedited seismic evaluation process (ESEP) [4], which has been endorsed by the US-NRC and applied by certain nuclear power plants in the USA. The primary benefit of this approach is that one of the options provided to derive a GMRS to review against, is to apply a scaled SSE spectra, which can currently be achieved. It also allows for much of the existing EE-SRA SMA analysis to be utilised to support the assessment. The equipment scope is limited to evaluation of the equipment that is required in a loss of AC power for 72 hours, which is the dominant accident sequence in a seismic event.

It is currently not possible to specifically assess the impact of the high frequency component of an assumed (scaled) GMRS spectra without the new GMRS which will be produced from the SSHAC study. However, the EPRI High Frequency Program [5, 6, 7] did conclude that all of the tested equipment that was identified as being susceptible to high frequency seismic vibrations was found to be already susceptible to seismic vibrations in the low frequency range. The scaled GMRS is therefore expected to provide some degree of confidence that important equipment susceptible to the high frequency issues will be identified with low frequency seismic capacity concerns.

3.4.2 Duynefontein Probabilistic Seismic Hazard Study

It was agreed to between Eskom and the NNR that an enhanced SSHAC Level 2 study will be conducted for the Duynefontein site, the details of which has been the subject of extensive discussion with the NNR to-date. This PSHA will be conducted in accordance with latest SSHAC Guidance (incl. NUREGs 2117 and 2213), and involves comprehensive data compilation as well as extensive new geological and seismological data collection, informed by hazard sensitivity calculations. The project will involve continuous updating of a baseline hazard model developed at the start of the project using existing data and knowledge, including insights provided by previous hazard studies for the site. The new enhanced SSHAC level 2 will be executed following the same essential structure and steps of a SSHAC Level 3 study, but allows increased flexibility to focus on those elements with greatest uncertainty or greatest impact on the final hazard. Of particular significance is adherence to the SSHAC process, and the role assigned to the facilitation/integration team(s) that organizes and directs the PSHA project and its use of experts. In this way Eskom will ensure a carefully structured, transparent, and thoroughly documented approach that fully considers available information, quantifies uncertainties, and documents the analysis.

Until the SSHAC results are available, where the high frequency spectra needs to be considered, as the current design GMRS is not believed to be adequately enveloping, the results of the PC Rizzo study may be considered as an information source, recognizing its limitations. Currently, it is considered the best available indication of the anticipated GMRS from the SSHAC study. This will be replaced by the SSHAC study results as soon as they become available. Currently the only areas where this is envisioned to be applied, will be limited to the screening in the PSA, and design input guidance for design extension conditions to expedite the post Fukushima enhancements. In addition, as soon as they are available, Eskom will use the results of the SSHAC baseline study as input to develop a preliminary Seismic PSA.

3.4.3 Final Seismic Evaluation

The final seismic evaluation will be based on the outcomes of the SSHAC studies. Updated GMRS and seismic hazard curves are the primary outputs of the SSHAC. The overall seismic re-evaluation strategy will follow EPRI Seismic Evaluation Guidance [3], which has also been endorsed by the US-NRC. In order to timeously perform the final seismic evaluation, it is necessary to make some initial assumptions to develop an implementable strategy. To determine the scope of the evaluation, based on the currently available information (see Appendix A), and the opinions of SSHAC team leads for both the Thyspunt and current Duynefontein SSHAC studies, it is assumed that the high frequency spectra could exceed the GMRS the plant was designed to. As there is still uncertainty regarding the exceedance of the spectra in the 1 to 10 Hz region, it has been decided to conservatively assume that this will be exceeded, as well. This is to adequately plan for the applicable work that is to be executed before commencement of LTO, assuming unfavourable results from the SSHAC studies.

Using these assumptions, according to the EPRI Seismic Evaluation Guidance a high frequency assessment and spent fuel pool evaluation should be conducted. These will be conducted in accordance with the latest EPRI implementation guidance [5] and EPRI high frequency test results [6, 7] from their high frequency program, and the latest EPRI Seismic Evaluation Guidance: Spent Fuel Pool Integrity Evaluation [8] for the Spent Fuel Pool evaluation.

To address any potential low frequency exceedances, EPRI proposes that either a seismic PSA (SPSA), or seismic margin assessment (SMA) is conducted, to assess the seismic risk and robustness of the plant (see 3.4.4 below).

To quantify the seismic risk at Koeberg the seismic PSA (SPSA) approach will be adopted. This is considered the more comprehensive approach, aligns with the current NNR risk based regulations, and some preparatory work is currently underway to develop a Seismic PSA model. The seismic risk for the plant will be quantified and included in the final seismic evaluation strategy report, together with the SSHAC outcome, the updated GMRS, the updated FMRS and equipment compliance.

New FMRS will be derived from updated structures modelling, and will provide the basis for deriving the new floor response spectra from the new GMRS. These can be used both in the development of the Seismic PSA, and for any future seismic equipment qualification requirements.

Equipment classified with a seismic classification (as per KSA 010), will be verified against the updated GMRS and FMRS. They will either be confirmed to be adequately robust, or identified for additional treatment (e.g. specific testing, replacement or modification).

The DSSR, SAR, and other appropriate documentation will to be appropriately updated with the new updated GMRS, FMRS, seismic re-evaluation results, and design guidance for both design basis and design extension condition.

3.4.4 Seismic Risk Quantification

The most effective tool for quantifying seismic risk is a seismic PSA (SPSA). The main objectives of a SPSA are:

- to develop an appreciation of accident behaviour;
- to understand the most likely accident sequences;
- to gain an understanding of the overall likelihood of core damage;
- to identify the dominant seismic risk contributors;

- to identify the range of peak ground acceleration that contributes significantly to plant risk;
- to compare seismic risk to risk from other events; and
- to compare the seismic risk against the seismic safety goals, such as those provided in NNR PP-014.

The intent is to use the seismic PSA to demonstrate that the plant meets the NNR Levels 1 and 2 Seismic Safety Goals, and Target Safety Goals, developed in NNR PP-0014 [17]. The SPSA is intended to be a full scope Capability Category II peer-reviewed Seismic PSA. The intent is to have this finalised before entering LTO. The SPSA will use plant specific fragility data (or generic data where necessary) to determine both the seismic contribution to both CDF and LERF.

The key steps for the development of a seismic PSA consist of:

1. Probabilistic Seismic Hazard Analysis, i.e. SSHAC study;
2. Seismic System Analysis;
    a. Binning Seismic Hazard Intensities
    b. Identify Seismically Induced external events e.g. seiche, tsunami.
    c. Potential Seismic Plant Walk-downs for System Analysis;
    d. Seismic Event Trees Development
    e. Seismic Fault Tree Development
    f. Seismic Induced Fires (fire protection system vulnerable to seismic events)
3. Seismic Hazard Equipment List (Iterative approach)
    a. Initial Listing based on PSA Internal Events Model;
    b. Potential Plant Walk-downs for Fragility analysis;
    c. Screen-out Seismically Robust Equipment;
    d. Update seismic PSA equipment list.
4. Structure and Equipment Seismic Response Analysis
    a. In-structure Response Spectra
    b. SSC Fragility Plant Walk-downs;
    c. SSC Fragility Data Analysis
5. Seismic PSA Model and Fragility Data Integration
6. Interpretation of Seismic PSA Results
    a. Overall Seismic PSA Risk (CDF and LERF)
    b. Comparison with NNR PSA and Seismic PSA targets;
    c. Identify Dominant Seismic Sequences;
    d. Identification of potential Seismic Safety Improvements;
7. Documentation of Seismic PSA
8. Seismic PSA Peer Review.

Eskom is already in the process of developing the demonstration model for the Seismic PSA, which will assist Eskom in expediting the finalisation of the PSA model and the results before the license expires. The Seismic PSA will incorporate the high frequency aspect of the component fragilities, as well as and include a seismic PSA model for the Spent Fuel Pool.

Once the Seismic PSA and the additional seismic re-evaluation, have been finalised both the SAR and the Risk Assessment Report will be updated to reflect the full seismic safety argument

3.5 Design Guidance for DEC Changes

To progress with modifications that require DEC considerations, as an interim position while the SSHAC studies are being finalised, it is proposed that the design guidance provided in "*Design Extension Related Guidance for Modifications and Equipment – Seismic (Eskom Report no. 240-121010217*)" is used. This guidance was specifically developed in order to reduce the risk of under-designing plant changes in both the low and high frequency range, while ensuring that the current design base remain unaffected, and providing conservatism in the low frequency range, while the new site GMRS are being finalised. This guidance aligns well with an update to the design engineering guide 331-87.

Once the SSHAC seismic hazard study results are finalised, the update of the seismic design guidance for DECs will be revisited, and updated appropriately taking into account the new GMRS.

4. Acceptance

This document has been seen and accepted by:

Name	Designation
Bravance Mashele	Koeberg Engineering Manager
Anton Kotze	Nuclear Engineering
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5. Revisions

Date	Rev.	Compiler	Remarks
December 2020	1	NAS Foster	Initial Revision

6. Development Team

The following people were involved in the development of this document:

- Neil Foster
- Irené Saayman

7. Acknowledgements

John Richards, EPRI.

Appendix A : GMRS/SSE Comparisons and Plant Screening

The EPRI methodology [3] compares new GMRS for the site against the plants Safe Shutdown Earthquake (SSE). The SSE is the plant licensing basis earthquake and is uniquely defined for each NPP site. The SSE consists of:

- A PGA value which anchors the response spectra at high frequencies (typically 33 Hz for the existing fleet of NPPs), which is 0.3g PHGA for Koeberg,
- A response spectrum shape which depicts the amplified response at all frequencies below the PGA (typically plotted at 5% damping), and
- The control point applicable to the SSE. It is essential to ensure that the control point for both the SSE and for the GMRS is the same (Not defined in Koeberg SAR, refer to top of bedrock according to EPRI).

If the SSE is greater than or equal to the GMRS at all frequencies between 1 and 10 Hz, then no requirement to perform a SMA or SPSA is required (after providing a confirmation, if necessary, that SSCs which may be affected by high-frequency ground motion, will maintain their functions important to safety. If not, a seismic SPRA or a full scope SMA (NRC style) is to be performed.)

Based on the result of the PC Rizzo and the Thyspunt studies, there is currently indication that the Koeberg SSE may largely envelope the new GMRS in the 1 to 10 Hz range, see figure 1 and 2, but this cannot currently be conclusively be stated. The GMRS, produced by PC Rizzo, (which is currently considered as unconservative, without being updated with addition geotechnical data) indicates that it will exceed the SSE above 8 Hz.

South Africa lies within a stable continental region (SCR) well removed from active plate boundaries and, similar to other SCRs, and the region is a very close analogue with the Central and Eastern United States (CEUS) [28]. Both regions experienced continental-scale compression during the Paleozoic period followed by major continental extension in the Mesozoic period, thus giving rise to major compressional structures that have been locally reactivated by normal faulting and the development of extensional basins during continental separation [28]. Further, both regions have very low levels of Quaternary uplift and an absence of significant contemporary deformation. There is evidence of local Quaternary deformation and the activity and paleoseismic behaviour of the Kango fault finds close analogues with similar faults in the CEUS [28].

Another important respect in which the Duynefontein site is similar to the CEUS is with respect to the hard bedrock conditions that underlie the site. This will have a profound effect on the shape of the Uniform Hazard Response Spectra (UHRS) to be produced by the SSHAC studies. As Ground Motion Prediction Equations (GMPEs) will be used that have been calibrated for similar shear-wave velocities, the response spectra is expected to reach their maximum ordinates at high frequencies, a feature that is generally not correctly captured by many standard design spectral shapes (such as [30]) that were actually calibrated to softer rock (Western United States) sites.

It is therefore currently anticipated that the SSHAC studies result will produce a GMRS that could exceed the existing GMRS in the high frequency region (i.e. > 10 Hz). In the low frequency range the predicted results are not certain. This is further supported by the previous results of the Thyspunt SSHAC study [28] and the PC Rizzo study [30] that was conducted for the PBMR demonstration plant, as indicated in the figure 2 and 3, on the following page.

A.1.1 Previous Site Hazard GMRS Characterisation

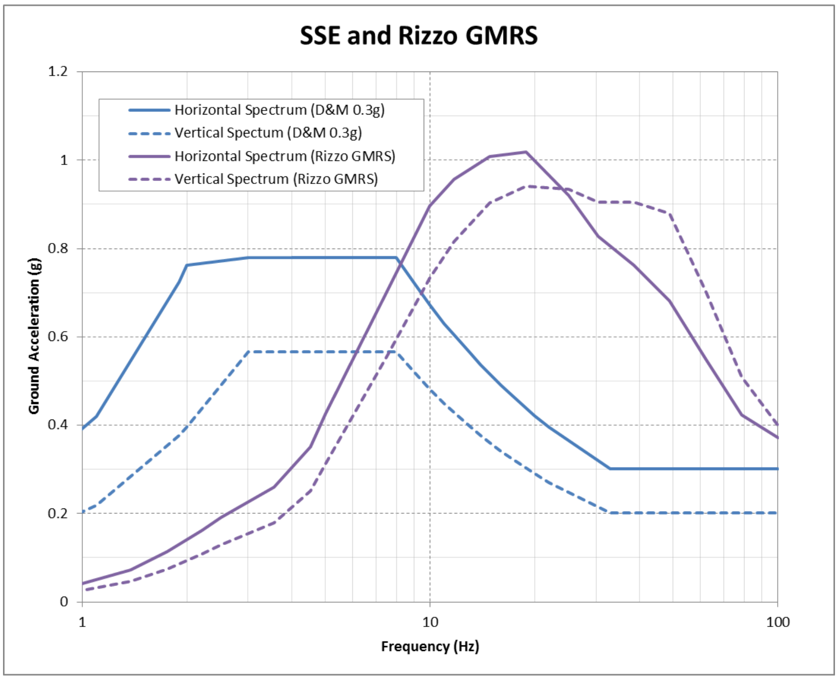

Figure 2: *PC Rizzo Duynefontein GMRS versus current Koeberg GMRS.*

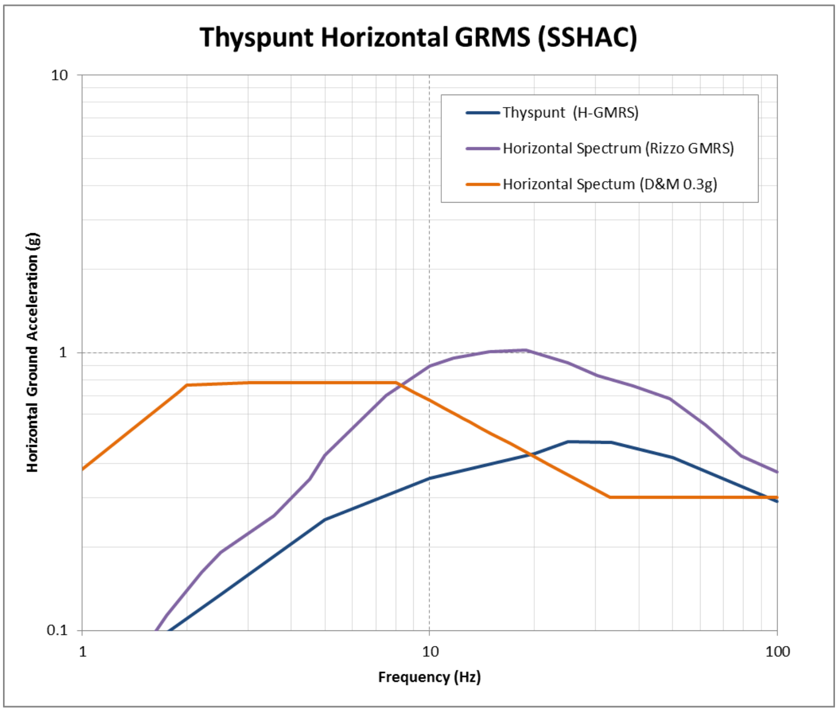

Figure 3: *Thyspunt Horizontal GMRS versus current Koeberg GMRS.*