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EXECUTIVE SUMMARY

The Aseismic Bearings play a crucial role in the seismic response of Koeberg Nuclear Power Station. The Aseismic Bearings dictate the seismic behaviour of the Nuclear Island and subsequently the respective horizontal floor response spectra which are used in design for essential SSCs, especially with respect to the horizontal seismic response of the Nuclear Island.

A change in the mechanical properties of the Aseismic Bearings has a direct impact on the response of the Nuclear Island, especially with respect to the shear modulus and damping provided by the Aseismic Bearings. Changes in mechanical properties can occur due to aging and degradation.

In this report the main expected ageing and degradation mechanism of the Aseismic Bearings are discussed and it is determined that polymer oxidation is a dominant ageing mechanism. It is noted that the internal neoprene of the Aseismic Bearings is protected by an external neoprene wrapping. Accordingly, the degradation of the internal neoprene due to polymer oxidation of the Aseismic Bearings is expected to be minimal.

Analyses show that changes in the shear modulus of the Aseismic Bearings (whether it is increasing or decreasing), have negligible impact on the Nuclear Island response. This is concluded with two different approaches, first by considering the clipping of narrow band spectra in-line with research conducted by EPRI; and by considering the ductility of the structures founded on the Nuclear Island, allowing only limited permanent distortion. Both sets of analyses provide confidence that the impact of the Aseismic Bearings' degradation will not have a significant impact on the integrity of the structures; which is supported by international operational experience.

To address the concerns relating to variations between Eskom's shear modulus test results and EdF shear modulus test results, the safety case committed to better characterise the aseismic bearings and update the AMP based on the findings. A literature review of aseismic bearing ageing, testing and monitoring, and a desktop study of the Koeberg test results as well as a review of international operational experience did not provide a reason for the variation. However, KNPS has obtained a better understanding of the ageing mechanisms and behaviour of the aseismic bearings and it has been confirmed that the aseismic bearings are fit for purpose to enter LTO. Additional testing is however recommended during the next inspection interval (during LTO) mainly to verify Koeberg's shear modulus test results. This will also support the future work after the SSHAC study's results become available.

Furthermore, KNPS has implemented a monitoring programme which is consistent with international best practice, such as the IAEA IGALL AMP 314 and U.S. NRC NUREG 7253. The monitoring programme includes visual inspections, non-destructive indicative property measurements in the form of Shore Hardness measurements and testing of representative samples. This monitoring programme has been performed in accordance with the Koeberg's nuclear licensing requirements.

The implementation of the monitoring programme, the lack of confirmed degradation mechanisms and by extension time dependant degradation mechanisms, as well as the analysis performed to date, illustrates that the bearings are suitable for use going into LTO and the current condition of the Aseismic Bearings does not challenge the findings of the interim seismic assessment that KNPS has performed.

Koeberg however notes the change in international opinion regarding the use of the Newmark-Hall Seismic Response Spectra and has commissioned a SSHAC study in line with international best practice. The re-assessment of the Nuclear Island, due to the possibility of a new seismic hazard being developed, will be complimented by additional testing with respect to the bearings' shear modulus, to ensure that the uncertainties surrounding the shear modulus of the Aseismic Bearings are eliminated and the capability of the bearings during LTO considered as committed to in the Koeberg seismic evaluation strategy.

Recommendations are made in this report, most notable that the inspection and monitoring procedures need to be updated and that the shear modulus of the in-situ bearings need to be verified during LTO.

CONTENTS

FIGURES

TABLES

1. Introduction

Koeberg Nuclear Power Station (KNPS) is located on the west coast of South Africa, in the Western Cape province. During the development of KNPS, intensive studies were conducted to consider the geotechnical conditions [10] which was used to determine the seismic hazard for KNPS. The study considered seismo-tectonic fault lines, as known in 1974 (See Appendix A).

Ultimately, the studies showed that the site for KNPS has a seismic hazard. The design limits were determined to be at 0.15g for an Operating Base Earthquake (OBE) and 0.3g for a Safe-Shutdown Earthquake (SSE). It was decided that specialized foundations are required which would be able to dampen probable horizontal seismic accelerations to a level where the Systems, Structures and Components (SSCs) would be able to withstand these perceived seismic events. Specialized foundations, which will provide the dampening of the seismic actions when called upon, was provided in the form of low damping elastomeric anti-seismic bearings here-on referred to as the Aseismic Bearings.

Redact: 3rd party information, PAIA 37(1)(a). Information is not available publicly

Furthermore, the original designed plant life, and subsequent timeframe of the operating license of KNPS was for a 40-year period. With Unit 1 and Unit 2 being commissioned in 1974 and 1975 respectively, the current 40-year license period expires in 2024 based on Unit 1. Eskom has provided the NNR with a safety case and application to extend the operating licence by 20 years. Included in the supporting LTO safety case, a number of commitments have been made. One of them being the characterisation of the aseismic bearing shear modulus and update of the ageing management programme.

As part of the life extension effort, Eskom has evaluated numerous components that are considered life limiting and conducted ageing analyses of these components to determine if these components would remain suitable for their intended use during long-term operation (LTO) i.e., for another 20-years.

One of these critical components that require evaluation, is the base isolation system that would perform a crucial role during seismic events. The material properties of the isolators are subjected to ageing over the lifetime of the plant which may have an effect on the performance of the isolators and subsequently an impact on the seismic response of the Nuclear Island.

Although the Interim Seismic Evaluation for Koeberg [8] provided reasonable assurance that the Koeberg units are sufficiently robust to safely shut down and will be able to cope with a significant seismic event, the evaluation did not consider any changes in the Aseismic Bearings' material properties.

The Aseismic Bearings are license binding [37] and nuclear Safety Related, and therefore KNPS has over the years implemented an inspection regime to monitor and track the condition of the Aseismic Bearings to ensure that the bearings are not compromised and will continue to fulfil their design function (also for the LTO period).

In line with the agreed seismic evaluation strategy [10], KNPS has embarked on a re-analysis of the Nuclear Island to derive new floor response spectra from updated structural modelling. This will be done by the development of a 2-dimensional finite element model (referred to as the new 2D Analysis) which will be used to reanalyse the Nuclear Island and utilise the SSHAC study results to determine future seismic equipment requirements.

2. Supporting Clauses

2.1 Scope

The scope of this report is to provide a holistic overview of the current position of KNPS regarding the Aseismic Bearings and discusses the way forward. It considers the actual condition of the Aseismic Bearings, based on the implemented in-service inspection regime, and supports the LTO safety case [2].

The report provides an overview of the important properties of the bearings, the effect changes in these properties might have on the floor response of the structures supported by the bearings, and consequently if it invalidates the findings of the Interim Seismic Evaluation for Koeberg [10].

The scope of this report focusses on the following parameters and topics, which have been addressed in the past in various reports, studies and regulatory correspondence:

1. The Friction Coefficient of the friction couple and corrosion of the interface,
2. Delamination of the neoprene from the steel plates under shear loading,
3. Shore Hardness tests,
4. Distortion, and
5. Shear Modulus.

The report further discusses the historic monitoring and trending values and discusses the current and future ageing management of the Aseismic Bearings. Furthermore, there are a number of concerns associated with the Aseismic Bearings and their monitoring which has been the topic of deliberation in recent years. These are briefly documented below:

- The expected neoprene ageing, due to oxidative degradation, should result in a hardening effect when considering the Shore Hardness tests, but this has not yet been conclusively observed. [1]
  - There could be some explanations for this, e.g. only the external neoprene surfaces (wrapping) are checked for hardness and do not represent the internal condition. This is in line with international experience and EPRI research results where only the external surface degrades with time due to atmospheric contact, but the interior remains unaffected for very long periods.
  - Additionally, the Shore hardness testing is very subjective and not sensitive enough to pick up minor changes in the cross-chain link density of the neoprene material.

- The Static and Dynamic Shear Modulus test results of the bearings are expected to show an increase in shear modulus and subsequently stiffness (not expected to be stable or reducing over time) in line with an expected neoprene ageing.

[1] § 5.3.3.2 postulates the observation is due to subjective changes which occurred between 2004-2005

    - This expectation has been extensively documented in research literature as well as confirmed by the test results of EdF. The EdF results confirmed the ultimately expected plateau of approximately a 37% increase in shear modulus and EdF showed that this value still respects their original design assumptions, with respect to the response of the Nuclear Island.

- There is a finite number of sample bearings available and intended only for a 40-year plant life. Only 10 untested neoprene sample bearings remain available for testing in LTO.

These issues form part of the scope of this report and are discussed throughout. Conclusions on the way-forward for each issue are also provided.

Other topics which are not considered issues but are worth addressing include:

- Differential Settlement and
- Loading of the Bearings.

The scope of this report focusses on the seismic bearing and therefore excludes:

1. The upper raft,
2. The lower raft, and
3. The reinforced concrete Aseismic Bearings pedestals.

***Note**: all the above-mentioned components will be addressed under the civil recovery programme, as deemed necessary.*

2.1.1 Purpose

The purpose of this report is multi-fold. The main themes of the report is to:

(1) provide an overview of the historical information in order to consolidate institutional knowledge related to the Aseismic Bearings that is starting to disappear, due to the change of personnel;

(2) to summarize the existing ISI and licence requirements associated with the Aseismic Bearings' monitoring;

(3) determine if the design intent and function of the Aseismic Bearings is being challenged, including characterising the ageing mechanisms, evaluating Koeberg test results, and international operational experience and literature; and finally

(4) to support the LTO safety case and consider the requirements for LTO.

In achieving the above, this report is to provide interim supporting justification for continued operation with the existing Aseismic Bearings until the final seismic re-evaluations[2] are finalised. This will supplement the interim safety seismic re-evaluation, the LTO safety case [2] and safety justification for KNPS, for an additional 20-years of operation. It will also provide the way forward regarding the future assessment of the Aseismic Bearings.

The report considers components and other aspects important for the functioning of the Aseismic Bearings system (with an emphasis on the neoprene) and addresses its:

1. Design Intent,

[2] The "re-evaluations" refer to the SSHAC Study

2. Original Design Parameters (applicable to the FRS),
3. Regulatory, Licencing and Analysis History,
4. Negative Consequence of Potential Degradation,
5. Current Monitoring Programme, and
6. Planned Way Forward.

In the 'planned way forward section' of the report, the way forward will be clearly stipulated for envisaged milestones and/or projects and will differentiate between the:

1. LTO, safety case and Aging Management Programme (AMP) requirements, and
2. Re-analysis of the Nuclear Island by means of the new 2D model, which may include consideration of a change in Aseismic Bearings mechanical properties.

2.1.2 Applicability

This document is applicable to the LTO of KNPS and civil structures located on the Nuclear Island which is supported by the Aseismic Bearings.

2.1.3 Effective Date

This document is effective once authorized.

2.2 Normative/Informative References

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs, unless revision numbers are specified.

2.2.1 Normative

[1] 23CB047: KNPS – Monitoring of the Aseismic Bearings Summary Report

[2] 331-618: Safety Case for Long-term Operation of Koeberg Nuclear Power Station

[3] CE 18261: Specimens Obtained from the In-Situ Aseismic Bearings

[4] H43-005: KNPS – 1989 Test Series, Friction Couple Tests, Report on the Evaluation of the Test Results

[5] J43/87-002: KNPS – Aseismic Bearings, Technical Manual for the Monitoring of the Aseismic Bearings

[6] KAA-671 (240-166150229): Management of License Binding Civil Monitoring Programme Surveillances at Koeberg Nuclear Power Station

[7] KAU-030 (240-166148961): Basis and Scope for License Binding Civil Surveillances at Koeberg Nuclear Power Station

[8] Koeberg Safety Analysis Report § II-1.8.1: Protection of the Buildings Against Earthquakes

[9] Koeberg Safety Analysis Report § II-1.9: Civil Works – Buildings

2.2.2 Informative

[10] 240-160677773: Koeberg Seismic Re-evaluation Strategy

[11] 3002012994: EPRI report: Seismic Fragility and Seismic Margin Guidance for Seismic Probabilistic Risk Assessments (2018)

[12] 32-T-IPDK-002: Interim Seismic Evaluation for Koeberg NPS

[13] 653947R: Geologic Report – Koeberg Nuclear Power Station

[14] ASCE 43-19: Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

[15] Bouaziz, R. et. al. Elastic Properties of Polychloroprene Rubbers in Tension and Compression during Ageing (2020)

[16] Celina, M. et. al. Correlation of Chemical and Mechanical Property Changes During Oxidative Degradation of Neoprene (2000)

[17] Celina, M. et. al. Review of polymer oxidation and its relationship with materials performance and lifetime prediction (2013)

[18] IAEA IGALL AMP 314: Seismic isolation (Version 2020)

[19] IAEA TECDOC-1905: Seismic Isolation Systems for Nuclear Installations

[20] ISBN 2-913638-61-9: French Experience and Practice of Seismically Isolated Nuclear Facilities

[21] ISO 9001 Quality Management Systems

[22] JN497-NSE-ESKB-R-5741: Shear Modulus Testing of the Aseismic Bearing Samples – Report

[23] JN843-NSE-ESKB-L-8468: Aseismic Vault - Level Deformation Survey (2021)

[24] JN843-NSE-ESKB-R-8469: Monitoring of the Aseismic Bearings Summary Report – 2021

[25] k18589N: KNPS – Approval Request NAR-1385 SAR Change Notice CN-47

[26] K-21194-E Extension of Aseismic Bearing Testing Prog – JN415-NSE-ESKB-R-4995

[27] K5385: KNPS – Aseismic Bearings Monitoring, Response to k-8453-E

[28] k5966: KNPS: Aseismic Bearings, Shear Modulus Test.

[29] KBA09A2C00013: Nuclear Island Foundation Design Guide

[30] KBA09A2C05002: Layout for Bearing Pads and Neoprene

[31] KBA09A2D00034: Aseismic Bearings – General Statement

[32] KBA1222E221013 Rev Z2: Filter Effect of Aseismic Bearings

[33] KWR-IP-CIV-013: Aseismic Sample Bearing Testing

[34] KWU-DE-015: Load Monitoring of Aseismic Sample Bearings

[35] KWU-DE-020: Long Term Monitoring of Aseismic Bearings

[36] NISTIR-4613: Long Term Performance of Rubber in Seismic and Non-Seismic Bearings, A Literature Review (1991)

[37] NIL-01 VAR 19: Koeberg Nuclear Installation Licence

[38] NP-1558: Review of Equipment Aging Theory and Technology, Revision 1 (2020)

[39] NUREG 1.122: Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components (1978)

[40] NUREG/CR-7253: Technical Considerations for Seismic Isolation of Nuclear Facilities

[41] NUREG/CR-7255: Seismic Isolation of Nuclear Power Plants using Elastomeric Bearings

[42] SmiRT-25: Response Spectrum Broadening Methodology (2019)

2.3 Definitions

2.3.1 **NUREG:** Reports or brochures, produced by the U.S. NRC

2.3.2 **BEARIUM:** BEARIUM ® B-10 metal is a 70% Copper, 10% tin, and 20% lead alloy

2.4 Abbreviations

Abbreviation	Explanation
AMP	Ageing Management Programme
D&M	Dames and Moore
EdF	Électricité de France
EPRI	Electric Power Research Institute
FRS	Floor Response Spectrum
HRX	Reactor Building
IAEA	International Atomic Energy Agency
IGALL	International Generic Ageing Lessons Learned
ISI	In-Service Inspection
KNPS	Koeberg Nuclear Power Station
LTO	Long-Term Operation
NNR	Nation Nuclear Regulator
NRC	Nuclear Regulatory Commission
OBE	Operating Base Earthquake
PRA	Probabilistic Risk Assessment
SAR	Safety Analysis Report
SSCs	Systems, Structures and Components
SSE	Safe-Shutdown Earthquake
SSHAC	Senior Seismic Hazard Analysis Committee

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 Ground Motion Response Spectra 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) and for updating the SAR.

Component Engineering is responsible for managing the Aseismic Bearings in accordance with the ISI requirements.

Inspection and Test is responsible for performing the ISI of the Aseismic Bearings in accordance with the approved License Binding Procedures.

The Responsible Engineer (Civils) is responsible inter alia for, (1) overseeing plans, procedures and programs for monitoring Civil Structures, (2) providing direction and oversight to personnel performing inspections and monitoring activities, (3) evaluation and acceptance of inspection and monitoring data and (4) reviewing and acceptance of repair or replacement actions relating to the Aseismic Bearings and the other Civil safety related components.

Material Reliability Group (MRG) is responsible for developing AMPs.

2.6 Process for Monitoring

N/A

2.7 Related/Supporting Documents

N/A

3. Background – Structural Description of Foundation Components and Function

The section of the report provides a brief overview of some of the SSC applicable to this report.

3.1 Overview Aseismic Bearings and affected SSC

The nuclear safety related structures

Redactions due to Detailed information on the plant's physical design that may be exploited by persons with malicious intent. NNR Act 47, Section 51, PAIA 38(b).

are constructed on a common foundation, referred to as the aseismic island foundation or the Nuclear Island. The function of the Nuclear Island was to adapt the Reference Station (Tricastan[3]) design to the more severe seismic conditions required at the Koeberg Site without making major changes to the structures themselves and so prevent damage during a seismic event [9].

The aseismic island foundation comprises of the following components:

- a lower raft supported on the soil-cement sub-foundation,
- reinforced concrete pedestals (on which the Aseismic Bearings are situated),
- Aseismic Bearings and
- an upper raft supported by the bearings.

The upper raft forms the foundation to all the nuclear safety related structures on the aseismic island. These components are illustrated in Figure 1 and Figure 2.

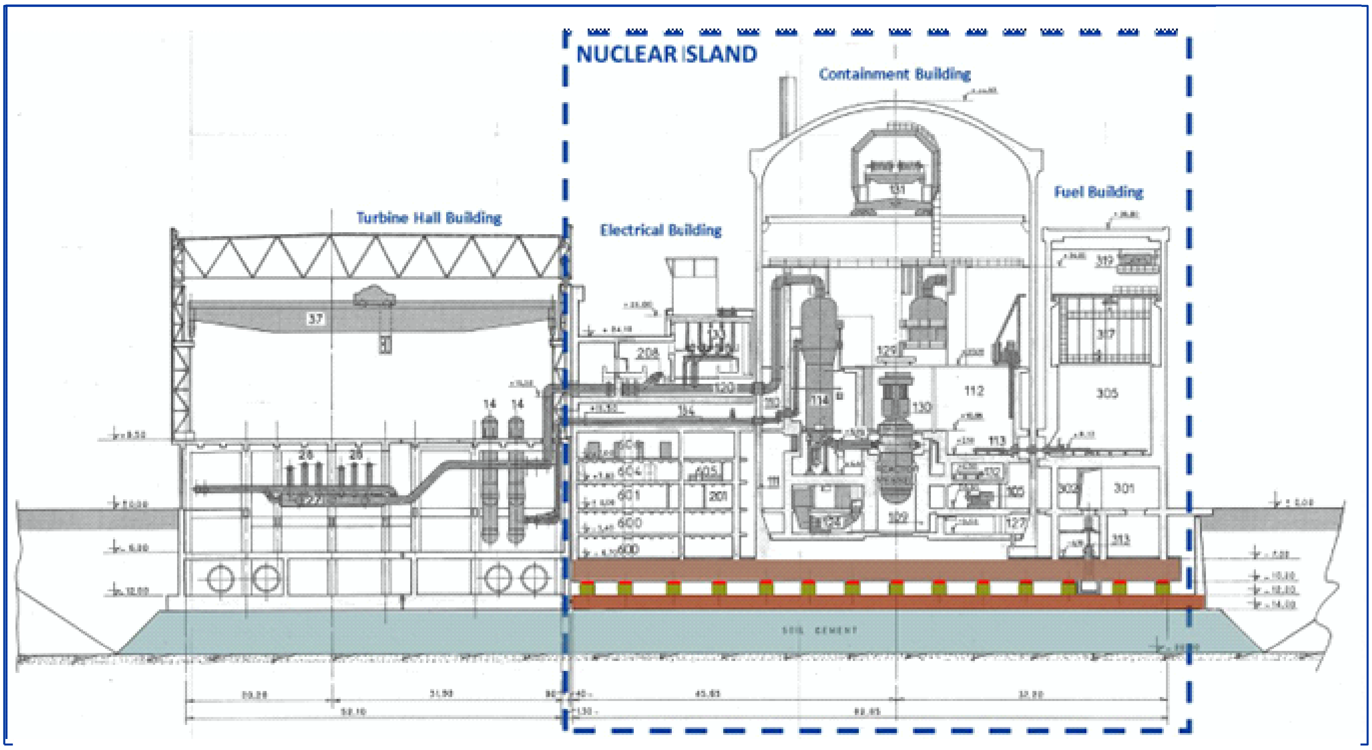

Figure 1: Overview of KNPS Main Plant

[3] The 'Reference Station' is Tricastan, however Tricastan does not have neoprene bearings. The only EdF station with neoprene aseismic bearings is Cruas.

Note: Elevation indicated on Figure 1 and Figure 2 are in reference to terrace level, which is at +8.00 m above mean sea level.

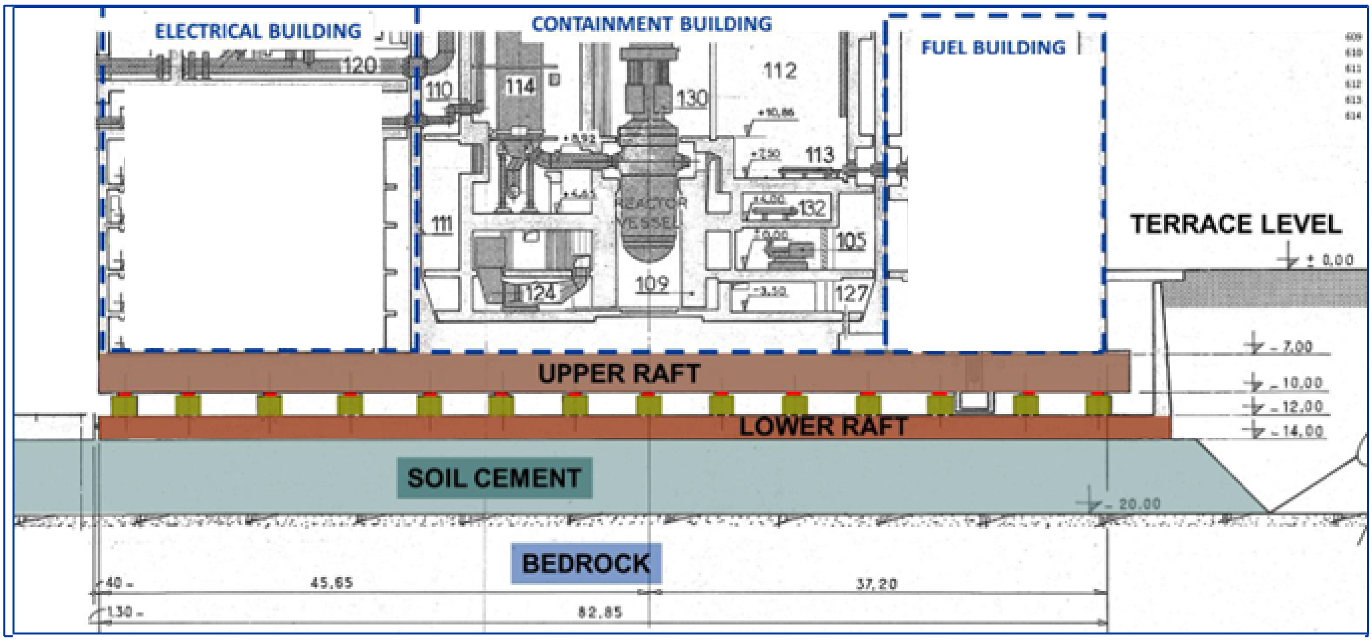

Figure 2: Overview of KNPS Nuclear Island Foundation

The aseismic Nuclear Island is designed such that vertical loads from the structures and plant supported by the upper raft are safely transmitted to the lower raft and the soil cement sub-foundation under all operating conditions. The load distribution is such that minimal differential settlement occurs in the lower raft, which could adversely affect the operation of the plant on the island.

During a seismic event the Aseismic Bearings limit the participation of the Nuclear Island to the fundamental mode of ground vibration resulting in an overall horizontal translation of the Nuclear Island structures which is almost uniform throughout the structures.

3.2 Component Description

The ground layers, and plant structures/components, are described from the bottom to the top.

Redacted information:Detailed information on the plant's physical design that may be exploited by persons with malicious intent. NNR Act 47, Section 51, PAIA 38(b).

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3.2.5 Aseismic Bearings

A total of 1829 Aseismic Bearings are mounted on the bearing pedestals, typically four per pedestal. Each bearing comprises a reinforced neoprene bearing pad which deforms under horizontal load (but is almost incompressible under vertical load) and a friction couple which results in sliding of the friction surfaces under sufficiently high horizontal loads. The friction couple is designed to limit the horizontal forces acting on the bearings and structures.

The bearings are designed to act as a filter between the bedrock and the nuclear safety related structures effectively acting as a soft spring under horizontal distortion but as a stiff spring under vertical compression. The effect is to obtain an overall horizontal translation of the Nuclear Island structures under earthquake excitation which is almost uniform throughout the structures, and which limits the response to the participation of the Redacted information:Detailed information on the plant's physical design that may be exploited by persons with malicious intent. NNR Act 47, Section 51, PAIA 38(b).

Section 4 discusses the bearings in more details.

3.2.6 Upper Raft

Upper raft is supported on the Aseismic Bearings with the upper part (Stainless steel plate) of the bearing friction couple cast into the soffit of the upper raft. It provides a foundation for the nuclear safety structures on the Aseismic Island. The upper raft is completely isolated from the surrounding retaining wall by a gap designed to accommodate the horizontal movement expected during the design earthquake.

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An illustration of the components mentioned above is shown below in Figure 3.

3.2.7 The Aseismic Vault

Redacted information:Detailed information on the plant's physical design that may be exploited by persons with malicious intent. NNR Act 47, Section 51, PAIA 38(b).

As a result, the Aseismic Bearings are protected by a layer of Polyane sheeting that covers the space between the bearing pedestal and the upper raft. The Polyane protective screens is connected to the top of the concrete and hangs much like a curtain to the sides of the pedestals (See Figure 8 for the locarion of the polyane protective screen). The top is fixed with a special mastic and at the bottom it is taped to the pedestal. The bottom of the protective screens can easily be lifted to allow for visual inspections and non-destructive testing.

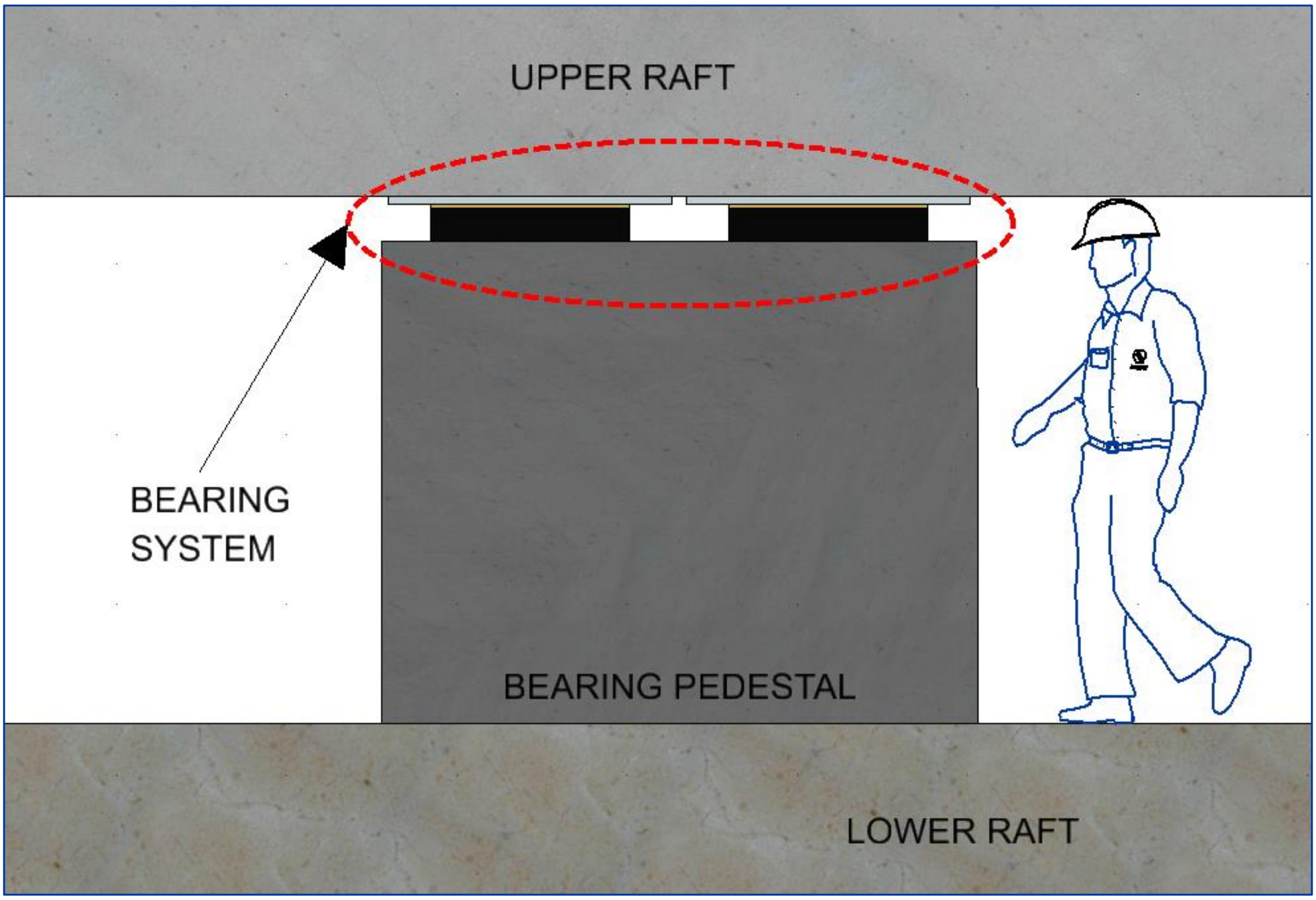

Figure 3: Schematic of Nuclear Island Foundation System

3.2.8 Environmental Conditions

The humidity and the temperature of the aseismic vault has been monitored since 2011, at 16 different locations. The humidity and temperature results since 2020 are shown in Figure 4 and Figure 5 respectively.

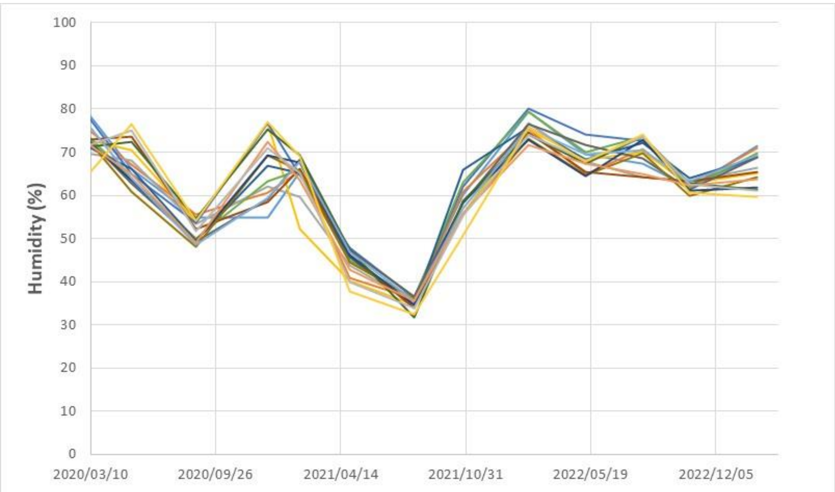

Figure 4: Humidity Trend Results (2020-2023)

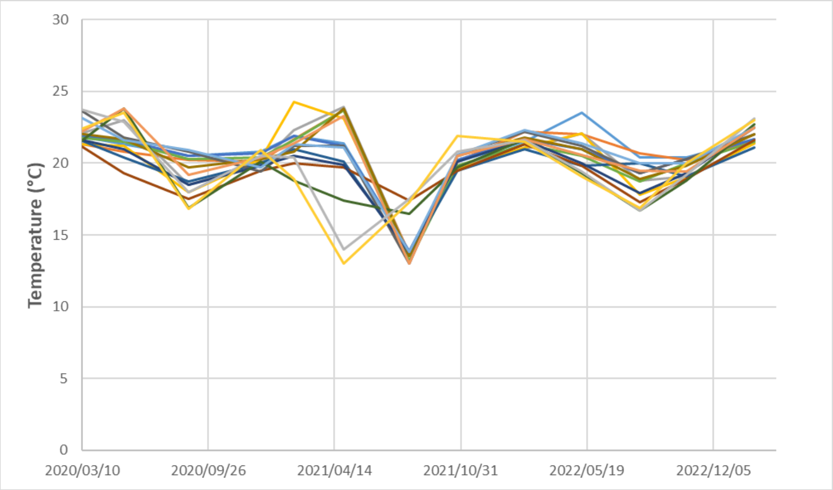

Figure 5: Temperature Trend Results (2020-2023)

Environmental information from manufacturing and construction is not available, however it is noted that the aseismic bearings and the monitoring samples (see § 3.3 below) shared similar conditions since commissioning.

The polyane protective screens were however placed over the bearings after placement to protect the bearing system during construction. See Figure 8 for the locarion of the polyane protective screen.

3.3 Monitoring – Sample Bearings

The design, manufacture and installation of the Aseismic bearings took place over a period of time, from 1976 to 1980, with further discussions and decisions regarding the possible corrosion of the bearings extending into 1983 and 1984. During this construction period, it was decided that certain tests would be performed on sample bearings at intervals throughout the life of the plant. The mechanical properties of these sample bearings would be obtained and would be checked against the values used in the design basis of the plant. Sample bearings were designed, manufactured and stored in the aseismic vault under similar environmental conditions as the in-situ bearings.

The size of the three different rig types vary according to the size of the sample and number of samples in the rig, however, all the rigs are prestressed to 50 kN compressive load to induce a pressure across the sample bearings. The compressive load in the storage rigs is checked bi-annually, and whenever a storage rig is removed for testing.

Three sets of sample bearings were manufactured and were earmarked for testing of different properties of the in-situ bearings at different intervals during the life of the plant. These sample bearings are stored in the aseismic vault at KNPS (to be subjected to similar environmental conditions as the Aseismic Bearings) in three different types of storage rigs, namely:

1. The friction couple sample bearings are arranged in seven rigs, ten samples per rig.
2. The neoprene sample bearings are arranged in six rigs, ten samples per rig.
3. The corrosion couple sample bearings are arranged in eight storage rigs, five samples per rig.

The sample bearings represent the in-situ bearings conservatively. A report which investigated the use of aseismic bearings and the experience of Edf, Cruas states that reduced scale samples oxidize faster than full-scale bearings. This is as a result of lateral exposed surface is proportionally greater compared to their plane surface. Therefore, the reduced scale samples age faster than the actual isolators.

3.3.1 Neoprene Samples Bearings

These bearings are used to monitor the shear modulus properties of the neoprene as it ages. They are approximately 150 mm x 200 mm x 52 mm thick. There are 60 of these neoprene sample bearings arranged in 6 storage rigs (Rigs A, B, C, D, E and F), 10 samples per rig.

Prestressed to 50 kN with an induced stress of 1.667 MPa.

3.3.2 Friction Couple Sample Bearings

There are 70 Friction Couple sample bearings, stored in 7 rigs, placed in the aseismic vault for use in measuring the coefficient of friction between the upper stainless-steel plate and the lower Bearium plate. These sample bearings are loaded in storage rigs, 10 bearings per rig.

Prestressed to 50 kN with an induced stress of 0.56 MPa.

3.3.3 Corrosion Couple Sample

There are 40 Corrosion Couple sample bearings stored in the aseismic vault, in 8 storage rigs. Each sample consists of a stainless-steel plate and a Bearium plate which is bonded to reinforced elastomer pad. The interface between the stainless steel-Bearium plates is sealed with Condat 757 grease, similar to the in-situ Aseismic Bearings. These samples are used to monitor the long-term development of corrosion between the stainless steel and Bearium plate interface and to determine the effects that grease will have on the interface.

These corrosion samples were delivered to KNPS from an Iranian plant. The origin and manufacturing of the Corrosion Couple Samples has not been confirmed and are not currently envisaged to form part of the testing programme.

NOTE: In most cases reference to tests were performed on the sample bearings. While there are important physical differences, the sample bearings have been carefully set up in terms of stress, exposure to environment and shape factor so that the results of tests on the samples are indicative but conservative of the in-situ bearings..

3.4 Differences Between Sample and In-Situ Bearings

The following table is provided (Table 1) in summary of the differences in the Neoprene Samples, Friction Couple Samples, Corrosion Couple Samples and the In-Situ Bearings, while Figure 6 provides a schematic of the differences:

Table 1: Summary of Different Bearings

Parameter	Neoprene Samples	Friction Couple Samples	In-Situ Bearings	Corrosion Couple Samples
No. Off	60	70	1829	40
Overall Dimensions [w × b × h (mm)]	150 × 200 × 52.5	300 × 300 × 115	700 × 700 × 155	325 × 325 × 175
Neoprene Layers [No., Thickness (mm)]	1, 10 1, 20	3, 15	2, 10 3, 20	2, 10 4, 20

Parameter	Neoprene Samples	Friction Couple Samples	In-Situ Bearings	Corrosion Couple Samples
Reinforcement Plates [No., Thickness (mm)]	1, 5	2, 5	4, 5	4, 5 1, 10
Base Plate (mm)	2.5	20	15	20
Bearium (mm)	15	15	15	12
Stress (MPa)	1.67	0.56	1.84 - 8.16	0.47
Shape Factor	2.14	5.00	8.75	4.06
Stainless-steel Plate	No	Yes, 25 mm	Yes, 25 mm	Yes, 26mm

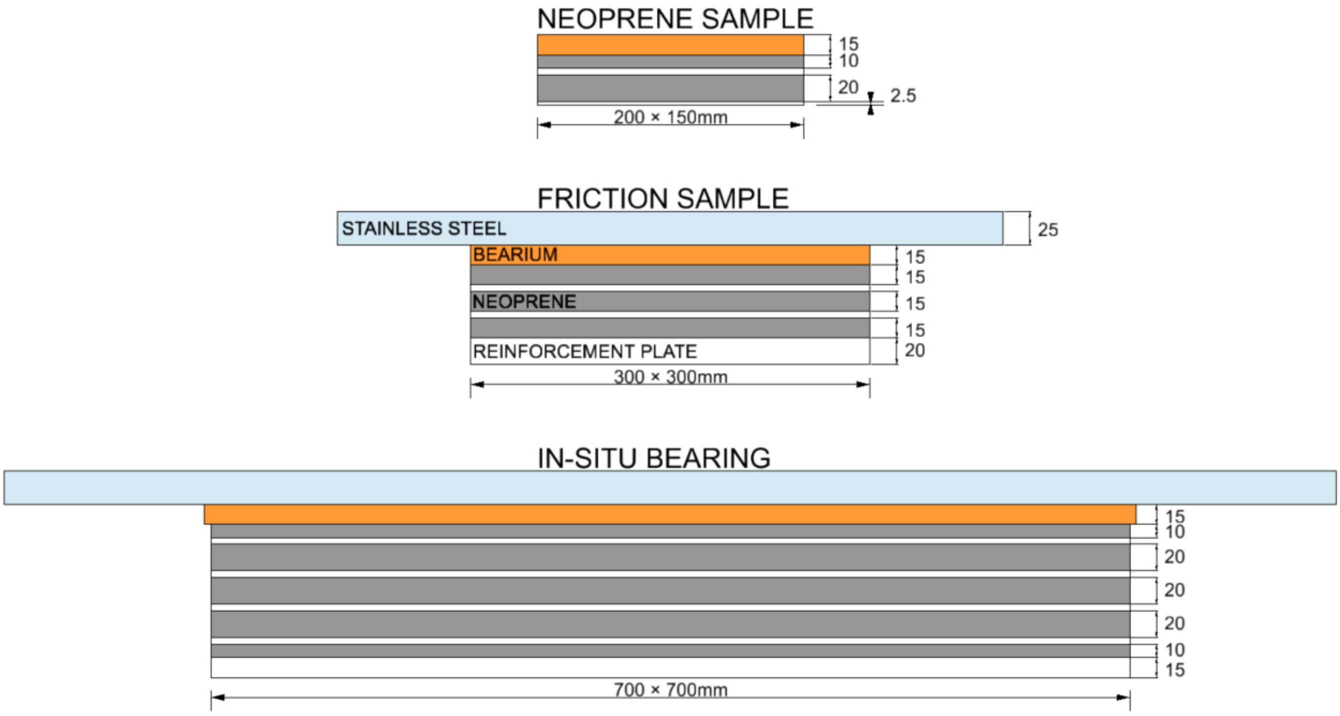

Figure 6: Overview of Samples and In-Situ Bearings Composition

3.5 Monitoring – Settlement

As part of the ISI programme, the upper and lower rafts are surveyed 5-yearly, with the latest survey performed in 2021 [23].

3.5.1 Upper and Lower Raft Monitoring

The 5-yearly survey focusses on the settlement and monitoring of the upper and lower rafts and report the differential movement between the respective rafts.

From the topographic survey it is noted that both the upper and the lower rafts have settled, on average, as follows:

- -0.0018mm Lower Raft

- -0.0019mm Upper Raft (Underneath Unit 1)
- -0.0013mm Upper Raft (Underneath Unit 2)

The latest result is shown in Figure 7 where the 2016 results are compared to 2021.

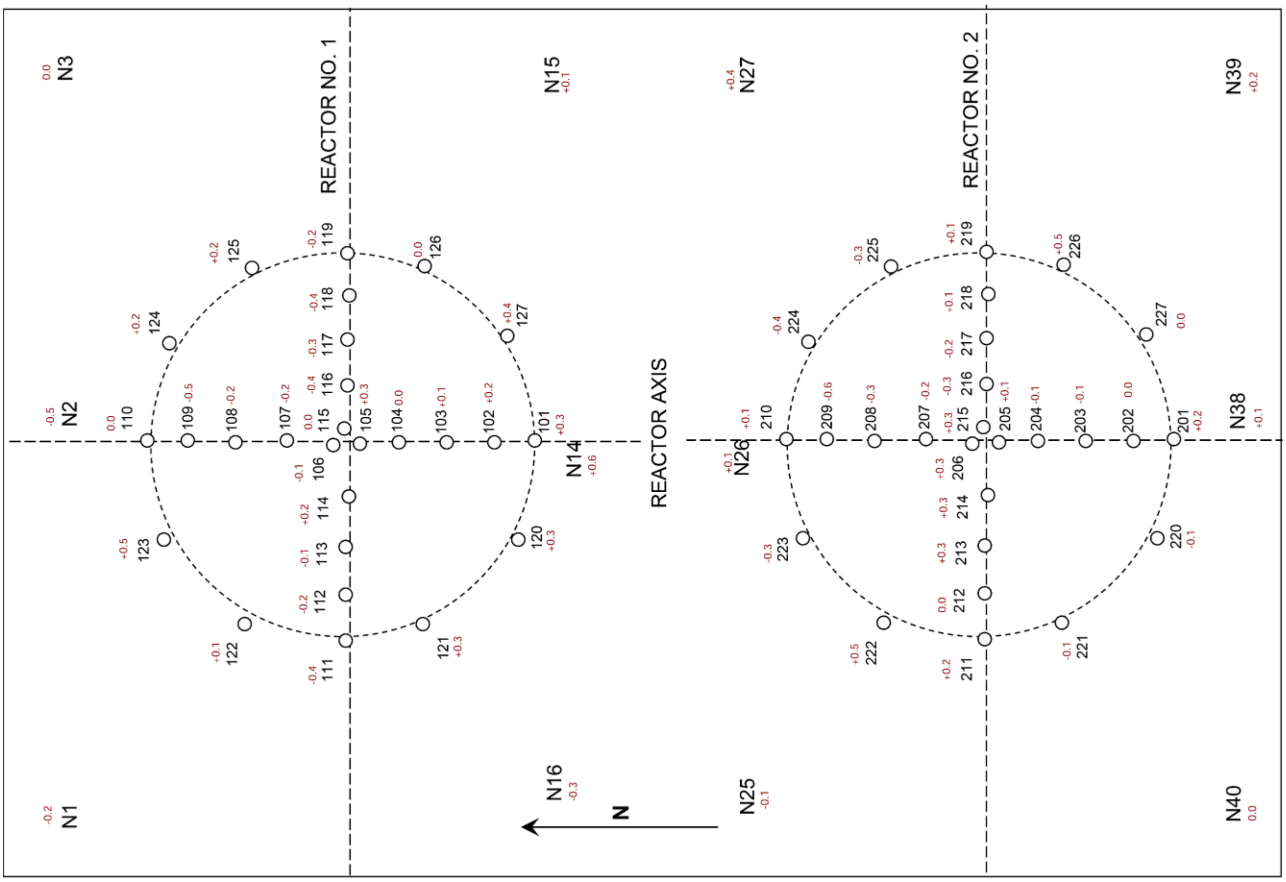

Figure 7: Aseismic Vault - Relative height differences in millimetres, 2021-2016

It is noted that the extreme relative movement between the upper and lower raft (i.e., the residuals) are +0.6mm and -0.5mm. It is concluded in the topographic survey report that the “residuals fall within the precision range of the survey and cannot be seen as representative of any change at this stage.”

For this reason, no conclusion can be drawn regarding the distortion nor the trending of the settlement, and less so regarding the aseismic bearings’ vertical creep or swell.

4. Detailed Description of the Bearing System

4.1

Redacted information:Detailed information on the plant's physical design that may be exploited by persons with malicious intent. NNR Act 47, Section 51, PAIA 38(b).

4.2 Components of the Aseismic Bearings

The aseismic bearing components comprises of a friction couple and a reinforced low damping elastomeric pad. A schematic of the aseismic bearing assembly is illustrated in Figure 8 which includes all the components, excluding the Polyane protective screen that provides additional protection around the outside of the exposed part of the bearing:

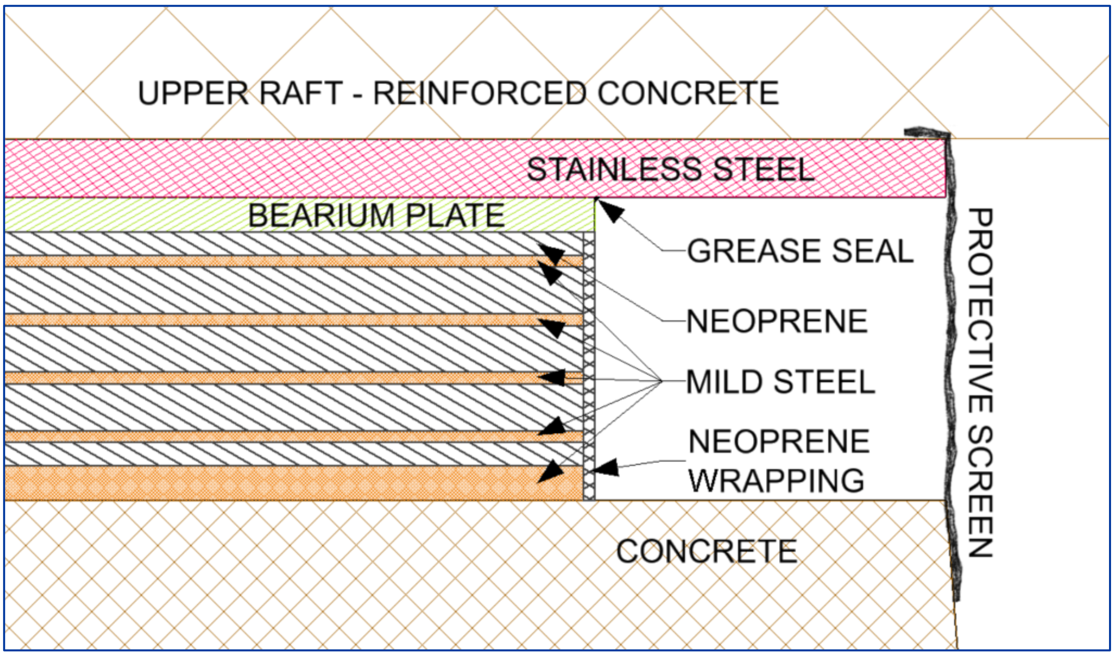

Figure 8: Composition of the Friction Couple and Reinforced Bearing

The details of the separate components of the aseismic bearing are presented below.:

4.2.1 Stainless Steel Plate

The upper stainless-steel plate has dimensions 1 m x 1m x 25 mm thick and which forms the upper portion of the friction couple, is cast into the soffit of the upper raft.

4.2.2 Bearium (Pb-Bronze) Plate

A bronze plate, with fine droplets of lead evenly distributed throughout and designated by the trade name of BEARIUM B10, has dimensions 700 mm x 700 mm x 15 mm thick. It is vulcanized to the elastomer bearing and is in contact with the upper Stainless-steel plate. This plate forms the lower plate of the friction couple, and has grooves milled in its surface which are designed to assist in the reduction of the coefficient of friction to the required level.

A ‘Grease Seal’ is placed on the perimeter of the BEARIUM plate at the interface with the Stainless-steel plate to limit any moisture ingress.

4.2.3 Bearing Pad

A reinforced elastomer bearing pad, of dimensions 700 mm x 700 mm x 100 mm, consists of alternating layers of neoprene and mild steel reinforcing plates form the main section of the Aseismic Bearings. There are four mild steel reinforcing plates, each 5 mm thick and 692 mm x 692 mm in plan, each separated by three layers of neoprene, 20 mm thick. The thicknesses of neoprene between the upper reinforcing steel plate and the Bearium plate, and also between the lower reinforcing steel plate and the steel base plate, is 10 mm thick.

Note that upon inspection, the reinforcing steel plates of the Aseismic Bearings are not visible due to an external layer of neoprene wrapping[4].

As part of the Aseismic Bearings’ manufacturing, the reinforced mild steel plates, the neoprene layers and the neoprene wrapping were vulcanized as a unit.

An example of an in-situ Aseismic Bearings is shown in Figure 9.

The external neoprene wrapping was placed to protect the reinforcing plates from corroding and the neoprene from ozone attack. [5]

[4] The position of the steel plates can be seen on a bearing that are showing signs of bulging.

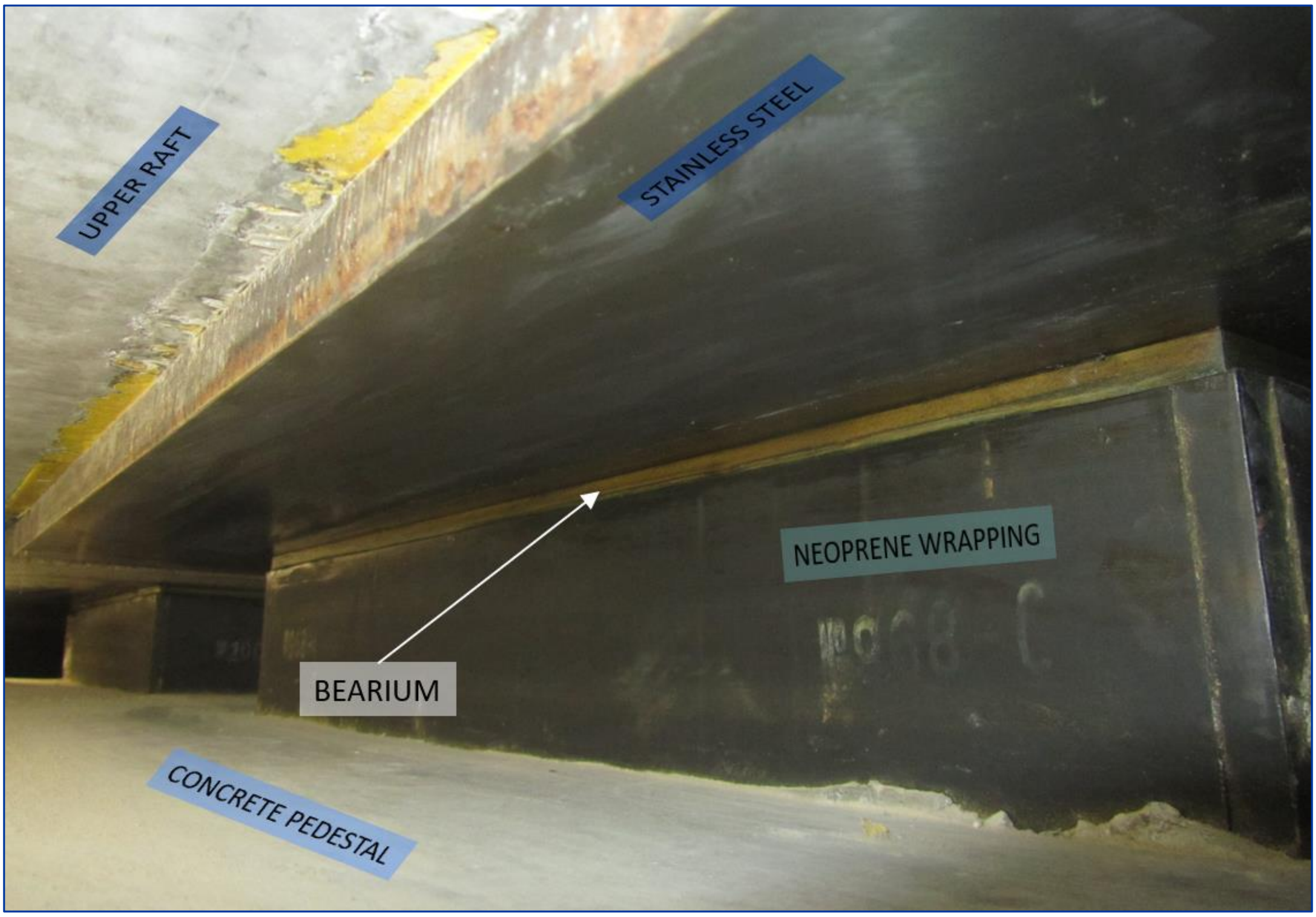

Figure 9: In-situ Aseismic Bearings

4.3 Ageing of Neoprene

The degradation of the neoprene is the primary concern of the Aseismic Bearings and their ability to perform their function. Therefore, the Neoprene, and the ageing thereof is looked at in more detail in this section.

Different degradation mechanisms in accordance with reference [26], that may affect the neoprene are listed in Table 3 and comment is made with regards to the relevance of the degradation mechanism on the neoprene in the Aseismic Vault as it relates to the primary function of the Aseismic Bearings.

It is also worth noting that in conventional aging, three reactions, or degradation mechanisms, act concurrently [38]. These degradation mechanisms are:

- Thermal decomposition,
- Oxidation, and
- Hydrolysis

It is highlighted that the degradation of the neoprene is dominated by oxidation rather than dehydrochlorination due to the composition of the neoprene bearings [16].

Reference [36] is a literature review on the 'Long Term Performance of Rubber in Seismic and Non-Seismic Bearings' which puts emphasis on the fact that "… compressively- loaded rubber bearings take advantage of many of the physical and chemical properties of rubber" and the literature review considers the effects of ozone, corrosion, temperature, and high-energy radiation in the study. The findings of Reference [36] is also included below:

Table 3: Degradation Mechanisms of Neoprene and Relevance to the Aseismic Bearings

DEGRADATION MECHANISM	COMMENT
1. Thermal degradation	• The temperature in the Aseismic Vault is relatively constant at 13-24°C [24]. This falls within the operating parameters recommended in USNRC 7253 [40] of 40°F – 80°F (4.4°C – 26.7°C). • At low temperatures, low oxygen consumption rates are expected [16], • The external wrapping is most prone to the changes in temperature, however due to the constant, low temperature in the Aseismic Vault, temperature is not considered a significant degradation mechanism. • Reference [36] indicates that neoprene is expected to "perform quite well" between -10°C – 70°C and therefore does not highlight any concerns with respect to the temperature effects on the aseismic bearings.
2. Oxidative degradation	• Degradation of the neoprene is dominated by oxidation [16], • Oxygen diffusion follows the non-linear profile of Fick's Law, • Diffusion-limited oxidation will therefore be expected in the neoprene pads, • The degradation effects of ozone are greatly accelerated, however, if a rubber is loaded in tension [36], which is not the case at KNPS. • It is therefore expected that the external surface (i.e., the wrapping) will experience oxidation degradation but the internal neoprene will have limited degradation. See for example references [16], [19] and [20].
3. Solvolytic degradation (hydrolysis)	• The humidity of the Aseismic Vault was measured to be ± 31-80% from the period 2020-2023Q1. • The external wrapping is mostly exposed to the vault atmosphere (and humidity). • The wrapping will, as in the case with oxidation and temperature, protect the internal neoprene, and it is expected that the main neoprene layers will be mostly unaffected by the moisture.
4. Radiation degradation	• There are no to limited low levels of radiation in the Aseismic Vault. • Neoprene degradation only occurs between $5{\times}10^6$ rad [38] and $10{\times}10^6$ rad [36], • The bearings will not experience these levels of radiation.
5. Mechanical degradation	• The mechanical conditions of the in-situ Aseismic Bearings are static, ranging from 1.84-8.16 MPa, including operational loads, with a mean value of 5.0 MPa [5]. • Live loads and other variations in loads will have a negligible impact on the mean vertical stress compared to the magnitude of the dead loads. (Consider

DEGRADATION MECHANISM	COMMENT
	that the mass of the nuclear island is ≈ 382,000 t, and all 1 steam generator contributes 0.08% of the toatal mass) • The aseismic bearings have not been subjected to meaningful seismic events. • There are no large shear gradients in the Aseismic Bearings. • It is therefore no degradation mechanisms expected from mechanical degradation.
6. Temperature Embrittlement	• Rubber loses its elastic properties and assumes glasslike properties below the glass transition temperature [36] • At the glass transition temperature, the shear modulus of the rubber increases by a factor of about 10000 and its maximum elongation to break is greatly reduced [36]. • For Neoprene, the glass transitioning temperature is - 40°C which is well below the temperature of the vault. • Glass Transitioning is therefore not expected to be a concern at KNPS. • The ISI will however continue to monitor for any degradation.
7. Cold crystallization and Strain Crystallization	• Cold crystallization is a first order, time- and stress -dependent, crystal nucleation and growth process which causes changes in the microstructure of the rubber resulting from the formation of locally- ordered regions of the macromolecules [36]. • Many properties change when cold crystallization occurs, including increases in the hardness and shear stiffness, and a decrease in its maximum elongation. • For Neoprene, the glass crystallization temperature is - 10°C which is well below the temperature of the vault. • Crystallization is therefore not expected to be a concern at KNPS. • The ISI will however continue to monitor for any degradation. • Strain induced crystallization is an alignment of the polymer molecules primarily in tension. The changes in the rubber under compression due to strain crystallization is considered to be negligible.
8. Crosslinking	• Most rubbers degrade through crosslinking which increases both the modulus and hardness of the rubber while decreasing the maximum elongation to break [36], at all ranges of temperature. • At temperatures above 70°C [36] (well above the vault temperature), many rubbers degrade via a mechanism of crosslinking. This increases the hardness and modulus of the rubber, resulting in embrittlement. • It is expected that the increase in crosslinking density overtime occurs very slowly at themperatures experienced in the aseimic vault. • Crosslinking is a product of natural ageing of neoprene and is increased by other degradation mechanisms such as radiation, oxidation and high temperatures, which is shown not to be a concern at KNPS.

DEGRADATION MECHANISM	**COMMENT**
9. Creep	• Monitoring of the Creep of the aseismic bearings has also not been performed as part of the Koeberg in-service inspection program, nor was it required and therefore no information is available. • The IAEA TECDOC 1905 [19] does however mention that: “Creep resistance of rubber bearing has been widely demonstrated on numerous applications.” • Creep will have no effect on the applied load on the aseismic bearings.

Reference [34] also points out that compressively- loaded rubber bearings take advantage of many of the physical and chemical properties of rubber. This is especially true with respect to the effect of solvents and air pollutants, which are often of major concern.

Furthermore, a report compiled by AFCEN, AREVA, EdF and NUVIA which describes the French experience and practice of seismically isolated nuclear facilities states [20]:

> *Durability is a key issue of the nuclear projects. Effect of ageing has a major impact on long-term mechanical properties deviations.*
>
> *Temperature, chemical environment (hydrocarbon…), ambient air (ozone and air), radiations are some of the external conditions driving the ageing of the isolators. However, for NPP isolation under the upper basemat, air attack is the main parameter causing CR (Polychloroprene Rubber) and NR (Natural Rubber) ageing.*

It is therefore concluded that degradation of the Aseismic Bearings’ neoprene is <u>expected</u> to be minimal as thermal decomposition, oxidation, and hydrolysis need to act concurrently, and the wrapping limits the levels of oxidation.

Furthermore, the wrapping will experience the majority of the oxidation, protecting the internal neoprene and it is expected that the wrapping will degrade at a greater rate than the internal neoprene.

5. Design of the Aseismic Bearings and Current Status

The Aseismic Bearings are complex and comprises of several components, each with its own function, requirements, ageing mechanisms and degradation mechanisms. There is also a lot of history to some of the components, and this section of the report provides context and addresses each component in more detail.

It is worth noting that EdF went through extensive testing to address several issues considered at Cruas. [4]. The outcome of the extensive testing was that the shear modulus and damping is the parameters that could affect the FRS (Floor Response Spectra) of the Nuclear Island. Report [4] states that:

> *These tests indicated, inter alia, an increase in shear modulus and a decrease in damping* ***to be the primary effects of the aging which could affect the seismic characteristics of the bearings****. A seismic analysis of the Nuclear Island at Cruas revealed that such changes had little effect on the overall response and that the calculated response spectra were still below the envelopes of the design spectra [4].*

The primary aspects (degradation) that affect the seismic characteristics of the bearings (and hence the nuclear island), is an increase in shear modulus, and the associated decrease in damping. While other aspects related to the aseismic bearings are discussed in this section for completeness, it should always be kept in mind that it is this overall seismic characteristic of the bearings that is the critical aspect to be considered.

It continues into the current state of the components (and other aspects important to the functioning of the Aseismic Bearings) and provides the planned intended considerations going forward by considering international best practice in accordance with, for example the IAEA IGALL AMP 314 [18] and NUREG 7253 [40].

It is worth noting that essentially, the Aseismic Bearings dictate the behaviour of the Nuclear Island and subsequently the structures on the Nuclear Island during seismic activity (as discussed in Appendix E). This translates, in structural engineering terms, to the shape of the floor response spectra (FRS) at each level of the structures located on the Nuclear Island. Therefore, negative consequences of potential degradation are discussed in terms of the FRS.

5.1 Friction Couple

5.1.1 Design Intent and considerations

The SAR [8] describes the Aseismic Bearings as follows:

> *The basic concept of the aseismic bearing foundation system consists of interposing a filter between the soil and the structures to filter vibration frequencies. The response of the structure becomes tuned to the frequencies where the seismic energy is small.*

The SAR [8] follows that:

> *The friction plates are designed to limit the horizontal force acting on the structure. The concept of the combined elastomer and friction plate type Aseismic Bearings is illustrated in [Figure 10] by a qualitative comparison of the horizontal earthquake response of a structure founded alternatively on:*
>
> • *soil,*
>
> • *elastomeric (lateral distortion) pads,*
>
> • *friction plates (sliding devices),*

• aseismic bearing pads (elastomer + friction plates).

For a low acceleration earthquake, no sliding takes place; the energy is dissipated mainly by the distortional damping of the elastomer blocks. For a high acceleration earthquake, distortion of the elastomer blocks is followed by sliding of the friction plates, i.e., energy is mainly dissipated in friction.

The above description of the Aseismic Bearings can be presented visually, as indicated in Figure 10.

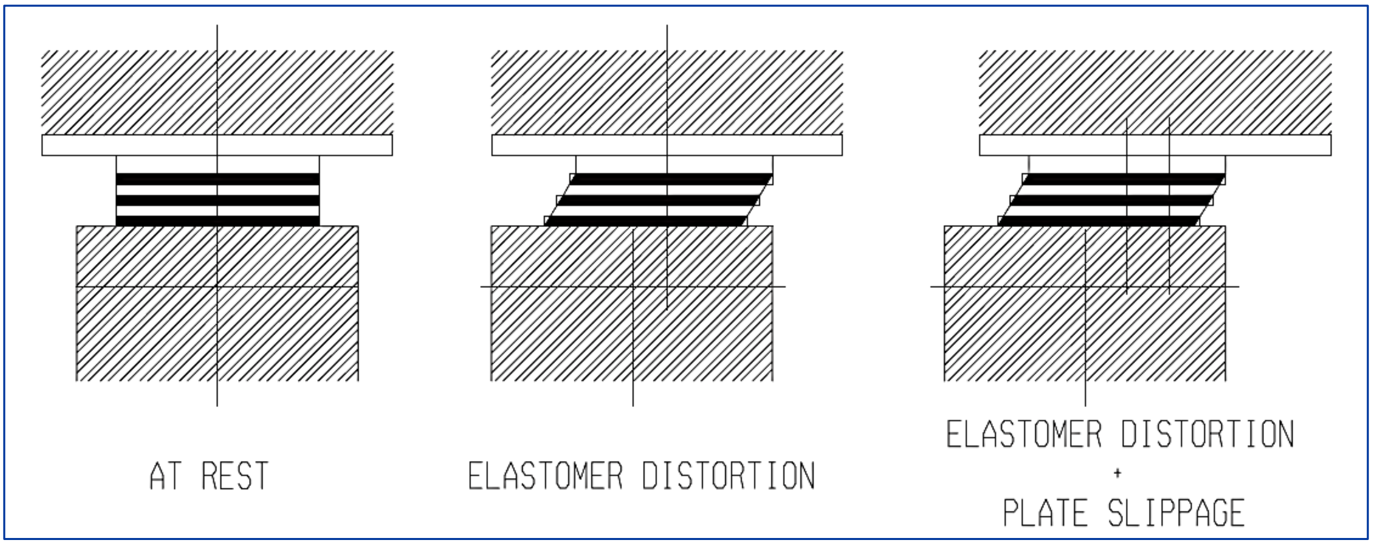

Figure 10: Dynamic Behaviour of the Aseismic Bearings

Figure 10 (Left) indicates the normal position of the Aseismic Bearings, where no seismic action (i.e., vertical or horizontal loads) are applied other than the static mass of the Nuclear Island.

Figure 10 (Middle) presents horizontally applied load on the Aseismic Bearings from a seismic action. The Aseismic Bearings deform; however, all the load is transferred to the pedestal, and subsequently the lower raft, through the elastomeric behaviour of the Aseismic Bearings.

Figure 10 (Right) At very large horizontal loads, the friction plate will slip and will displace with respect to the two components of the couple (Bearium and Stainless Steel). This only occurs once the horizontal forces exceed a certain value.

5.1.2 Original Design Parameters, applicable to the FRS

The material property which was originally determined and used in the design of the Aseismic Bearings and Nuclear Island, is the friction coefficient, specifically at the Bearium and Stainless-Steel interface.

The original friction coefficient bounds were:

Lower limit, μ=0.15

Upper Limit, μ=0.25

And during a baseline friction test performed in France, an average coefficient of friction of **0.15** was obtained [1] & [4].

5.1.3 Regulatory, Licencing and Analysis History

5.1.3.1 Significant Deficiency (SD-014)

A *Significant Deficiency* (SD-014) was raised concerning the Aseismic Bearings during construction (circa 1984) when corrosion on the exposed surfaces of some of the Aseismic Bearings was noted (Note Ref [9] § II-1.9.1.7.2). An extensive series of corrosion and friction tests were then undertaken in France and South Africa and a monitoring programme instituted at Koeberg.

Any corrosion at the interface of the friction couple will directly lead to an increase in the friction coefficient, hence the assessment of SD-14 was required.

Note that when reference is made to the friction couple, the corrosion of the interface is directly inferred and is addressed as one concept.

5.1.3.2 Monitoring History

As part of the in-service inspection (ISI), continuous monitoring of the Aseismic Bearings was performed at regular frequencies since 1983. The initial monitoring programme indicated that the friction will be tested at 5 (1989), 15 and 30-years after construction [1].

Inspection	'84	''85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	2000
Visual Insp		6 months			1 year				4 years					5 years			5 years
Lower Raft Insp		6 months			1 year				4 years					5 years			5 years
Distortion			1 year						5 years					5 years			5 years
Shore Hardness			1 year						5 years					5 years			5 years
Rig Prestress	1 year		3 years				3 years			3 years			3 years		3 years		
Friction			5 years							10 years							15 years
Shear Modulus			5 years							10 years							15 years
Corrosion Couple			5 years					5 years						5 years			5 years

The 1989 test series friction coefficient test series was performed through the University of Stellenbosch. The 1989 test report concluded that the friction coefficient had already increased and could be above the maximum value assumed for the design basis [4]. The report subsequently performed a seismic analysis of the Nuclear Island and concluded that:

> *"…this seismic analysis of the Nuclear Island with a high value for the coefficient of friction demonstrates that the structures and plant on the Nuclear Island will still be within their design bases as determined in the original design, and that this high value will have no adverse impact on the safety of the structures or plant."*

The report on the 1989 test series [4] already recommended the friction couple be excluded from the design base entirely. The cover letter for the NNR submission of the 1989 test series stated:

> *"… the design basis of the Aseismic bearings should be modified so as to exclude the performance requirements of the friction couples entirely, thus relying upon the elastomer properties of the Aseismic Bearings to provide the required "filtering" effects."*

With the 1989 test series an analysis was performed which indicated that at the higher friction coefficient, the effect of said higher friction coefficient on the safety of the plant and structures on the Nuclear Island is negligible, as noted above. The original request to remove the friction coefficient from the design basis was approved in 1990 [27], however the change to the design base was halted while EdF performed additional testing.

Subsequently, during the 1999 test series [1], further analysis was conducted on the friction coefficient (and included the 'surface flatness tests'). The 1999 test series report reiterated the *"minimal change in structural response under strong ground motion"* and again recommended that the friction coefficient[5] be removed from the Nuclear License.

Finally, in 2007, under SAR change request CN-47 the friction monitoring was removed from the Nuclear License and all requirements for a lower and upper bound for the friction coefficient was removed as documented in K-18589-E [25].

5.1.4 Negative Consequence of Degradation

The analysis reports [1] & [4] indicated that there is no adverse impact on the safety of the structures or plant due to the increased friction coefficient. This position is documented in the SAR [9].

This was based on reference [4] where a seismic analysis of the Nuclear Island with μ = 0,37 was performed. The study concluded that at μ=0,37 the "sliding surface is effectively 'locked-up' and the same response will occur with friction values higher than (sic) 0,37".

The study concluded that the neoprene portion of the Aseismic Bearings influences the filtering of the seismic motions. Furthermore, this study [4] was based on a damage study earthquake, which is 20% above SSE.

5.1.5 Current Monitoring Programme

In accordance with the approved Management of License Binding Civil Monitoring Programme [6] and Basis and Scope for License Binding Civil Surveillances at KNPS [7] there are no requirements for monitoring, as stipulated above, the friction has been removed from the Nuclear License and Design Basis.

5.1.6 Planned Way Forward

5.1.6.1 LTO and Safety Case Requirements

The friction coefficient (and subsequently, corrosion at the couple interface) has no impact on the LTO Safety Case as it pertains to the design basis. There are no changes regarding the monitoring of the friction coefficient envisaged as it does not affect the long-term operation and is not part of the design basis.

5.1.6.2 Re-Analysis of the Nuclear Island

The friction coefficient will not form part of any re-analysis of the Nuclear Island for the current design base through either of the planned analysis projects.

A sliding functionality may be considered during the development of finite element models of the Nuclear Island during beyond design base accidents; however, this is not considered a necessity. This may be considered for possible future investigations once the SSHAC results become available. Furthermore, the SAR states that:

---

[5] The last friction coefficient values were measured to be μ = 0.37 – 0.4 in 2009 [1]

> *"During studies where coefficient of friction values higher than 0,25 were used, it was found that the friction couple has little effect on the seismic response of the Nuclear Island."*

Therefore, the above approach is deemed appropriate for the current investigations and LTO safety case. The friction couple will be incorporated into the new 2D model.

5.2 Delamination

5.2.1 Design Intent and considerations

During the manufacturing of the Aseismic Bearings, the mild steel reinforcing plates and the neoprene layers were connected to one another through a process called vulcanization. This means the mild steel plates and neoprene have a *vulcanized bond*, or a 'hot bond'.

5.2.2 Original Design Parameters, applicable to the FRS

There are no design conditions or parameters associated with the vulcanized bond between the steel and the neoprene rubber.

The intent of the bond is to ensure the assembly remains functional as an elastomeric composite assembly.

5.2.3 Regulatory, Licencing and Analysis History

During initial testing of the Neoprene Samples Bearings (See § 3.3.1) delamination of the neoprene from the reinforcing steel plates occurred. Tests were performed to determine the extent of the delamination and the samples were subjected to cyclic loads to determine the propagation of the delamination. A report [1] which investigated the delamination stated:

> *"In order to assess whether the delamination of the sample bearings would continue under a repeated number of cycles, dynamic tests were performed on two bearing pairs with 380 half cycles being imposed on one pair and 312 half cycles on the other. In both cases the extent of delamination did not exceed 20mm (the maximum thickness of the neoprene). Delamination did, however, continue to occur in one sample along the edges parallel to the direction of loading, indicating a zone around the edge of the sample in which the strength of the bond was reduced."*

The cause of the "weakness in the bond" (i.e., delamination) of the steel and neoprene was postulated to be a result of the sawing of the sample from a larger bearing during the manufacture stage [5]. Note that the in-service bearings were not sawn.During a recent investigation conducted by KNPS however, corner specimens of a few in-situ bearings were cut for additional testing [3]. The samples were visually inspected by KNPS, and it was noted that, of the four samples, one sample's bond between the neoprene and steel plates were broken and showed no resistance in tension. This broken bond in the cut specimen is illustrated in Figure 11.

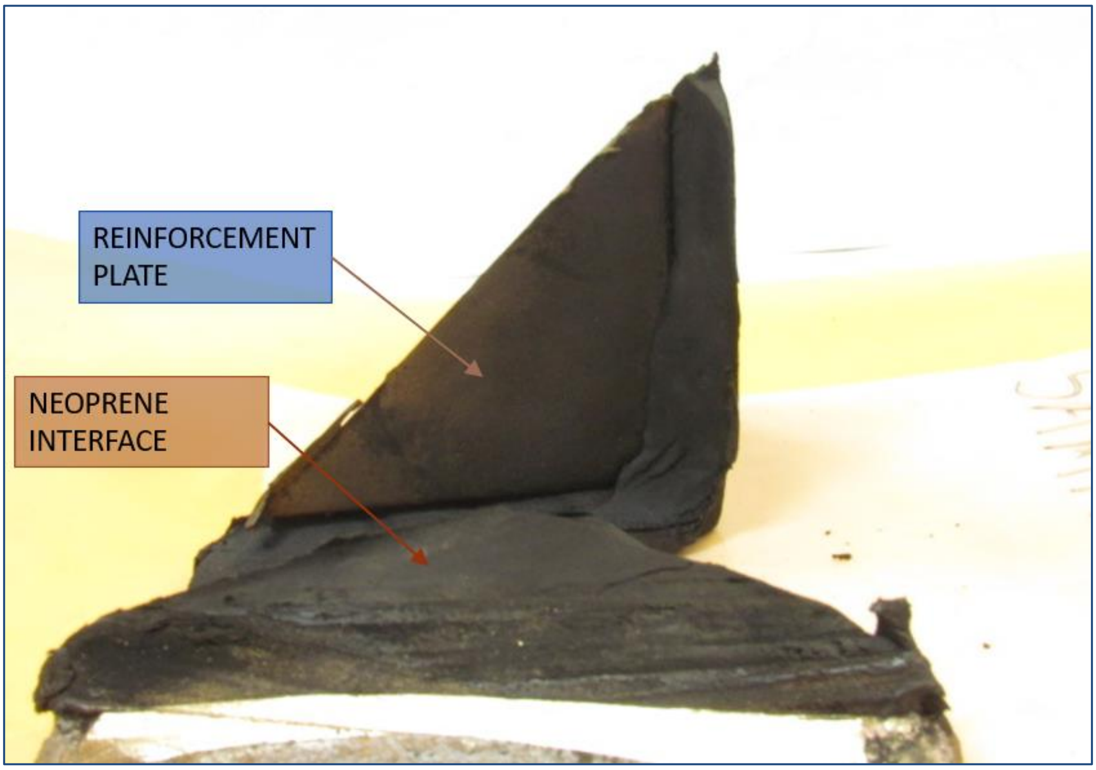

Figure 11: Broken Bond between Reinforcement Plate and Neoprene

When a bearing is compressed, the steel reinforcing plates are subjected to lateral tension while the rubber layers are compressed, except along the edges of the reinforcing plates where the rubber is in tension according to Martin (1991). These tensile forces along the edges of the reinforcing plates may be another possible cause of the break of the bond at the edge of the aseismic bearings.

It is however noted that the compression stress on the bearings varies from 1.84-8.16 MPa [5] and direct tensile resistance of the bearings is highly unlikely. This is supported by reference [5] which conducted a check on the bonding between the neoprene and the reinforcing plates:

> *It was proved that the stresses induced in the samples undergoing tests were in the majority of cases greater than those analysed for the in-situ bearings and, hence proved that the effect of a similar degree of delamination in the actual bearings would not result in failure of the bearing.*

Furthermore, due to the stress on the bearings, horizontal stress will be transferred by friction through the bearing assembly, even if the bond is completely broken throughout the surface area of the neoprene and reinforcement interface. For complete bearing failure to occur as a result of delamination, two aspects need to be met:

1. Complete loss of the bond across the entire interface area, and
2. The friction coefficient between the neoprene and the steel reinforcement plates needs to be less than 0.15.

Only once the above aspects are true, would the complete failure of a bearing due to delamination be a concern. The above conditions are considered improbable.

Redacted information:The information was provided to Eskom by the NNR. Both the NNR and EDF are third parties in terms of PAIA 37(1)a and/or b

Redacted information:The information was provided to Eskom by the NNR. Both the NNR and EDF are third parties in terms of PAIA 37(1)a and/or b

This is supported by the latest shear modulus testing report [22] (which also investigated delamination). The report performed finite element analyses of delaminated bearing and bearings with no delamination. The investigation concluded that:

Redacted information:The information was provided to Eskom by the NNR. Both the NNR and EDF are third parties in terms of PAIA 37(1)a and/or b

It is possible that delamination of the sample bearing may be noted during testing in future and these will be considered on a case-by-case bases. However, it is confirmed that delamination is not a concern for in-situ bearings and the issue is closed.

5.2.4 Negative Consequence of Degradation

The consequences of the delamination were analysed, and the investigation [5] report concluded that:

Redacted information:The information was provided to Eskom by the NNR. Both the NNR and EDF are third parties in terms of PAIA 37(1)a and/or b

EdF also closed the issue of delamination in July 1991 by conducting full scale test on Aseismic Bearings which they had removed from the bearing pedestals at Cruas.

Comparing the 1999 [1] and 2016 [22] it is noted that the respective test series did not indicate an increase in measured delamination, with the maximum and average delamination measured in 1999 being 19.5mm and 7.44mm [1] respectively, and 13.05mm and 6.15mm in 2016 [22]. Therefore, the delamination can be seen to not have changed over the time and therefore the position remains valid.

Furthermore, Martin (1991) does however indicate that a crack that extends into the interlaminar regions of a bearing, however, may reduce the fatigue life of a bearing loaded in, accelerate debonding of the adhesive from the metal plates and facilitate the corrosion of the reinforcing plates. The current monitoring programme does inspect the aseismic bearings for defects affecting the neoprene wrapper.

It is noted that, for complete bearing failure to occur as a result of delamination, two aspects need to be true:

1. Complete loss of the bond across the entire interface area, and
2. The friction coefficient between the neoprene and the steel reinforcement plates needs to be less than 0.15.

To date, no evidence that the bond between the neoprene and the steel plates has completely broken and it is highly unlikely that the friction coefficient of the two materials in contact would be less than 0.15.

It is therefore concluded there are no negative consequences due to delamination. This position is documented in the SAR [9].

5.2.5 Current Monitoring Programme

In accordance with the approved Management of License Binding Civil Monitoring Programme [6] and Basis and Scope for License Binding Civil Surveillances at KNPS [7] there are no requirements for monitoring the delamination of the Sample Bearings.

Delamination of the Sample Bearings shall be reported and monitored as part of the continuous Civil Monitoring Programme.

5.2.6 Planned Way Forward

5.2.6.1 LTO and Safety Case Requirements

The delamination of the steel and neoprene is considered a closed item, and is captured in the SAR as follows:

> Redacted information:The information was provided to Eskom by the NNR. Both the NNR and EDF are third parties in terms of PAIA 37(1)a and/or b

This position remains valid, and no further actions are required.

There are currently no delamination monitoring requirements applicable to the AMP of the Aseismic Bearings.

5.2.6.2 Re-analysis of the Nuclear Island

There are no severe consequences of the delamination, and therefore no re-analysis of the delamination phenomenon is to be performed. The issue has been sufficiently analysed in previous studies [1] & [22] and therefore will not be considered further.

5.3 Shore Hardness Measurements

As part of the Civil Management Programme [35], Shore Hardness measurements are taken on the Aseismic Bearings. The measurements are used for acceptance and trending of the condition of the Aseismic Bearings.

5.3.1 Design Intent and Considerations

The Shore Hardness measurements of the Aseismic Bearings have no direct impact on the functionality of the bearings nor any consequence on the filtering effect (floor response) of the structures located on the Nuclear Island.
Essentially, the Shore Hardness measurements act as an *indicative* material property (Bouaziz, 2020) which is used to monitor the bearings' behaviour and ageing. It adds little value from an analytical perspective and only acts as an indicator for degradation.

The design guide [29] provides no characteristic material properties for the Shore Hardness, and therefore the Shore Hardness does not influence the calculations for the Nuclear Island concrete structures. Accordingly, the Shore Hardness has no acceptance criterion [5] related to the design base of the Nuclear Island.

The Shore Hardness is measured as part of the Visual Inspection regime of the Aseismic Bearings which is referenced as a possible monitoring value in accordance with the IAEA IGALL AMP [18]. The intent of the Shore Hardness and distortion measurements is to trend the conditions of the in-situ Aseismic Bearings without removing full bearings, cutting of specimens or performing other destructive testing. The Shore Hardness and distortion measurements are indicators of any deterioration in the Aseismic Bearings' condition [5].

5.3.2 Original Design Parameters, applicable to the FRS

Shore Hardness is a material property and has no direct influence on the design of the Aseismic Bearings; furthermore, distortion measurements are utilized for monitoring degradation and deformation, and changes in both Shore hardness and Distortion of the neoprene do not impact the function of the Aseismic Bearings. Therefore, there are no design criteria for Shore hardness and Distortion in the design of Aseismic Bearings.

There are however measurement for the original Shore Hardness, which are stipulated in the SAR [9] and is provided below:

Shore Hardness = 63 to 70.

There are however no acceptance criteria associated with the Shore Hardness, i.e., if the values are exceeded, there are no consequences to the performance of the Aseismic Bearings, rather the Shore Hardness is used as an indicative material property.

5.3.3 Regulatory, Licencing and Analysis History

For the measuring of the Shore Hardness, a sample set of in-situ bearings were selected (i.e., not all bearings are tested). The below results and discussion are therefore applicable to the sample set, which is considered representative of the Aseismic Bearings.

Additionally, during the past submission of the monitoring reports, from as early as 1987, there has been concerns raised about the subjectivity of the monitoring of the Aseismic Bearings, including the repeatability of the Shore Hardness and distortion measurements. The issue of subjectivity with respect to the Shore Hardness measurements remains a contentious issue, although the subjectiveness has been estimated to be in the vicinity of ± 3.56% [24].

Redacted information:The information was provided to Eskom by the NNR. Both the NNR and EDF are third parties in terms of PAIA 37(1)a and/or b

5.3.3.1 Shore Hardness

The Shore Hardness measurements are taken on a sample set of in-situ bearings. The original sample (No. 24) set was increased in 2004 (No. 32) and again in 2021 (No. 48). The location of the bearings which are used as the reference for the shore hardness is illustrated in Appendix C. The location of the reference bearings was selected to monitor the hardness of the bearings directly underneath the reactor, as well as bearings on the circumference of the containment buildings. These bearing pedestals only have three bearings and therefore a greater load.

The results of all the measurements taken from 1978 through to 2021 is illustrated in Figure 12. The tests are repeated on the same bearings for each test interval.

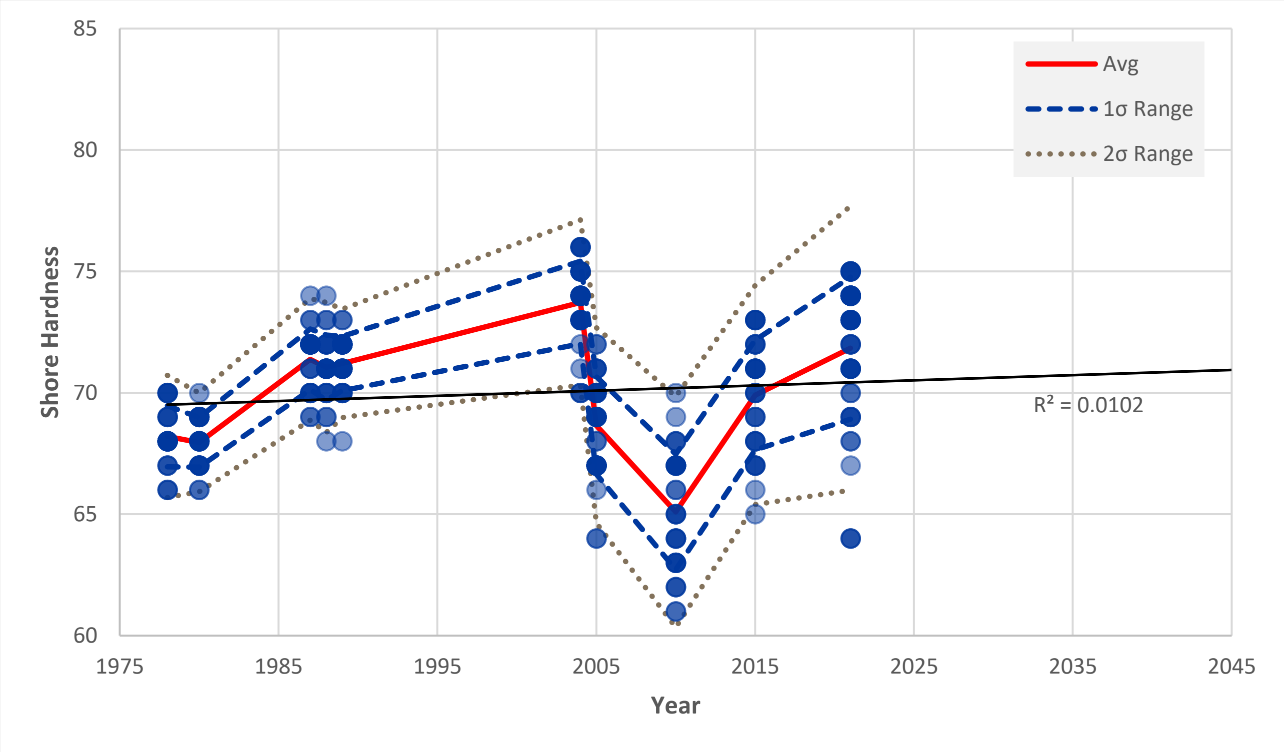

Figure 12: Shore Hardness Values from Monitoring Programme

Note the linear trend line coefficient of determination, denoted that the correlation (R^2) is low. The trend is also relatively flat and only indicates a slow hardening of the neoprene wrapping with only a slight hardening effect over the 60-year period when extrapolating the trend.

It is further noted that there is a large ‘dip’ in the values from 2004 to 2005 (the average is lower by a Shore Hardness value of 5, which is significant for such a short period). As mentioned there has been concerns in the past about the subjectivity of the measurements of the Shore Hardness (and others). Additionally, this ‘dip’ may be due to a change in personnel, equipment, or calibration.

A correction was therefore applied on the Shore Hardness values of post 2004, by adjusting the Shore Hardness values upward by the difference in the 2004 and 2005 averages (i.e., +5). The result is indicated in Figure 13.

Note the coefficient of determination for the data improves from **$R^2 = 0.0102$** (from Figure 12) to **$R^2 = 0.502$** (from Figure 13). The trend also then indicates that the Shore Hardness is on an upward trend (which is more consistent with the expected behaviour of neoprene). Therefore, the adjusted Figure 13 is more likely to be representative of the actual Shore Hardness values of the wrapping.

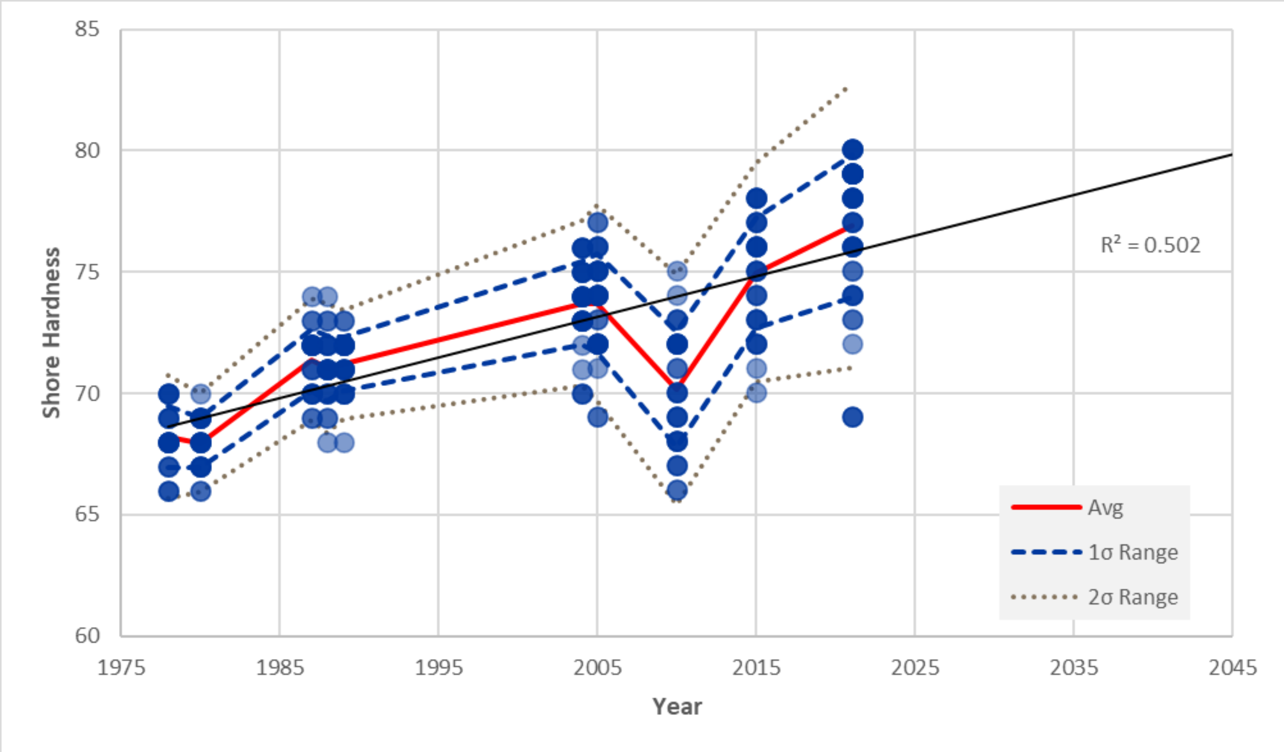

Figure 13: Adjusted Shore Hardness Values from Monitoring Programme

Again, it is noted that there is no acceptance criterion for the Shore Hardness values.

Furthermore, it is noted that, according to the latest inspection report [24], the Shore Hardness measurements have a repeatability error of ± 3.56%. This should be kept in-mind when analysing the results.

It is emphasised that the Shore Hardness measures are performed on the wrapping of the in-situ bearing, and not on the internal neoprene layers. The wrapping is expected to undergo hardening and Figure 13 may be more representative of the actual trend. This is in line with international experience and EPRI research results where only the external surface degrades with time due to atmospheric contact, but the interior remains unaffected for very long periods. A plan has been developed to obtain a suitable specimen from the in-situ bearings to measure and compare the internal neoprene hardness.

This is supported by Celina (2013) which states that "most elastomers harden as part of oxidative aging which facilitates stress cracking and loss of desirable properties." Celina (2013) continues to show the internal portion of a particular geometry experiences "inert degradation in the centre and oxidatively dominated thermal degradation toward the exterior". The Celina (2013) analysis predictions is illustrated below in Figure 14.

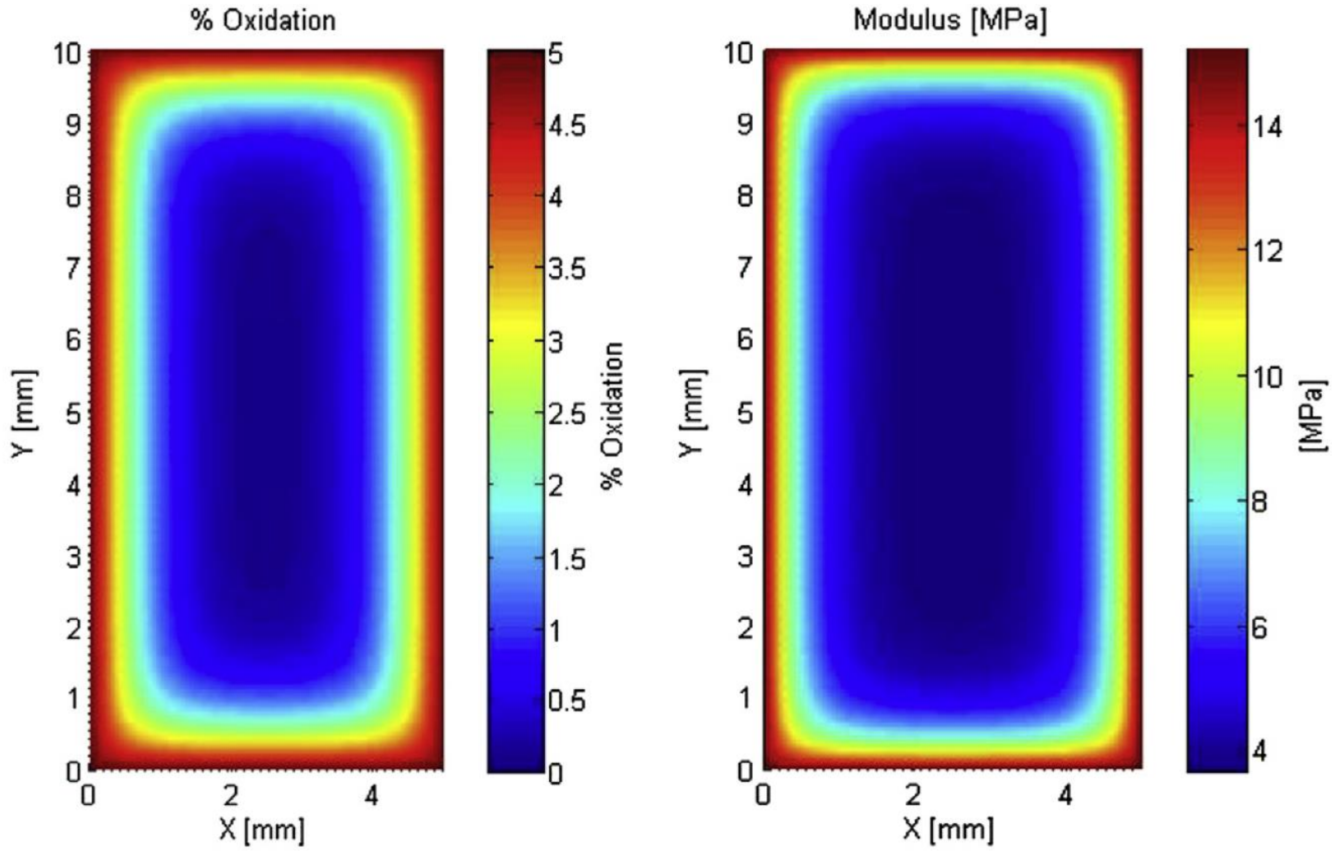

Figure 14: Diffusion limited oxidation and its predicted correlation with localized modulus for a neoprene elastomer[6]

Martin (1991) [36] indicates that ozone attack leads to an increase in crosslinking density and eventually rubber embrittlement and cracking, especially when the material is under tension however states that several researched concluded that bearings should be able to withstand 50 years of exposure to ozone without major deterioration. Martin supports Celina (2013) and concludes that "ozone attacks and cracks the outer protective cover of a bearing, but this degradation should only affect the appearance of a bearing, and not its structural performance."

5.3.3.2 Internal Shore Hardness Measurements

As noted in § 5.2.3, during 2022 an investigation was conducted by KNPS where corner specimens of the in-situ bearings were cut for additional testing [3]. The samples were visually inspected by KNPS, and Shore Hardness measurements were taken of the external (wrapping) part of the specimens and the internal neoprene (which is protected by the external neoprene wrapping and sandwiched between the reinforcement steel plates).
The internal and external Shore Hardness measurements for the in-situ specimens cut from the bearings are illustrated in Figure 15.

[6] Diffusion limited oxidation and its predicted correlation with localized modulus for a neoprene elastomer specimen under highly accelerated thermal aging conditions of 15 days at 125°C. It shows the absence of oxidative damage and therefore soft material in the center. (Celina, 2013)

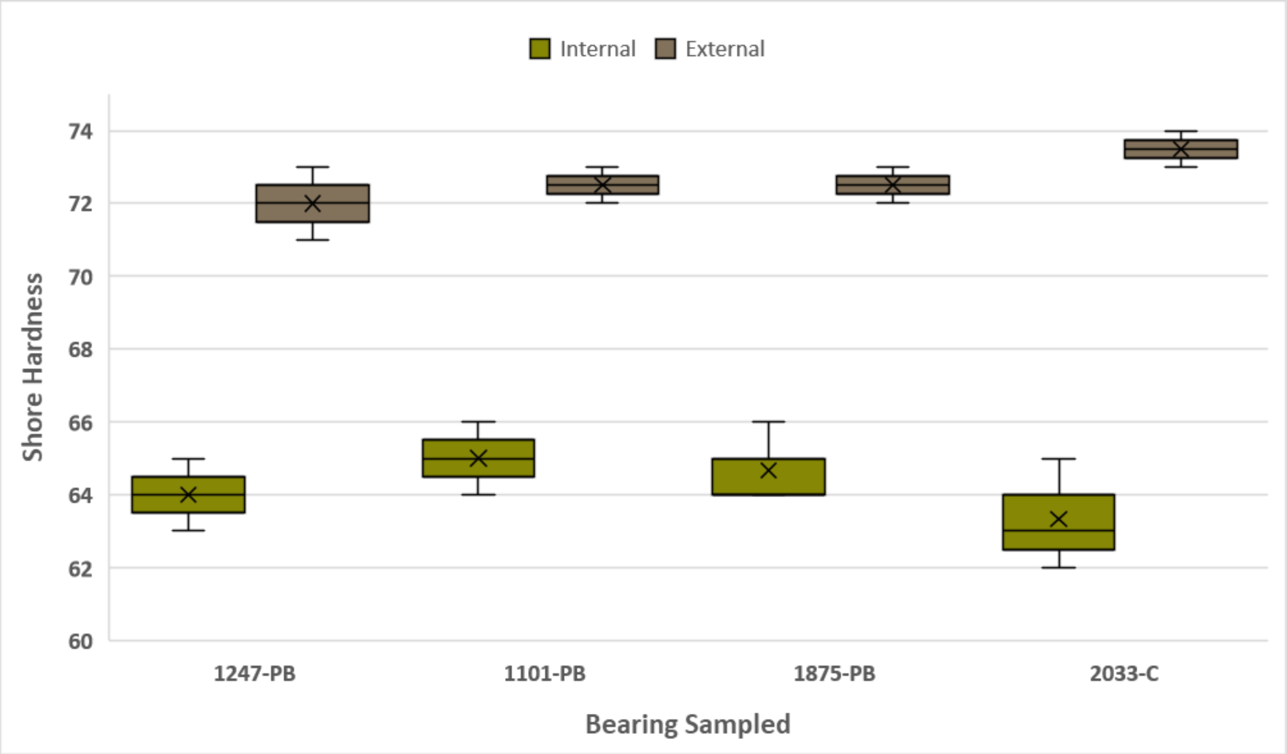

Figure 15: Internal vs. External Shore Hardness Measurements

As expected, the external wrapping is experiencing a greater rate of degradation, as it is exposed to the oxygen in the Aseismic Vault. The internal neoprene is still well within the initial range of 63-70 and on average had a Shore Hardness of 8.4 lower than the external neoprene wrapping.

5.3.4 This supports the conclusion that the internal neoprene undergoes minimal degradation because it is protected by the neoprene wrapper.Negative Consequence of Degradation

There are no negative consequences of the potential change in external Shore Hardness on the Nuclear Island. The conclusion is made on the premise that the external Shore Hardness is an indicative material property and will not influence the design intent of the Aseismic Bearings, and the internal neoprene's Shore Hardness was seen to be unchanged. Furthermore, as mentioned, the Shore Hardness is an indicative material property and has no effect on the response of the Nuclear Island.

By trending the results of the Shore Hardness and extrapolating to 2045, the Shore Hardness of the wrapping may reach 80, and it is again reiterated that there are no acceptance criteria.

Lastly, it is noted that the internal neoprene layers remain unaffected by the effects of the primary degradation mechanism (oxidation) as it is protected.

5.3.5 Current Monitoring Programme and Acceptance Criteria

In accordance with the approved Management of License Binding Civil Monitoring Programme [6] and Basis and Scope for License Binding Civil Surveillances at KNPS [7] the Shore Hardness are performed during the inspections and surveillances on in-situ Aseismic Bearings.

- Shore hardness tests shall be performed to measures the hardening of the neoprene layers. There is no acceptance criterion, and the measurements are taken as indicative material properties.

5.3.6 Planned Way Forward

5.3.6.1 LTO and Safety Case Requirements

There are currently no plans to change the Current Monitoring Programme with respect to the Shore Hardness.

It is highlighted that KNPS is continuously monitoring the condition of the Aseismic Bearings and as part of continuous improvement activities, KNPS has initiated additional tests that will be performed on several material properties. Should the additional testing illustrate that the Monitoring Programme requires a Revision, the Responsible Engineer shall investigate the results and consider the revision accordingly as specified in [7].

It is however recommended that the Shore Hardness test be investigated and scrutinized to determine the effectiveness of the testing and the lack of an acceptance criteria. This investigation should consider the following aspects:

- The effectiveness of measuring the Shore Hardness of the wrapping,
- The correlation (if any) in the Shore Hardness of the wrapping and the internal neoprene layers,
- Alternative testing methods, to monitor the internal Shore Hardness, or an equivalent material property, that can be used to replace the intent of the Shore Hardness, i.e., "keep track of the conditions of the in-situ Aseismic Bearings",
- Acceptance criteria values, for either the Shore Hardness tests, or an alternative test method to monitor and accept the internal neoprene, as opposed to the wrapping.

Alternatively, if suitable replacement measurements are implemented, the Shore Hardness measurements can be removed from the licence basis accordingly.

5.3.6.2 Re-analysis of the Nuclear Island

The Shore Hardness does not influence the performance or functionality of the Aseismic Bearings and therefore shall not be considered for re-analysis.

5.4 Distortion Measurements

As with the Shore Hardness Measurements per the Civil Management Programme [35], Distortion measurements are taken on the Aseismic Bearings. The measurements are used for acceptance and trending of the condition of the Aseismic Bearings.

The location of the bearings which are used as the reference for the distortion measurement is illustrated in Appendix C. The location of the reference bearings was selected to monitor the distortion of the bearings that would represent the global behaviour of the upper raft, the distortion has however been minimal, and no trending has been performed. These bearing pedestals only have three bearings and therefore a greater load.

The distortion measurements are measured on the same 22 bearings during each testing interval and the east-west as well as the north-south distortion is measured. The results and trending presented in Figure 16 below therefore consider all 22 bearings.

5.4.1 Design Intent and Considerations

There are no design considerations associated with the Distortion Measurements. The measurements are monitored, as with the Shore Hardness Measurements, as indicative measurements.

5.4.2 Original Design Parameters, applicable to the FRS

The Distortion measurements have no "original values" although it can be assumed that they were installed vertical, which implies the distortion is 0mm. The Distortion measurements do however have an acceptance criterion (or limit). The limit is noted in the SAR as 63.42° [9]. This translates to a displacement acceptance criterion for distortion of any bearings < **50 mm**.

5.4.3 Regulatory, Licencing and Analysis History

For the measuring Distortion, a sample set of in-situ bearings were selected (i.e., not all bearings are tested). The below results and discussion are therefore applicable to the sample set, which is considered representative of the Aseismic Bearings.

5.4.3.1 Distortion Measurements

The Average Distortion Measurements for the Aseismic Bearings from 1978 to 2021 is illustrated in Figure 16. The latest inspection report [24] notes that:

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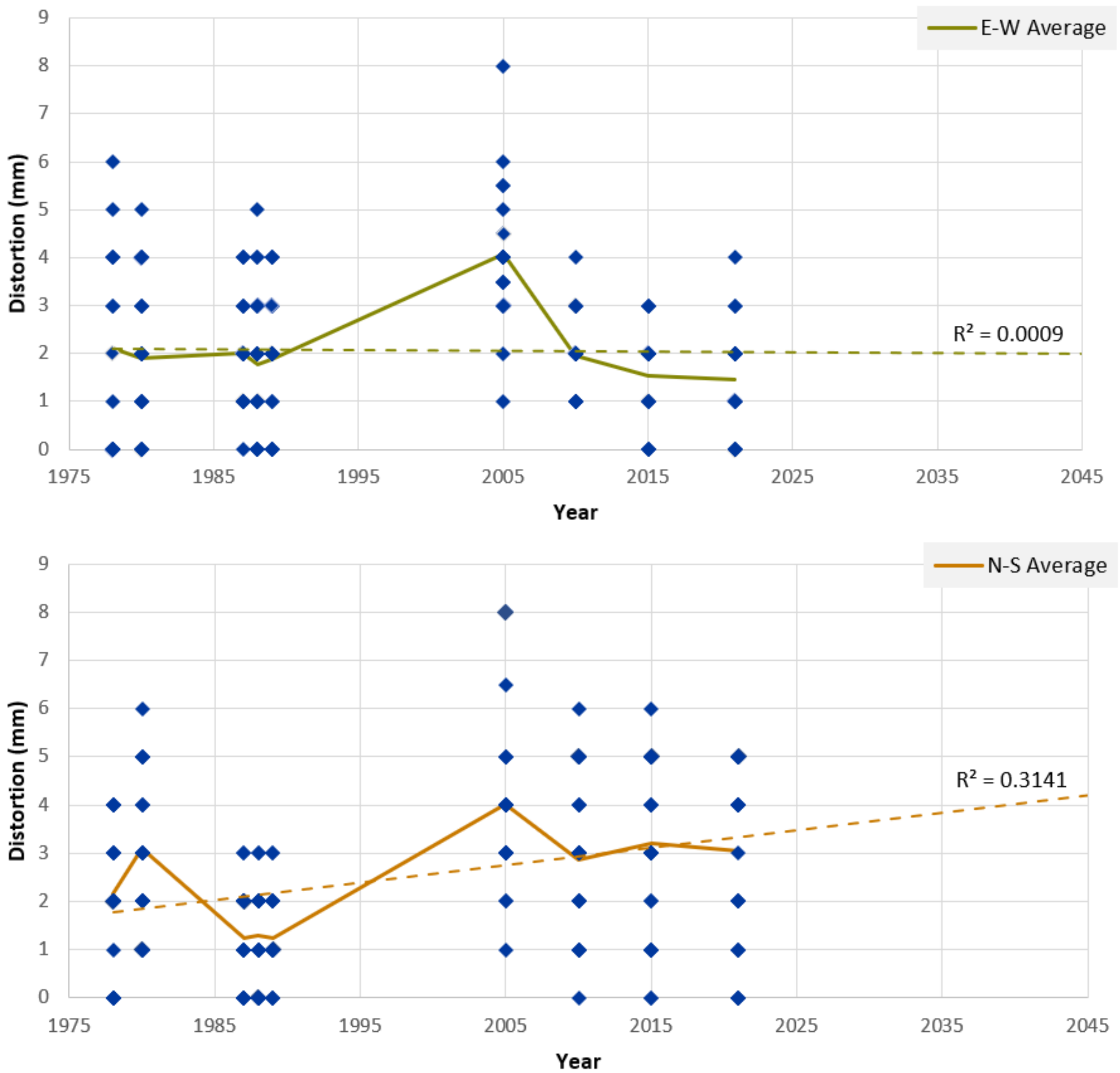

Figure 16: Average Distortion measurements trend for the Aseismic Bearings

An attempt was made to determine a trend for the data, however there was poor correlation of the data. Therefore, it is recommended that the distortion measurements be extended to obtain more data to develop further trends, however, it is noted that the distortion is well below the limit of 50 mm with the average distortion 20 times below the acceptance criterion. The recommendation is therefore needed to better understand the trend of the distortion, if any exists.

Additionally, the trend is relatively flat and is not expected to exceed the acceptance criterion within the 60-year LTO period.

5.4.4 Negative Consequence of Degradation

There are no negative consequences of the potential change in the Distortion Measurements on the Nuclear Island.

The trending of the Distortion Measurements remains relatively flat and well within the acceptance criteria.

5.4.5 Current Monitoring Programme and Acceptance Criteria

In accordance with the approved Management of License Binding Civil Monitoring Programme [6] and Basis and Scope for License Binding Civil Surveillances at KNPS [7] the Distortion Checks are performed during the inspections and surveillances on in-situ Aseismic Bearings.

5.4.6 The distortion checks shall be performed to verify that distortion of the bearings is below the permissible limit of 50mm.Planned Way Forward

5.4.6.1 LTO and Safety Case Requirements

There are currently no plans to change the Current Monitoring Programme with respect to the Distortion Checks.

It is highlighted that KNPS is continuously monitoring the condition of the Aseismic Bearings and as part of continuous improvement activities, KNPS has initiated additional tests that will be performed on several material properties. Should the additional testing illustrate that the Monitoring Programme requires a Revision, the Responsible Engineer shall investigate the results and consider the revision accordingly as specified in [7].

5.4.6.2 Re-analysis of the Nuclear Island

The Shore Hardness and Distortion does not influence the performance or functionality of the Aseismic Bearings and therefore shall not be considered for re-analysis.

5.5 Shear Modulus

5.5.1 Design Intent and considerations

To best illustrate the significance of the Shear Modulus; and how the Shear Modulus influences the fundamental aspects of the Aseismic Bearings, the following basic equations of dynamic structural analysis are highlighted:

Equation 1: Horizontal Natural Frequency

$$f_H = \frac{1}{2\pi} \cdot \sqrt{{G_d \cdot g}/{\sigma \cdot T}}$$

Equation 2: Horizontal Stiffness

$$K_H = G_d \cdot \frac{a \cdot b}{T}$$

Equation 3: Displacement

$$\delta = \frac{2t^3 \cdot \sigma}{a^2 \cdot G_d}$$

Where:

$\boldsymbol{f_H}$ = Horizontal resonant frequency

$\boldsymbol{K_H}$ = Horizontal Stiffness

$\boldsymbol{\delta}$ = Deflection of each elastomer layer

$\boldsymbol{G_d}$ =Dynamic Shear Modulus

$\boldsymbol{a, b, t, T}$ = Dimensional and physical properties.

It can be seen from the equations (by inspection) that an increase in the Shear Modulus ($\boldsymbol{G_d}$), Equation 1 and Equation 2 will lead to an increase in both the horizontal resonant frequency ($\boldsymbol{f_H}$) and horizontal stiffness ($\boldsymbol{K_H}$), and a decrease in the deflection ($\boldsymbol{\delta}$) by Equation 3. This is also true (albeit through a different set of equations) for the vertical resonant frequency, -stiffness, and -deflection.

The change in the Shear Modulus therefore directly influences the Floor Response Spectra (FRS) of the Nuclear Island structures.

5.5.2 Original Design Parameters, applicable to the FRS

The SAR [9] provides the following properties for the neoprene shear modulus:

- Static Shear Modulus of the bearings = 0.95 MPa ± 15%
- Dynamic Shear Modulus of the bearings = 1.30 MPa ± 15%

The ±15% acceptance criterion is slightly more stringent than the recommendation in NUREG 7253 [40] which provides an acceptance criterion of ± 20%. The NUREG continues and states that:

5.5.3 Regulatory, Licencing and Analysis History

The first test series of the Shear Modulus tests were performed on neoprene samples bearing rigs A and B in 1991 by the The result for the Static Shear Modulus were found to be within the specification [1].

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The second test series were performed by in Pretoria using neoprene sample bearing rigs C and D. The results of the Static Shear Modulus tests all fell within the acceptance range of 0.8075MPa to 1.0925MPa. Similarly, the results of the Dynamic Shear Modulus tests all fell within the acceptance range of 1.105MPa to 1.495MPa.

The final test series for the 40-year life of plant was performed by a using neoprene sample bearings rigs A (previously tested) and E

The Static Shear Modulus results indicated 2 bearing pairs that fell below the acceptance criteria. Hence, 2 of the 18 test results or 11% of the samples failed to meet the acceptance criteria, as illustrated in Figure 17, where the two lower results are clearly visible. Although the two 'failed' tests results clearly seem to be outliers, this necessitated that the Dynamic Shear Modulus tests be performed on all the bearing samples.

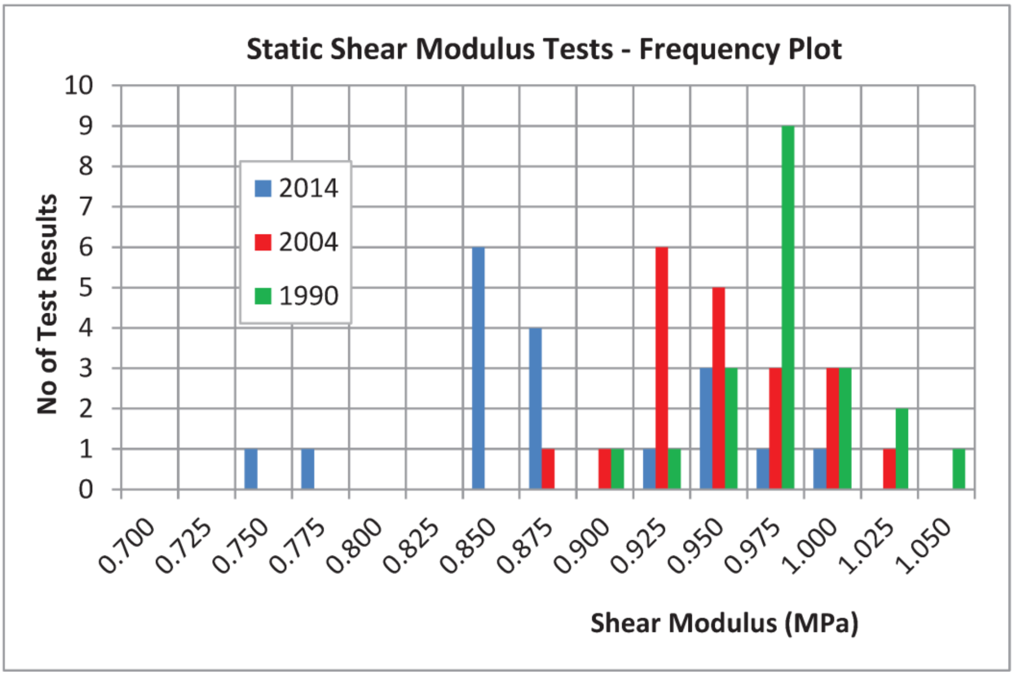

Figure 17: Frequency Plot of Static Shear Modulus Results for the last 3 Test Series [22]

The final Dynamic Shear Modulus results indicated the same 2 bearing pairs having Dynamic Moduli below the acceptance criteria. Hence, 2 of the 18 test results or 11% of the samples failed to meet the acceptance criteria [22]. The average static shear modulus as observed from the last 3 test series appears to be dropping over time whilst the average dynamic shear modulus as observed from the last 2 test series appears to be stable over time. The impact of a reduction in the dynamic shear modulus is a reduction in the horizontal natural frequency of the Nuclear Island and a corresponding reduction in seismic response (K22321N).

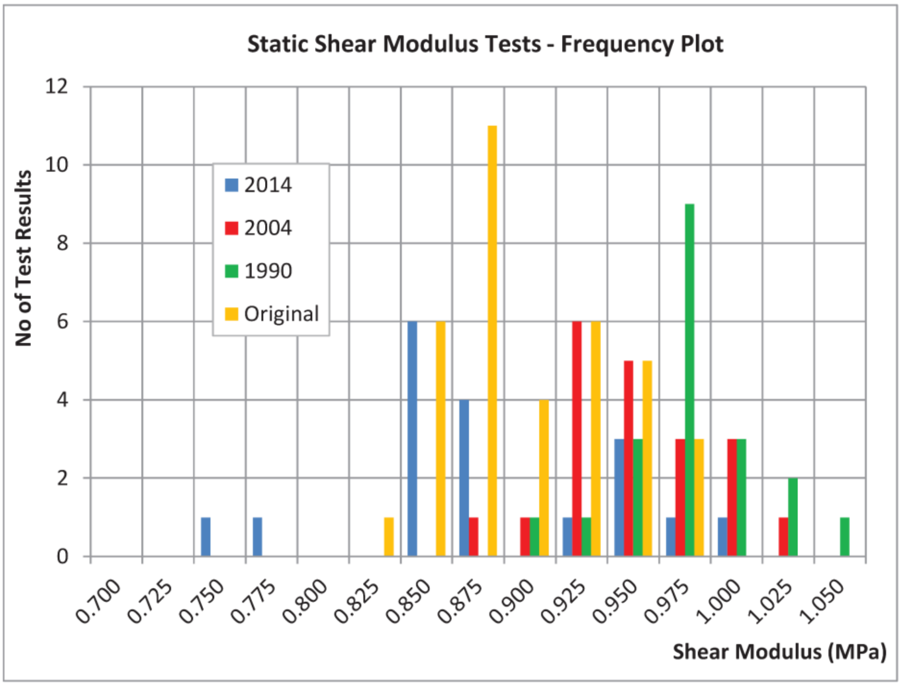

Figure 18: Frequency Plot of Static Shear Modulus for the last 3 Test Series and the Original Test Data [22]

A summary of all the bearings' status (i.e., compliant vs. non-compliant) is shown in Table 4.

Table 4: Summary of the static and dynamic shear modulus test results

Bearing pair	Static shear modulus compliance [0.95 MPa ± 15%]	Average dynamic shear modulus compliance [1.3 MPa ± 15%]
A2-A6	Non-compliant (Tear in A2)	Not tested as bearing pair during dynamic tests
A6-A10	Not tested as bearing pair during static tests	Compliant
A3-A7	Compliant	Compliant
A4-A8	Compliant	Compliant
A5-A9	Compliant	Compliant
A7-A10	Compliant	Not tested as bearing pair during dynamic tests
E1-E6	Compliant	Compliant
E2-E7	Compliant	Compliant
E3-E8	Compliant	Compliant
E4-E5	Compliant	Compliant
E9-E10	Compliant (Retest with sufficient contact)	Compliant
A8-A10	Compliant	Compliant
A4-A6	Non-compliant	Compliant
A3-A5	Compliant	Compliant
A7-A9	Compliant	Compliant
E1-E10	Compliant (Retest with sufficient contact)	Non-compliant
E2-E9	Compliant	Compliant
E3-E7	Non-compliant	Non-compliant
E4-E8	Compliant	Compliant
E5-E6	Compliant	Compliant

It is noted that the majority of the samples were compliant.

It is also reiterated that the tests were performed on sample bearings, and not the actual in-situ bearings. There were some challenges that the contractor experienced while the tests were performed. The possibility that:

a. the contractor did not adequately perform the tests,

b. the issues experienced led to invalid results, or

c. the issue of delamination of the sample bearings influenced the results significantly

cannot be excluded.

It should however be remembered that the tests are performed on sample bearings, that the results are indicative and that they are more likely than not in a worse condition than the in-situ bearings due to the lack of a protective sheet and protective wrapping.

Notwithstanding, a decrease in shear modulus would imply a decrease in the stiffness and subsequently a lower resonant frequency and peak acceleration values in the FRS.

Alternatively, an increase in shear modulus would have more negative consequences and the effect would reduce the seismic margin, albeit slightly. The SAR [9] notes that:

5.5.4

Redacted information:the information is based on a preliminary 2D model produced by a third party which has not been accepted by Eskom and further analysis is ongoing. in terms of PAIA 37(1)a and/or b

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Redacted information:the information is based on a preliminary 2D model produced by a third party which has not been accepted by Eskom and further analysis is ongoing. in terms of PAIA 37(1)a and/or b

5.5.5 Current Monitoring Programme

In conformance with the requirements of the Nuclear Licence (NIL-1), a series of tests and visual inspections are required to be performed on the in-situ Aseismic Bearings and sample bearings to demonstrate that specific parameters are still within the design basis. These tests and inspections are carried out in accordance with Eskom procedure KWU-DE-020 [35]. The frequency at which each test is performed varies according to the summarised schedule given in Table 2.

Table 5: Frequency of Aseismic bearing inspection and testing activities

Inspection	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Visual Inspection	6 months			1 year			5 years																		5 years					
Distortion Measurement	1 year						5 years																		5 years					
Shore Hardness	1 year						5 years																		5 years					
Rig Prestress	1 year			3 years																	1 year				1 year					
Shear Modulus	5 years											10 years													10 years					
Friction Couple	5 years											10 years						discontinued												
Corrosion Couple	5 years																													

All the testing has been completed for the 40-year plant life and the results of the Shear Modulus Testing are shown in Table 6.

Table 6: Horizontal Natural frequency of the Nuclear Island

	Original Average	Specification			2004 Test Average	2014 Test Average
		Lower	Average	Upper		
G_{dyn} (MPa)	1.29	1.11	1.30	1.50	1.19	1.22
K_h (MN/m)	14 428	12 359	14 540	16 720	13 309	13 645
f_h (Hz)	0.98	0.91	0.98	1.05	0.94	0.95

The measured results indicate there was very little to no change in the stiffness (and subsequently Shear Modulus) of the neoprene and that the current parameters are still within their design basis. This contradicts the operational experience from the EdF Aseismic Bearings' sister plant Cruas which found that a 40% increase in stiffness is expected over a 40-year life span and is the basis for the concerns surrounding the latest test series.

It is however highlighted and reiterated that, even at the (measured) reduced or (possible) increased shear modulus, the effect on the Nuclear Island's FRS is negligible. Accordingly, the change in shear modulus is not considered detrimental.

It is however noted that the testing programme was extended in 2014 to include the testing of 10 samples which were previously tested. A detailed analysis of all the results (testing intervals in 1991, 2004 and 2014), including the trending of the results, are presented below:

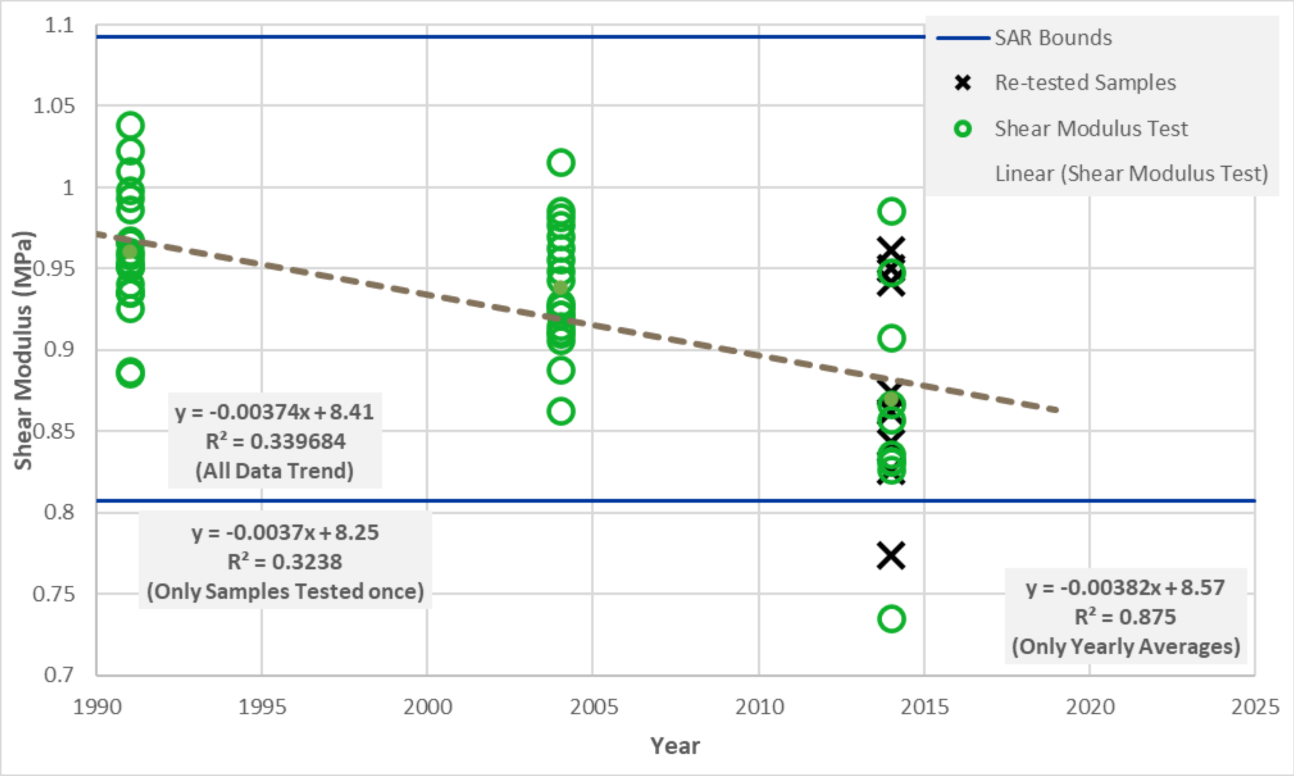

Figure 22: All Static Shear Modulus Results

A linear trend provides a relatively poor correlation (R^2=0.3395) and an estimated rate of change of **-0.003736 MPa/year** when all the data is considered, including the re-tested samples and **-0.003766 MPa/year** when only the samples are considered which were tested once. Considering only the averages of each year (i.e., three data points), the rate of degradation is similar at **-0.003819 MPa/year**.

Furthermore, the samples from test rig 'A' that were tested in 1991 and re-tested in 2014 were considered separately. Note the samples are tested in pairs, and therefore the shear per sample is taken as the total shear modulus divided by the two samples. According to the test procedure, the samples are then placed in different pair groupings and re-tested. The shear modulus of the sample was then calculated as the average of the two different tests. This was necessary to be able to compare the sample degradation, per sample, between 1991 and 2014.

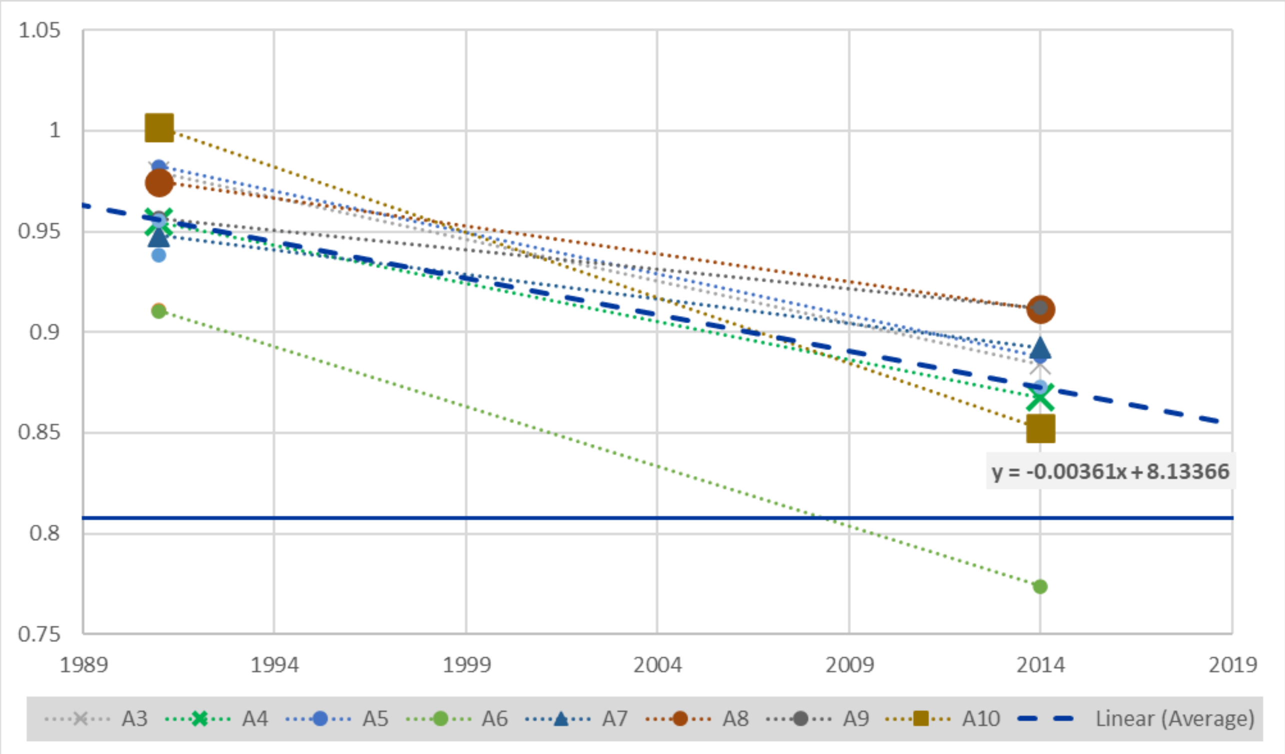

Figure 23: Static Shear Modulus Results of Samples tested in 1991 and re-tested in 2014

It is noted that Sample A6 falls below the criterion. By inspection it is seen that Sample A6 had a lower shear modulus compared to the other samples from 1991.

The results of the above scenarios are summarized below for ease of reference:

Table 7: Summary of Trends of Different Sample Considerations

Scenario	R^2	Rate of Change (MPa/Year)	Difference to All Data (%)
All Samples, All Data	0.340	-0.00374	0.00%
All Samples (Excluding Re-Tested Samples)	0.324	-0.00377	0.80%
Only Averages Considered	0.875	-0.00382	2.12%
Only Re-tested Samples (1991 & 2014)	1	-0.00361	3.54%

It is noted that the trend of the re-tested samples conservatively envelope the degradation of the samples that have only been tested once. It may therefore be practical to continue re-testing used samples once all the samples have been utilized at least once.

5.5.6 Planned Way Forward (Shear Modulus)

The planned way forward consists of three main aspects: (1) a review of the current ISI testing procedures by the Responsible Engineer; (2) the development of a new validated 2D stick model to reproduce the original Dames & Moore seismic analysis and (3) determining the Shear Modulus of the in-situ bearings as committed to in the safety case [2].

The new model will be developed in accordance with the required regulatory directives and guides and used for future analysis as required, for example to analyse the new seismic hazard being developed as part of the SSHAC studies.

The following is therefore based on the aforementioned aspects:

5.5.6.1 LTO and Safety Case Requirements

The current AMP and results indicate that there are no major departures from the Shear Modulus acceptance criteria and that the re-analysed FRS showed little change in the response due to the change in Shear Modulus values and that the design base of KNPS is not being challenged. This is supported by reports [1] & [4], the Koeberg SAR [9] and as documented in this report.

Therefore, there are no actual additional requirements for LTO or the associated Safety Case, as the design basis is not being challenged. The planned additional testing is aimed at confirming the shear modulus of the bearings; however, it is noted that as the design basis is not being challenged, the testing is planned to investigate the validity of the concerns surrounding the shear modulus of the bearings and therefore this is not a pre-requisite for LTO.

Continuous monitoring of the Aseismic Bearings' Shear Modulus will be performed in accordance with the License Binding Civil Surveillances at Koeberg Nuclear Power Station [7] and in accordance with the inspection and monitoring procedures [33], [34] & [35].

It is however recommended that a desktop study be performed to investigate the possibility of determining the Shear Modulus of the in-situ bearings using non-destructive test methods.

Additionally, the planned additional testing may indicate that the current KNPS inspection regime has shortcomings, and thereafter the AMP of the Aseismic Bearings may be revised.

5.5.6.2 Re-analysis of the Nuclear Island

Additional testing was initiated to determine the Shear Modulus of the in-situ bearings. Therefore, the additional testing will be used to validate or contradict the current data.

Where the additional testing contradicts the data obtained through the KNPS inspection programme, the contradiction will be analysed through a new 2D stick model, following due KNPS and regulatory processes.

KNPS is in the process to produce a new 2D stick model of the Nuclear Island, in accordance with the original analysis methods. This model is aimed to analyse the Nuclear Island with the results of SSHAC study currently underway; it could be used to analyse uncertainties that may be discovered through the additional testing.

Such an analysis, if required, will be in-line with NUREG 7253 [40] which states:

And IAEA IGALL AMP [18]:

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6. Visual Inspection Results (Trending)

6.1 Corrosion Defects

Although the friction coefficient monitoring has been removed from the license and the design base, the corrosion of the stainless-steel plates is still being inspected and monitored in accordance with the Basis and Scope for License Binding Civil Surveillances at Koeberg Nuclear Power Station [7], although it technically adds no value.

Notwithstanding, the corrosion trend according to the latest inspection report [24] is provided below in Figure 24. Note that the Inspectors started including defects on the side of the stainless-steel plates circa 2010 in the *Class 2* defects. Therefore, the *Class 2* corrosion defects are separated from circa 2007 to illustrate the effect the corrosion on the side of the stainless-steel plates has on the trending.

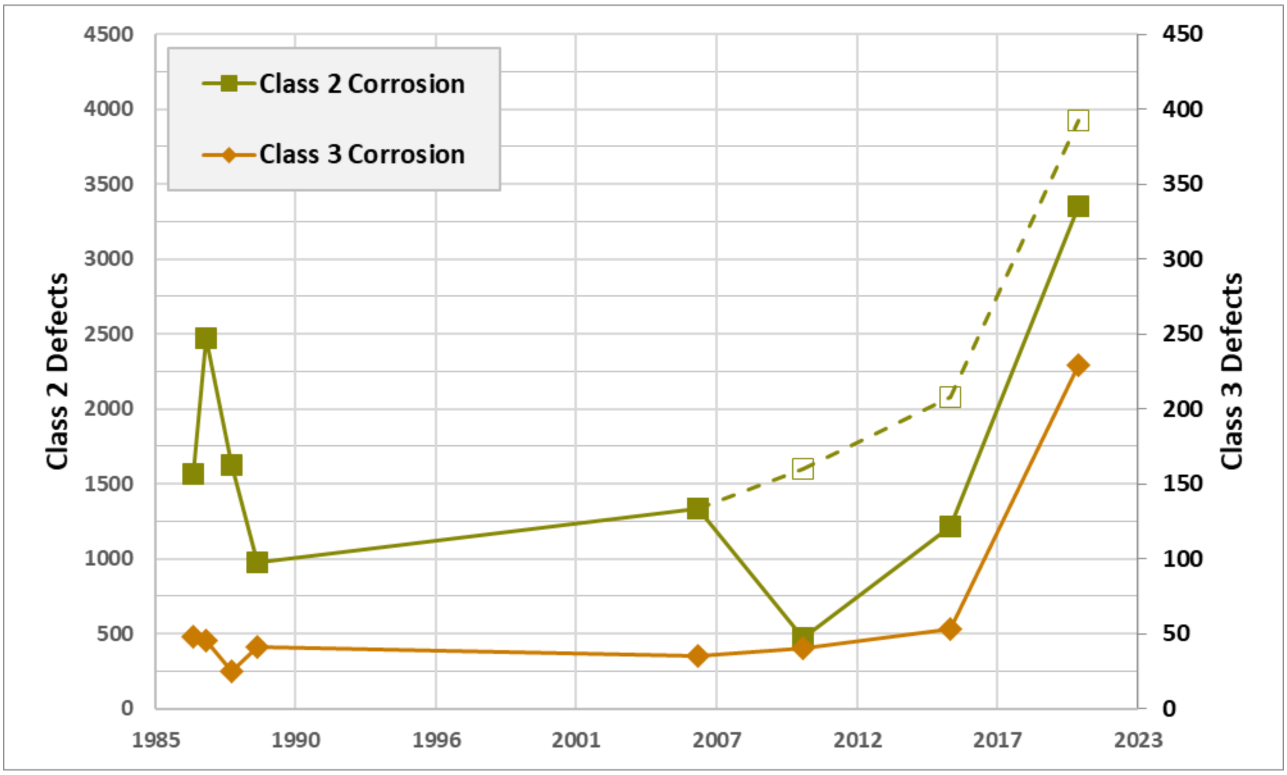


Figure 24: Corrosion Defects Trending

The reason for the upward trend is not yet understood. It however postulated in the inspection report [24] that the increase may be "related to the presence of excessive amounts of water in the aseismic vault caused by the sumps that are not frequently pumped out, flooding from system water, and rain water ingress

It is therefore recommended that this hypothesis be investigated and documented, although it is noted that there is no consequence to the Aseismic Bearings, their performance, or the design basis of the Nuclear Island.

It is also recommended that the inspection report be updated so that inspectors be accompanied by a cleaning team which will remove superficial corrosion as part of the inspection periodically. This will remove the need and limit the time between inspection and cleaning operations.

6.2 Other Defects

Other defects are monitored as part of the License Binding Civil Surveillances at Koeberg Nuclear Power Station [7]. These include defects on the bearings and defects on the grease seals. The trend of the defects is shown in Figure 25.

Note that the grease seals have been periodically replaced, and therefore can be reduced to zero at times.

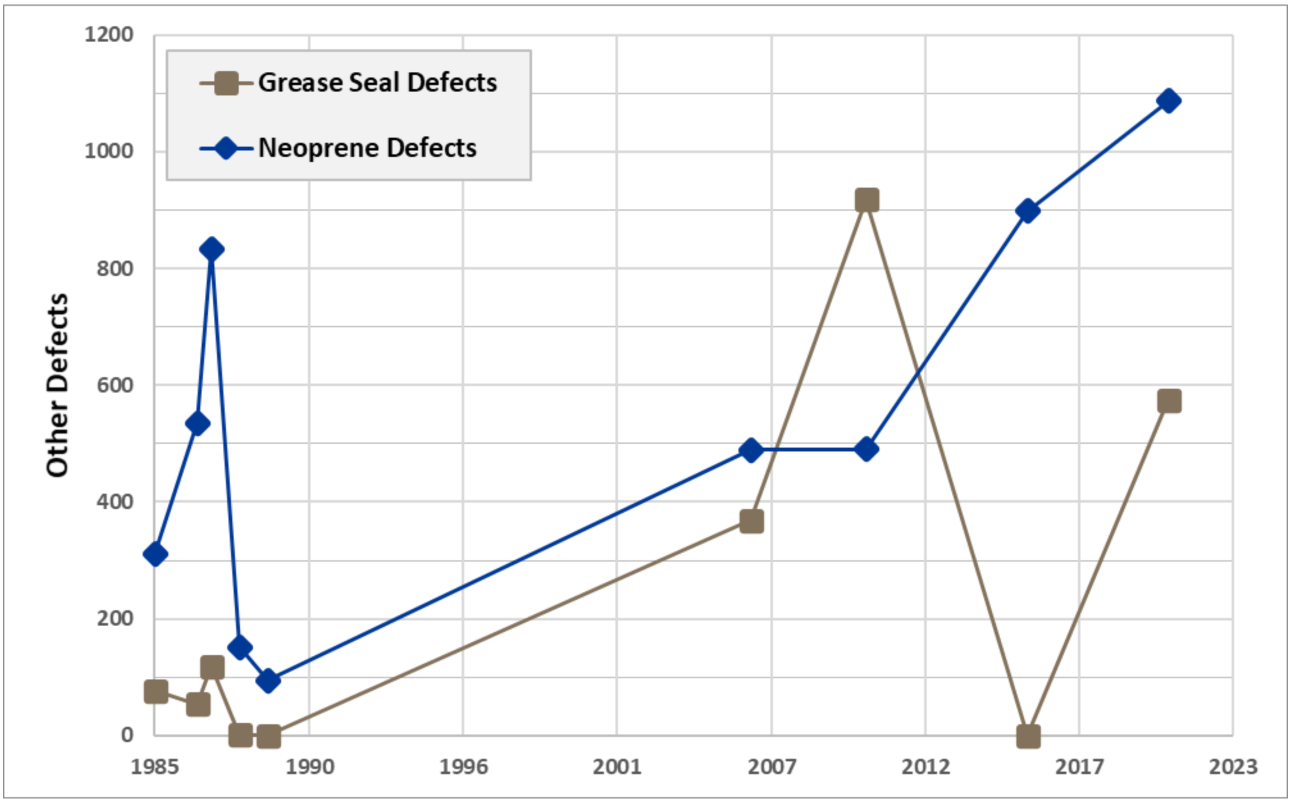


Figure 25: Other Defects Trending

It is also recommended that the inspection report be updated so that inspectors be accompanied by a re-greasing team which will reinstate the grease seals as part of the inspection periodically. This will remove the need and limit the time between inspection and re-greasing operations. It is however noted that the grease seals have no impact on the Aseismic Bearings, their performance, or the design basis of the Nuclear Island.

7. Visual Inspection and Monitoring Programme

7.1 Current KNPS ISI Programme

The ISI programme implemented at KNPS is a condition-monitoring programme and neither general nor specific recommendations are provided to mitigate ageing effects. This is consistent with AMP 314 [18].

To date Koeberg has monitored the seismic bearings as per the relevant regulations (as documented in [6] & [7]) and the qualified responsible engineer accepted all results prior to sharing these with the NNR.

There has been only limited maintenance (plate interface grease seal replacement) required. The visual and test results of the in situ and sample bearings have shown that there is no significant change in material properties and based on these facts it has been concluded that the bearings are able to perform their design function, to remain fit for purpose and suitable for long term operation.

The inspection programme of KNPS is deemed sufficient and consistent with international best practice such as NUREG 7253 which states that:

Redacted information:The information was provided to Eskom by a third parties in terms of PAIA 37(1)a and/or b

KWU-DE-015: Load Monitoring of Aseismic Sample Bearings [34] KWU-DE-020: Long Term Monitoring of Aseismic Bearings [35] should be evaluated and authorized as a matter of urgency.

7.2 AMP 314 [18] – Monitoring and Trending of Ageing Effects:

The IGALL AMP consists of the following elements:

- **Visual Inspection:** Visual inspections are performed by examining the condition of the seismic base isolation system. These inspections are intended to keep track of the condition of the in-situ bearings and detect any deterioration in their condition. Visual inspection is augmented by distortion and Shore Hardness measurements taken on selected bearings.
- **Shear Modulus Tests:** Tests on the seismic base isolation system are performed periodically to determine the static and dynamic shear moduli of the elastomeric material, and to determine whether these parameters are still within the design basis throughout the period of operation. These samples are stored in the aseismic vault in the same conditions as the in-situ bearings. The test results obtained are trended and extrapolated. The values obtained after extrapolation are compared to the design values as documented in the licensing basis documents.
- **Lower Raft Inspections:** Periodic visual inspections of the lower raft on which the aseismic bearing pedestals are supported are performed to ensure that the raft is sound and that the leakage of water into the aseismic vault is within the required tolerances in accordance with IGALL AMP-306: Structures Monitoring (Version 2018) .
- **Inspections following an extreme external event:** Following an occurrence of a significant natural phenomenon such as tornado, flood, earthquake, hurricane, or intense local rainfall, a special inspection is performed of the Aseismic Bearings, lower raft, retaining walls and the upper raft impacted by the event.

Notwithstanding the uncertainties surrounding the trend of the shear modulus test results, the ISI programme implemented by KNPS is in line with the IAEA IGALL 314 [18].

7.3 NUREG 7253 – In-service Inspection, Replacement and Maintenance

The USNRC states that the ISI programme “should include periodic verification of mechanical properties of isolator devices to assess the effect of ageing on their performance.”

It continues and recommends that “owners should maintain an adequate number of non-load-bearing isolators in the environment that is essentially identical to that of the in-service units. A representative compressive load should be maintained on the non-load-bearing isolators. Elements that meet operational needs, such as access to the isolation layer, strong points for jacking, and ability of the superstructure mat to span over one (or more) isolator unit should be incorporated into the design.”

The current ISI programme of KNPS is noted to comply with these recommendations.

8. Conclusions

The purpose of this report is multi-fold as discussed throughout this document.

(1) an overview of the historical information is provided, and the institutional knowledge of previous reports, analyses and regulatory letters are discussed;

(2) the existing ISI and licence requirements associated with the Aseismic Bearings' monitoring is considered and it is concluded that the monitoring programme is consistent with international guidelines. It is however concluded that the inspection procedures be updated by the Responsible Engineer to incorporate additional enhancements;

(3) It is concluded that the design intent of the Aseismic Bearings is not challenged considering the current design basis; and

(4) The LTO safety case is supported, i.e the aseismic bearings are fit for purpose and it is recommended that confirmatory tests of the shear modulus be done through additional testing of samples. However these tests are not a pre-requisite for LTO.

Additionally, it has been shown that the structures on the Nuclear Island should have sufficient margin (ductility) to accommodate any anticipated exceedance of the FRS and therefore the safe operation of KNPS' is not being challenged.

The following conclusions are made with respect to the respective aspects as discussed throughout this report:

8.1 The Friction Couple

8.1.1 Historically, the friction couple has been shown to have a negligible impact on the design base FRS.

8.1.2 The friction couple is no longer part of the design base and has been removed from the SAR [25].

8.2 Delamination

8.2.1 It has been demonstrated that delamination is negligible in the previous monitoring reports.

8.3 Distortion

8.3.1 The distortion results are well within specification.

8.4 Shore Hardness

8.4.1 The concern that the Shore Hardness does not follow an 'expected' trend of hardening, can be attributed to subjectivity, change in equipment or personnel, et. al.

8.4.2 The Shore Hardness measurements are not an ideal test method, and should only be seen as an indicative material property.

8.4.3 The limited sample of shore hardness tests on the in-situ bearing material compares well with existing literature and industry experience that the shore hardness on the neoprene wrapper will be higher than that of the internal material.

8.5 Shear Modulus

8.5.1 There are concerns that the KNPS shear modulus has reduced in stiffness, whilst the OE from Cruas has indicated a stiffening of their bearings. This does cast some potential doubt over the accuracy of the latest test results. It is however possible that with a lack of significant degradation mechanisms, the Aseismic Bearings may be subjected to limited aging.

8.5.2 A wide range of shear modulus values was considered assuming the lower bound matching the lower measured results, and an upper bound based on the Cruas results.

8.5.3 If these lower and upper bound values of the anticipated potential shear modulus is considered (which envelopes the Cruas shear modulus results), it is shown that the effect over this range of changes has a negligible effect on the Nuclear Island FRS.

8.5.4 The functionality of the bearings is not considered challenged over this range of postulated stiffnesses.

9. Recommendations

The following recommendations are made:

9.1 Friction Couple:

9.1.1 As part of the development of representative analytical 2D models of the KNPS nuclear island, Koeberg intends on investigating the capability of the friction couple for beyond design base accident conditions.

9.1.2 A sensitivity analysis considering a lower and upper bound of the friction couple may be included to determine the effects of the different friction coefficient values on the FRS.

9.2 Delamination:

9.2.1 The risk of delamination should be incorporated into the new 2D analysis.

9.3 Distortion Checks

9.3.1 The Distortion Checks shall be continuously monitored as per the approved Management of License Binding Civil Monitoring Programme [6] and Basis and Scope for License Binding Civil Surveillances at KNPS [7].

9.3.2 The size of the test sample for distortion checks is to be increased in an effort to better understand if any trends exist. If any anomalies or concerns are identified, the Responsible Engineer shall recommend additional testing requirements.

9.4 Shore Hardness

9.4.1 An investigation into the Shore Hardness shall be conducted as recommended in § 5.3.6.

9.4.2 In the meantime the Shore Hardness shall be continuously monitored as per the approved Management of License Binding Civil Monitoring Programme [6] and Basis and Scope for License Binding Civil Surveillances at KNPS [7].

9.5 Shear Modulus:

9.5.1 The Shear Modulus shall be continuously monitored as per the approved Management of License Binding Civil Monitoring Programme [6] and Basis and Scope for License Binding Civil Surveillances at KNPS [7].

9.5.2 It is recommended that a desktop study be performed to investigate the possibility of determining the shear modulus of the in-situ bearings using non-destructive test methods.

9.5.3 Additional testing should be performed in the medium term to address the OE from Cruas with regards to the variation in shear modulus test results. However, this is not a pre-requisite for LTO.

9.5.4 Following undesirable results being obtained from the additional envisaged testing currently underway, a 2D model of the Nuclear Island may be used to perform a sensitivity analysis of expected, measured and/or literature shear modulus values to estimate the aging effect of the aseismic bearing's stiffness.

9.6 Corrosion Defects:

9.6.1 The cause of the sudden increase in the corrosion defects needs to be evaluated, however it is noted that the corrosion does not impact the design base of the Nuclear Island.

9.6.2 The inspection teams should be accompanied by cleaning teams, to ensure that the superficial corrosion can be removed while the inspections are performed.

9.7 Grease Seals:

9.7.1 The inspection teams should be accompanied by re-greasing teams, to ensure that the grease seals can be reinstated while the inspections are performed.

9.8 Current ISI

9.8.1 The inspection and monitoring procedures (which collectively constitutes the ageing management program) needs to be updated to incorporate additional enhancements.

10. Acceptance

This document has been seen and accepted by:

Name	Designation
Dr K Marcus	Senior Advisor
Mr A Kamroodien	Programme Engineering Manager
Mr AM Kotze	Chief Engineer
Mr B Francis	Engineer
Mr C Stolle	Chief Technologist
Mr N Ryland	System Engineering Manager
Mr NAS Foster	Chief Physicist
Mr TD Moila	System Civil Engineering Manager (Acting)
Ms M Koopman	Engineering Programme Group - Civil Programme Owner

11. Revisions

Date	Rev.	Compiler	Remarks
August 2023	2	SJ Venter	Review and Update and additions based on NNR response to Rev.1
February 2022	1	SJ Venter	First Compilation

12. Development Team

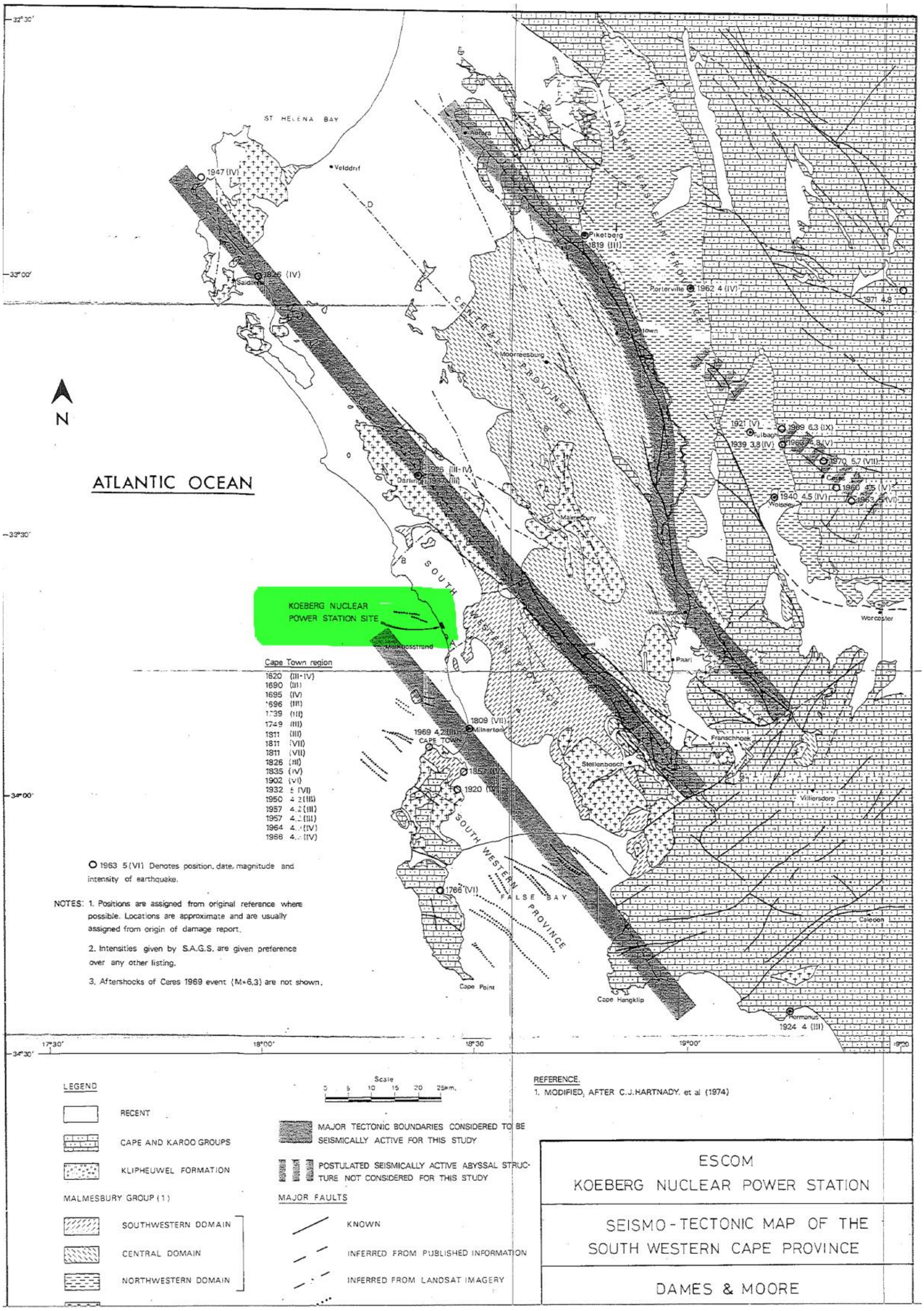
The following people were involved in the development of this document and co-compiled the document:

- Mr. Bradley Oaker
- Mr. Bienyamien Francis

13. Acknowledgements

N/A

APPENDIX A – D&M SEISMO-TECTONIC MAP OF THE SOUTH-WESTERN CAPE (1974)



CONTROLLED DISCLOSURE

Redacted information Detailed information on the plant's physical design that may be exploited by persons with malicious intent. NNR Act 47, Section 51, PAIA 38(b).

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