Guidelines for the management of structural ALE issues for mono-hull FPSOs

GUIDELINES FOR THE MANAGEMENT OF STRUCTURAL ALE ISSUES FOR MONO-HULL FPSOs

First edition

October 2019

Published by
Energy Institute, London
The Energy Institute is a professional membership body incorporated by Royal Charter 2003
Registered charity number 1097899

The Energy Institute (EI) is the chartered professional membership body for the energy industry, supporting over 20 000 individuals working in or studying energy and 250 energy companies worldwide. The EI provides learning and networking opportunities to support professional development, as well as professional recognition and technical and scientific knowledge resources on energy in all its forms and applications.

The EI's purpose is to develop and disseminate knowledge, skills and good practice towards a safe, secure and sustainable energy system. In fulfilling this mission, the EI addresses the depth and breadth of the energy sector, from fuels and fuels distribution to health and safety, sustainability and the environment. It also informs policy by providing a platform for debate and scientifically-sound information on energy issues.

The EI is licensed by:
– the Engineering Council to award Chartered, Incorporated and Engineering Technician status, and
– the Society for the Environment to award Chartered Environmentalist status.

It also offers its own Chartered Energy Engineer, Chartered Petroleum Engineer, and Chartered Energy Manager titles.

A registered charity, the EI serves society with independence, professionalism and a wealth of expertise in all energy matters.

This publication has been produced as a result of work carried out within the Technical Team of the EI, funded by the EI's Technical Partners. The EI's Technical Work Programme provides industry with cost-effective, value-adding knowledge on key current and future issues affecting those operating in the energy sector, both in the UK and internationally.

For further information, please visit **http://www.energyinst.org**

The EI gratefully acknowledges the financial contributions towards the scientific and technical programme from the following companies

BP Exploration Operating Co Ltd
BP Oil UK Ltd
Centrica
Chevron North Sea Ltd
Chevron Products Company
Chrysaor
CLH
ConocoPhillips Ltd
DCC Energy
EDF Energy
ENI
E. ON UK
Equinor
ExxonMobil International Ltd
Innogy
Kuwait Petroleum International Ltd
Nexen CNOOC
Ørsted
Perenco
Phillips 66
Qatar Petroleum
Repsol Sinopec
RWE npower
Saudi Aramco
Scottish Power
SGS
Shell UK Oil Products Limited
Shell U.K. Exploration and Production Ltd
SSE
TAQA Bratani
Total E&P UK Limited
Total UK Limited
Tullow Oil
Uniper
Valero
Vattenfall
Vitol Energy
Woodside
World Fuel Services

However, it should be noted that the above organisations have not all been directly involved in the development of this publication, nor do they necessarily endorse its content.

ISBN 978 1 78725 112 0

Published by the Energy Institute

Hard copy and electronic access to EI and IP publications is available via our website, **https://publishing.energyinst.org**.
Documents can be purchased online as downloadable pdfs or on an annual subscription for single users and companies.
For more information, contact the EI Publications Team.
e: **pubs@energyinst.org**

CONTENTS

Page

Foreword . . . 7

Acknowledgements . . . 8

1 Introduction . . . 9
1.1 Introduction . . . 9
1.2 Scope . . . 9

2 Application . . . 10

3 Regulatory requirements . . . 11
3.1 Introduction . . . 11
3.2 UK . . . 11
3.3 Other regions . . . 12
3.4 Industry standards and guidance . . . 12

4 Operator requirements . . . 14
4.1 General . . . 14
4.2 Establishing the goal . . . 14
4.2.1 Extending the field life with FPSO on-station . . . 15
4.2.2 Off-station modifications and repairs . . . 15
4.2.3 Replacing the asset . . . 15
4.2.4 Decommissioning the field . . . 16
4.3 Understanding the condition of the FPSO . . . 16

5 General considerations of ageing and life extension . . . 17
5.1 Introduction . . . 17
5.2 Data . . . 18
5.3 Evaluation . . . 18
5.4 Triggers for an engineering assessment . . . 19
5.5 Strategy . . . 19
5.5.1 Inspection planning . . . 19
5.5.2 Anomaly management . . . 20
5.5.3 Life extension strategy . . . 23
5.5.4 Decommissioning strategy and preparation for end of life . . . 23
5.6 Program . . . 24
5.6.1 Inspection and monitoring programmes . . . 24
5.6.2 Fabric maintenance programmes vs. dedicated tank coating refurbishment projects . . . 25
5.7 Review and audit . . . 25
5.8 Skills, training and competence . . . 25

6 Specific considerations for FPSOs . . . 27
6.1 General . . . 27
6.2 Important structural aspects of FPSOs . . . 27
6.2.1 Global loading . . . 27
6.2.2 Local loading . . . 28

Contents continued

		Page
6.3	Important practical aspects of FPSOs	28
6.3.1	Maintaining the structural integrity inspection program	28
6.3.2	Bow-wave of work	29
6.3.3	Accommodation	29
6.3.4	Gaining access	30
6.3.5	Ability to move 'off-station'	30
6.4	Tank contents	32
6.5	Examples of typical FPSO structural issues	32
6.5.1	General	32
6.5.2	Breakdown of internal protective tank coatings	33
6.5.3	Breakdown of external protective coatings	35
6.5.4	Corrosion	36
6.5.5	Fatigue cracks	40
6.5.6	External hull degradation issues	41
6.5.7	Structure deformation	42
6.5.8	Design and construction issues	42
6.5.9	Modifications	42
6.5.10	Breakdown of corrosion protection systems	43
6.6	Case studies	43
7	**ALE engineering assessment**	**44**
7.1	General	44
7.2	Triggers for an ALE engineering assessment	45
7.2.1	Change in criteria	45
7.2.2	External changes	46
7.2.3	Degradation or time related changes in condition	47
7.2.4	Change in intent	48
7.3	Screening assessment	48
7.4	Additional assessment and inputs	48
7.4.1	Follow-up inspection	49
7.4.2	Phased analysis	49
7.5	Assessment outcomes and actions	50
8	**Hull structural analysis**	**51**
8.1	General	51
8.2	Analysis provider	52
8.3	Analysis brief	52
8.4	Analysis assumptions	52
8.5	Pre-analysis review	53
8.6	Hydrodynamic analysis	54
8.6.1	Asset mass model	54
8.6.2	Hydrodynamic and mass model validation	54
8.6.3	Heading analysis	55
8.6.4	Environmental data	55
8.6.5	Heading analysis validation	55
8.6.6	Hydrodynamic response analysis	55
8.6.7	Radii of gyration for roll, pitch and yaw	56
8.6.8	Roll damping	56
8.6.9	Vessel loading conditions	56
8.6.10	Definition of wave headings	57

Contents continued

Page

8.6.11 Internal pressure loads (loads on tank boundaries) . . . 57
8.6.12 External pressure loads . . . 57
8.6.13 Hydrodynamic response validation . . . 57
8.7 Structural finite element analysis . . . 58
8.7.1 Extent of models . . . 58
8.7.2 Elements and mesh topology . . . 58
8.7.3 FE model verification . . . 58
8.7.4 Load transfer . . . 59
8.7.5 Verification of load transfer . . . 59
8.7.6 Verification of responses . . . 59
8.8 Hull strength assessment . . . 60
8.9 Hull fatigue assessment . . . 61
8.9.1 Fatigue stress range . . . 61
8.9.2 High cycle fatigue damage and fatigue life . . . 61
8.9.3 Low cycle fatigue damage . . . 61
8.10 Post analysis assessment . . . 61
8.11 Common analysis issues . . . 63

9 Assessment outcome and actions . . . 65
9.1 Typical structural repairs . . . 65
9.2 Coating protection . . . 66
9.3 Cathodic protection . . . 66
9.4 Onboard and structural monitoring systems . . . 67

10 Understanding the implications . . . 69
10.1 Life extension study . . . 69
10.2 Work methods . . . 70

11 Managing the future . . . 71
11.1 Following the approved strategy . . . 71
11.2 Managing and using the data set . . . 71
11.3 Transfering to an RBI scheme . . . 71
11.4 Technology . . . 73

Annexes

Annex A Abbreviations . . . 74

Annex B References . . . 76

Annex C FPSO practical case studies . . . 79

LIST OF FIGURES AND TABLES

Page

Figures

Figure 1 Structural integrity management flowchart . . . 17
Figure 2 Inspection and maintenance strategies . . . 20
Figure 3 Typical anomaly management process . . . 22
Figure 4 Example of premature coating failure due to poor preparations . . . 33
Figure 5 Example of typical FPSO water ballast tank erection joint coating failings . . . 34
Figure 6 Example of typical FPSO external protective coating failure (upper deck) . . . 35
Figure 7 Example of typical FPSO external protective coating failure (side shell) . . . 35
Figure 8 Example of typical FPSO external protective coating failure (underwater) . . . 36
Figure 9 Guidance on pitting extents . . . 37
Figure 10 Example of typical FPSO hull structure corrosion issues (water ballast tank) . . . 38
Figure 11 Example of typical FPSO hull structure corrosion issues (water ballast tank) . . . 38
Figure 12 Example of typical FPSO hull structure corrosion issues (cargo oil tank) . . . 39
Figure 13 Example of typical FPSO hull structure corrosion issues (cargo oil tank) . . . 39
Figure 14 Example of typical FPSO hull structure corrosion issues (cargo oil tank) . . . 40
Figure 15 Example of FPSO hull structure fatigue crack originating from a bracket toe . . . 41
Figure 16 Depleted anode following cleaning of loose anode material . . . 43
Figure 17 Engineering assessment flowchart . . . 44
Figure 18 High-Level FPSO life extension study . . . 69

Tables

Table 1 Off-station event considerations . . . 31
Table 2 Engineering trigger assessments . . . 45
Table 3 Common analysis issues . . . 63

1 INTRODUCTION

1.1 INTRODUCTION

Worldwide, there are many mono-hull FPSOs in operation that are approaching, have reached, or exceeded their original design life. During the life cycle of these assets there is a need to ensure that they remain fit-for-purpose (including hull structural integrity), which can be achieved through the application of a robust Structural Integrity Management System (SIMS). The SIMS must ensure that, as the FPSO ages, any degradation is properly predicted, detected, monitored, assessed and remediated as required.

There is considerable information available publicly for the application of SIMS. This document aims to complement existing information on SIMS to address issues specifically related to ALE of the hull structures of mono-hull FPSOs.

This document aims to guide the reader through the management of this process, highlighting the key stages and supporting analysis through to the potential implications and remedial actions on the asset.

It is highlighted that this document considers the main hull structure of mono-hull FPSOs. Other ALE aspects of FPSOs are not included within; however, where possible, relevant signposts are provided to existing publications and guidance.

Although this document relates to mono-hull FPSOs, much of the guidance notes contained within are applicable to other FPSO/floating storage unit (FSU) designs.

1.2 SCOPE

This document provides guidance to address common issues relating to the ALE of mono-hull FPSOs. The focus of this document is on hull structures for mono-hull FPSOs, including cargo oil tanks, water ballast tanks, voids, internal caissons, topside module structural connections which integrate with the hull structure, etc.

This document excludes guidance for the following:

– semi-submersible structures;
– topside structures;
– marine systems;
– watertight integrity;
– operational aspects;
– turrets and station keeping systems, and
– subsea-to-surface interface equipment, i.e. risers, mid-water arches, umbilicals etc.

2 APPLICATION

This document is intended as a guide to support duty holders, operators and contractors with the Structural Integrity Management (SIM) of ageing FPSOs in the oil and gas industry.

The document should be used to guide the reader through the engineering assessment process in response to common ageing related assessment triggers. The guidance is intended to be informative and offer possible assessment approaches for FPSO hull structural issues, but it is not intended to be a prescriptive assessment approach. Instead it should be used to select a suitable and proportionate assessment approach in response to a given triggering event, whilst considering the data available as part of a holistic approach.

It should be used alongside other industry information sources available, such as *Guidance on the management of ageing and life extension for UKCS floating production installations* and International Association of Classification Societies (IACS) *Common structural rules (CSR)*.

3 REGULATORY REQUIREMENTS

3.1 INTRODUCTION

This section provides guidance on some of the key regulatory requirements relating to the operation of FPSOs.

This section signposts the key regulatory requirements for the operation of FPSOs, specifically relating to ALE structural issues.

Guidance is predominantly provided for the UK; however, much of this guidance applies to worldwide operations.

3.2 UK

The UK regulatory regime is largely goal setting, in that the duty holder can operate an asset in accordance with their own strategies and procedures, provided compliance can be demonstrated to the regulator.

Relevant regulations applicable to offshore structures include:

- Health and Safety at Work etc. Act 1974.
- Management of Health and Safety at Work Regulations 1999.
- Offshore Installations and Wells (Design and Construction etc.) Regulations 1996.
- Offshore Installations (Safety Case) Regulations 2015.
- Provision and Use of Work Equipment Regulations (PUWER)1998.
- Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995.
- Offshore Installations and Pipeline Works (Management and Administration) Regulations 1995.
- International Convention for Safety of Life at Sea (SOLAS), 1974 including Protocol of 1978 and later amendments.
- International Convention for the Prevention of Marine Pollution from Ships (MARPOL), 1973 including Protocol of 1978 and later amendments.
- International Regulations for Prevention of Collision at Sea.
- International Convention on Load Lines, 1966, including supplements.
- International Convention on Tonnage Measurement of Ships.

The end of design life and, hence, start of a period of life extension, is not explicitly recognised in legislation; however, there is a requirement that the duty holder continuously maintain the integrity of the FPSO. Thus, to comply with this legislation the duty holder must demonstrate to the regulator that they are adequately managing the ageing process and any associated risk to the structural integrity of the vessel.

An overall framework for decision making which would ensure consistency and coherence across the full range of risks falling within the scope of the Health and Safety at Work etc. Act is set out in Health and Safety Executive (HSE) R2P2 *Reducing risk, protecting people*. Duty holder and code acceptance criteria for life safety are often linked to the criteria set out in this document, but it is noted that it is for the duty holder to set their own tolerability criteria.

There is a requirement to perform a thorough review of the Safety Case every five years, which normally addresses ALE.

3.3 OTHER REGIONS

Regulatory requirements and the associated stakeholders vary from region to region, from goal setting regimes like the United Kingdom Continental Shelf (UKCS), to more prescriptive approaches, for example as found offshore in Canada. It is important that operators fully understand the implications of the regulatory framework they are operating in, and act accordingly.

It is important to note that any regulatory requirements should be seen as minimum requirements, and that ultimately operators should ensure they implement a safety management strategy for their FPSO(s) which demonstrates that risks are mitigated to a level which is as low as reasonably practicable (ALARP). This is increasingly important in geographical areas where the regulatory requirements are less onerous than found elsewhere.

3.4 INDUSTRY STANDARDS AND GUIDANCE

Many FPSOs are operated under a Classification approach, typically following a similar path to trading tankers.

The Classification Society Rules have been a proven approach for shipping since 1760 and provide established rules and guidance defining prescriptive inspections schedules with scope typically increasing as the vessel ages.

It should, however, be noted that Class Rules are based on a five-year renewal (drydock) cycle that are not necessarily aligned with the business needs of the operator, and are certainly NOT a guarantee of structural integrity. FPSOs are not subject to periodic shipyard visits and cannot take action to avoid storms as per trading vessels.

The IACS document *Classification societies – What, why and how?* states the following:

> '*A certificate of classification…. …does not imply, and should not be construed as, a warranty of safety, fitness for purpose or seaworthiness of the ship.*
>
> *It is an attestation only that the vessel is in compliance with the Rules that have been developed and published by the Society issuing the classification certificate.*'

Extract from *Structural Integrity Management of ageing offshore installations review of Class Rules for floating installations on the UKCS*.

> '*Classification alone does not appear to meet the HSE regulatory requirements, which place responsibility for SIM on the duty holder. The experience to date of floating production installations is limited.*'