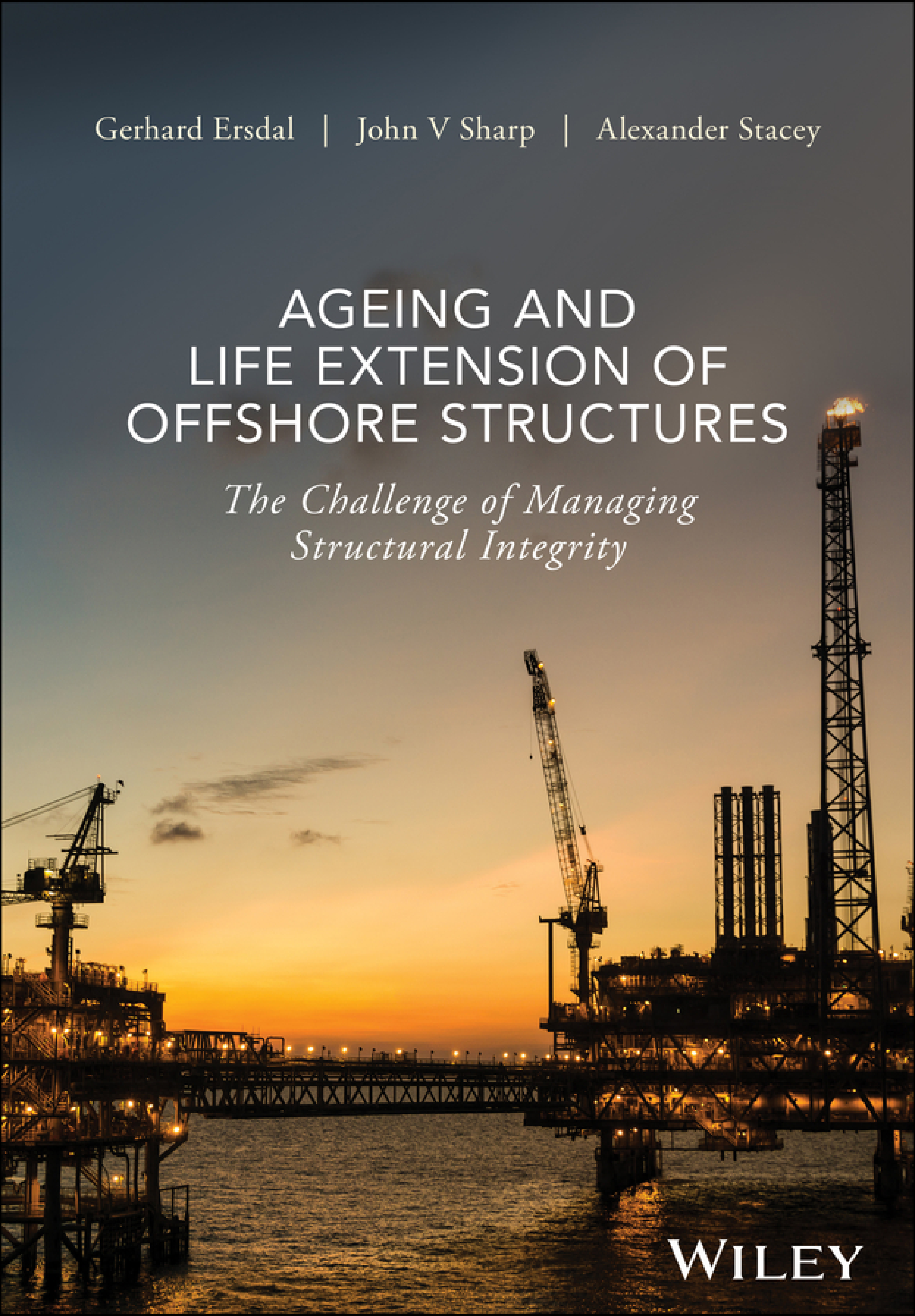

Gerhard Ersdal | John V Sharp | Alexander Stacey

AGEING AND LIFE EXTENSION OF OFFSHORE STRUCTURES

The Challenge of Managing Structural Integrity

WILEY

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Preface

In the last decade life extension has been a dominant topic in the Norwegian and UK offshore industries, where all three authors have been involved.

This book is about the fundamental issues relevant to ageing of offshore structures and the necessary considerations for life extension. The aim of the book is to investigate and understand how these structures change with age and how these changes can be managed and mitigated.

The literature on structures is largely aimed at structural design despite the fact that particularly in UK and Norwegian waters over 50% of offshore structures are now in a life extension phase and are experiencing ageing. The literature on the management and assessment of these ageing structures is limited. This book is intended to help bridge that gap.

The opinions expressed in this book are those of the authors, and they should not be construed as reflecting the views of the organisations the authors represent. Further, the text in this book should not be viewed as recommended practice, but rather as an overview of important issues that are involved in the management of life extension.

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Harwell, Oxfordshire, April 2018

Gerhard Ersdal
John V. Sharp
Alexander Stacey

Definitions

The definitions given below apply to how they are used in this book.

Accidental limit state (ALS) A check of the collapse of the structure due to the same reasons as described for the ultimate limit state, but exposed to abnormal and accidental loading situations

Ageing A process in which the integrity (i.e. safety) of a structure or component changes with time or use

Air gap The positive difference between the lowest point of the underside of the lowest deck and the crest height of an extreme wave for a given return period (often 100 years)

As low as reasonably practicable (ALARP) This is a term often used in the regulation and management of safety critical systems.

Asset integrity management (AIM) This is the means of ensuring that the people, systems, processes and resources that deliver integrity are in place, in use and will perform when required over the whole life cycle of the asset

Barrier A measure intended to identify conditions that may lead to failure, hazardous and accidental situations, prevent an actual sequence of events occurring or developing, influence a sequence of events in a deliberate way, or limit damage and/or loss

Bilge The area on the outer surface of a ship's hull where the bottom shell plating meets the side shell plating

Design service life Assumed period for which a structure is to be used for its intended purpose with anticipated maintenance but without substantial repair from ageing processes being necessary

Duty holder A UK term for the operator in the case of a fixed installation (including fixed production and storage units); and the owner in the case of a mobile installation

Fatigue limit state (FLS) This is a check of the cumulative fatigue damage due to cyclic loads or the fatigue crack growth capacity of the structure

Fatigue Utilisation Index (FUI) This is the ratio between the effective operational time and the documented fatigue life

Fixed structure This is a structure that is bottom founded and transfers all actions on it to the sea floor

Flooded member detection (FMD) This is a technique which relies on the detection of water penetrating a member by using radiographic or ultrasonic methods

FPSO Floating production, storage, and offloading unit

FSO Floating storage and offloading unit

FSU Floating storage unit

Hazard Potential for human injury, damage to the environment, damage to property, or a combination of these

High Strength Steels (HSS) In this book defined as structural steels with yield strengths in excess of 500MPa

Hydrogen induced cracking (HIC) This is the process by which hydride-forming metals such as steel become brittle and fracture due to the introduction and subsequent diffusion of hydrogen into the metal

Jack-ups Mobile offshore units with a buoyant hull for transport and legs for supporting the hull onto the seabed

Life extension This is when the structure is used beyond its originally defined design life

Limit state This is a state beyond which the structure no longer fulfils the relevant design criteria

Management of change (MoC) This is a recognised process that is required when significant changes are made to an activity or process which can affect performance and risk

Microbiologically induced cracking (MIC) This is a form of degradation that can occur as a result of the metabolic activities of bacteria in the environment.

NDE Non-destructive examination

NDT Non-destructive testing

Partial safety factor For materials: this takes into account unfavourable deviation of strength from the characteristic value and any inaccuracies in determining the actual strength of the material. For loads: this takes into account the possible deviation of the actual loads from the characteristic value and inaccuracies in the load determination

Passive fire protection (PFP) These coatings are used on critical areas which could be affected by a jet fire. There are several different types which include cementitious and epoxy intumescent based

Performance standards Statement of the performance required of a structure, system, equipment, person or procedure and which is used as the basis for managing the hazard through the life cycle of the platform

Prestressing tendons High strength tendons are required to maintain the structural integrity of a concrete structure, particularly in the towers. These tendons are placed in steel ducts which are usually grouted following tensioning

Primary structure All main structural components that provide the structure's main strength and stiffness

Push-over analysis This is a non-linear analysis for jacket structures used for determining the collapse/ultimate capacity

Redundancy The ability of a structure to find alternative load paths following failure of one or more components, thus limiting the consequences of such failures

Reserve strength ratio (RSR) The ratio between the design loading (usually 100-year loading) and the collapse/ultimate capacity

Residual strength Ultimate strength of an offshore structure in a damaged condition

Robustness This reflects the ability of the structure to be damage tolerant and to sustain deviations from the assumptions for which the structure was originally designed

Safety critical elements (SCE) and Safety and environmental critical elements (SECE) These are those systems and components (e.g. hardware, software, procedures, etc.) that are designed to prevent, control, mitigate or respond to a major accident event that could lead to injury or death. This was further extended in the 2015 version of the UK safety case regulation to include environmental critical elements (SECE)

Scour Erosion of the seabed around a fixed structure produced by waves, currents, and ice

Secondary structure Structural components that, when removed, do not significantly alter the overall strength and stiffness of the global structure

Serviceability limit state (SLS) This is a check of functionalities related to normal use (such as deflections and vibrations) in structures and structural components

S–N curve This is a relationship between the applied stress range (S) and the number of cycles (N) to fatigue failure (regarding fatigue failure, see *Fatigue limit state*)

Splash zone Part of a structure close to sea level that is intermittently exposed to air and immersed in the sea

Stress concentration factor (SCF) Factor relating a nominal stress to the local structural stress at a detail

Structural integrity The state of the structure and conditions that influence its safety

Structural integrity management (SIM) This is a means of demonstrating that the people, systems, processes and resources that deliver structural integrity are in place, in use and will perform when required for the whole lifecycle of the structure with the aim of providing an acceptable safety level

Structural reliability analysis (SRA) This is used to analyse the probability of limit state failure of structures

Surveillance All activities performed to gather information required to assure the structural integrity, such as inspection of the condition and configuration, determining the loads, records, and document review (such as standards and regulations), etc.

Topsides Structures and equipment placed on a supporting structure (fixed or floating) to provide some or all of a platform's functions

Ultimate limit state (ULS) This is a check of failure of the structure of one or more of its members due to fracture, rupture, instability, excessive inelastic deformation, etc.

Water tight integrity The capability of preventing the passage of water through the structure at a given pressure head

Wave-in-deck Waves which impact the deck of a structure, which dramatically increase the wave loading on the structure

1

Introduction to Ageing of Structures

It is the destiny of the man-made environment to vanish, but we, short-lived men and women, look at our buildings so convinced they will stand forever that when some do collapse, we are surprised and concerned.

Levy and Salvadori (2002)

1.1 Structural Engineering and Ageing Structures

How long can a structure last? Historically we have seen structures failing before they were ready to be used.[1] Others, such as historical monuments, have lasted for centuries and millennia.[2] The life span of a structure will depend on its design, its construction, and fabrication, the material used, the maintenance performed, the challenging environment it has been exposed to, the accidental events it has experienced, and whether it is possible to repair and replace any damaged or deteriorated structural parts. Metallic structures from the 1700s are still carrying their intended loads. Such evidence may lead us to believe that structures may last forever. However, only one of the Seven Wonders of the Ancient World is still standing, namely the Great Pyramid of Giza (constructed around 2500 BCE).

Changes start to appear in structures from the moment they are constructed. The material in structures will degrade (mainly by corrosion and fatigue) and accumulate damage (such as dents and buckles). The environment the structures are placed in will change, and that will influence the degradation mechanism. The loads on a structure will change with changes in use. The foundations of the structure may experience settlement and subsidence, which implies additional stresses in the structures and may introduce changes to the loading. Furthermore, technological developments may lead to materials, equipment, and control systems related to the structure being outdated and spare parts for these systems becoming unavailable (obsolescence). Compatibility between new equipment and the equipment that is already in place on the structure (e.g. to control stability and ballast on a floating structure) may prove to be difficult. Ultimately we may face the problem of changing to a new technological solution with possible issues

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[1] Examples of this are the Cleddau Bridge (Milford Haven, UK) collapse during construction in 1970 and the *Wasa* ship that sank during launching in 1628.

[2] Examples of this are the Caravan Bridge in Turkey (850 BCE), the Ponte Fabricio bridge in Rome (62 BCE), and the Pont du Gard aqueduct in France (18 BCE).

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concerning safety and functionality, or continue to use the old technological solutions with their limitations. All of the above may make a structure less safe.

The assessment of an ageing structure for possible further use has to be based on the available information. Ideally, information about the original design and fabrication of the structure, its use and the inspections performed over the years are required to determine whether a structure is fit for further use. This assessment needs to be based on an understanding of the current safety of the structure. However, for older structures, the necessary information required to show that they are sufficiently safe may be lost or impossible to obtain. Lack of information, new knowledge, and new requirements may change our understanding of the safety of a structure, and may force us to regard the structure as unsafe requiring further mitigation.

However, new knowledge, methods and requirements may provide information that leads to a better understanding of the integrity of an existing structure, including the possibility that the integrity is better than expected and sufficient for safe operation in the life extension phase.

Finally, as time passes since the design of a structure, the evolution of technical knowledge normally leads to society developing more stringent requirements for safety.[3] This improved understanding will increase expectations for the safe operation of structures, including older ones designed to lesser criteria.

Offshore structures are continuously exposed to all of the above types of change. They operate in an environment that causes corrosion, erosion, environmental and functional loads, incidents and accidents that deteriorate, degrade, dent, damage, tear, and deform the structure. In addition to the changes to the structures themselves, the loads and corrosive environments in which they operate will change over time. Further, the way these are used may change, which as a result will alter the loading, the environment these are exposed to and possibly the configuration of the installation. In addition, our knowledge about the structures will change, e.g. the type of information that we have retained from design and inspection of the structure. Further, the physical theories, mathematical modelling and engineering methods used to analyse the structures may change, typically as new phenomenon are discovered. Finally, our evaluation of offshore structures is also influenced by societal changes and technological developments. This may result in changes to the requirements that are set for offshore structures, taking into account obsolescence, lack of competence, and the availability of spare parts for old equipment.

These changes may be grouped into four different types:

- *Physical changes* to the structure and the system itself, their use, and the environment they are exposed to (condition, configuration, loading, and hazards).
- *Changes to structural information* (the gathering of more information from inspections and monitoring, but also potential loss of information from design, fabrication, installation, and use).

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[3] As an example, the number of traffic fatalities in Norway in the 1980s averaged 400 fatalities per year (0.01% of the population). Societal development has led to a lower acceptance of fatalities, and technological developments have led to safety improvements being possible, and the number of fatalities in 2015 reached a historic low of 125 (0.0025% of the population). At present, society expects further reduction in the number of traffic fatalities.

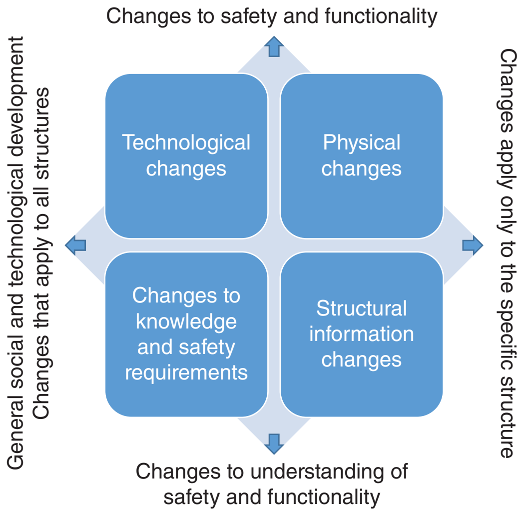

Figure 1.1 The four main elements of ageing of a structure.

- *Changes to knowledge and safety requirements* that alter our understanding of the physics and methods used to analyse the structure, and the required safety that the structure is supposed to have.
- *Technological changes* that may lead to equipment and control systems used in the original structure being outdated, spare parts being unavailable, and compatibility between existing and new equipment and systems being difficult.

These groups of changes are illustrated in Figure 1.1, where it is indicated that the physical and technological changes impact the safety and functionality of the structure directly, while structural information changes and changes to knowledge and safety requirements primarily change how we understand the safety and functionality of a structure. Further, it is indicated that physical changes and structural information changes apply to one specific structure, while technological changes and changes to knowledge and safety requirements are a result of societal and technological developments, and are applicable to all structures.

These issues are highly relevant for a structural engineer; as we will show in Section 1.2, as the early offshore structures in the oil and gas industry are getting rather old. Many offshore structures from the 1990s are now passing their planned life expectance. However, there is a need for many of these structures to remain in service as there is still oil and gas remaining in the reservoirs. Further, many fixed and floating structures provide an important hub for the increasing number of subsea installations. The continued use of these older structures has the potential to save substantial costs and minimise environmental damage by avoiding the building of new structures.

In Section 1.3 we will show that failure statistics for structures indicate that structures in the oil and gas industry have a significant failure rate, particularly for floating structures. Further, older structures fail more often compared with newer structures. This is not surprising taking into account that structures will degrade and accumulate damage, that their use may change in unfavourable ways, that systems related to the structures may experience obsolescence and that newer structures may be designed according to improved methods and more stringent regulations and standards.

Facing the challenge of having relatively many older structures in the oil and gas industry, and at the same time knowing that older structures fail more often than newer ones, structural engineers need to:

- Understand how structures change as they get older (Chapter 3).
- Develop methods to assess these structures properly so that the structures that are unfit for further service are decommissioned, either because they are unsafe or they cannot be proved to be safe due to lack of important information (Chapter 4).
- Manage these older structures properly in their life extension phase (Chapter 5).

This book is generally about these items, but in order to understand older structures it is important to know about early designs and maintenance practices, as these will have an impact on our understanding of older structures. Similarly, it is important to know about the present requirements, because older structures will in many regions of the world be measured to the same safety standards as new structures. Further, the design of early structures was based on the knowledge and experience at that time and the methods often resulted in safe designs. In the intervening period there have been significant improvements in knowledge and experience which can be applied to the management of these older structures. These topics are covered in Chapter 2.

1.2 History of Offshore Structures Worldwide

Over the years, several types of offshore platforms have been used to produce oil and gas. One of the earliest successful fixed platforms was a wooden platform used by Pure Oil (now Chevron) and Superior Oil (now ExxonMobil) 1 mile from the coast in a water depth of 4.3 m in 1937 (Offshore 2004). The first floating production was from around the same time, using steel barges on which drilling rigs were installed. These barges were ballasted to rest on the bottom for drilling. When the wells were completed, the barges could be refloated and towed away to new well sites. Fixed structures were typically built around the wells for protection and to provide a platform where the wells could be maintained and serviced (Offshore 2004). However, the birth of offshore technology (Clauss et al. 1992) occurred in the mid-1940s when two steel platforms were erected in the Gulf of Mexico (GoM). One of these platforms was built 18 miles off the Louisiana coast in 5.5 m of water in 1946 by Magnolia Petroleum (now ExxonMobil) and the other platform was built in 1947 in 6.1 m of water, also 18 miles off the Louisiana coast, by Superior Oil.

In the UK and Norwegian sectors, the present day's North Sea oil and gas production commenced in 1965 when BP's Sea Gem drilling rig found gas in the West Sole field. Subsequently, further discoveries were made in the West Sole field and the Viking gas field in 1965 and the Leman Bank, Indefatigable, Balder and Hewett gas fields in 1966. This was followed by a series of significant finds, including:

- In 1969, Phillips Petroleum's discovery of the Ekofisk field in the Norwegian sector and Amoco's discovery of the Montrose field in the UK sector were announced. The Ekofisk field has been one of the major oil producing fields in the Norwegian sector.
- In 1970 BP discovered the Forties field 110 miles east of Aberdeen, with the first production in 1975; this was one of the largest producing oil fields in the UK sector, with five fixed steel platforms.