STUDY ON PLANNING, FABRICATION AND MAINTENANCE OF TERTIARY CONSTRUCTION ELEMENTS AND PIPE SUPPORT

Tertiary structures and their connections

Petroleumstilsynet

Report no.: 2023-1207, Rev. 1
Document no.: 2031757
Date: 2024-04-22

DNV

Project name:	Study on planning, fabrication and maintenance of tertiary construction elements and pipe support	DNV AS Energy Systems Technology Centre Oslo Advisory-4100-NO Veritasveien Høvik 1363 Norway Tel: +47 67 57 99 00
Report title:	Tertiary structures and their connections	
Customer:	Petroleumstilsynet, Professor Olav Hanssens vei 10 4021 STAVANGER Norway	
Customer contact:	Morten A. Langøy	
Date of issue:	2024-04-22	
Project no.:	10385338	
Organization unit:	Technology Centre Oslo Advisory-4100-NO	
Report no.:	2023-1207, Rev. 1	
Document no.:	2031757	

Applicable contract(s) governing the provision of this Report:
Minikonkurranse 4/23

Objective:

Prepared by:	Verified by:	ed by:
Brit KF. Graver	Digitally signed by Løken Sondre Date: 2024.04.24 10:17:4(+02'00'	DNV 1864 SAFEGUARDING LIFE, PROPERTY AND THE ENVIRONMENT Digitally Signed By: Gustav Heiberg Location: Høvik, Norway Signing Date: 26.04.2024 Contact Info: +47 67579900
Brit Graver Principal specialist	Sondre Løken Head of Section - Materials Advisory	Gustav Heiberg Head of Section – Structural Integrity Advisory
Digitally signed by Iversen, Morten Date: 2024.04.23 13:34:02 +02'00'		
Morten Iversen Principal Engineer		
Digitally signed by Pål Jensen Date: 2024.04.22 18:28:24 +02'00'		
Pål Jensen Senior Principal Engineer		
Hasle, Tone Digitally signed by Hasle, Tone Date: 2024.04.22 20:08:15 +02'00'		
Tone Hasle Principal Engineer		
Digitally signed by Søfferud, Mario Date: 2024.04.22 18:05:55 +02'00'		
Mario Søfferud Principal Engineer		

The information in this document is classified as:

☒ Open ☐ DNV Restricted ☐ DNV Confidential* ☐ DNV Secret*

*Additional authorised personnel for distribution within DNV:

Can the document be distributed internally within DNV after a specific date?

☐ NO ☐ YES

Keywords Tertiary structures, outfitting structures, equipment, joining methods, corrosion, loads

Rev. no.	Date	Reason for issue	Prepared by	Verified by	Approved by
A	2023.11.30	DRAFT	brig/moriv/pgjen/tonha	sonlo	
1	2024.04.22	Issued after comments	brig/marso/moriv/pgjen/tonha	sonlo	ghei

Table of contents

1 EXECUTIVE SUMMARY 1

2 INTRODUCTION 3
2.1 SoW 3

3 TERTIARY OUTFITTING STRUCTURES 4
3.1 Definition type of structures 4
3.2 Types of joining methods and connections 5

4 DESIGN, MANUFACTURING/FABRICATION AND INSTALLATION 15
4.1 Design requirements 15
4.2 Manufacturing/fabrication/Installation 15

5 INSPECTION AND MAINTENANCE 16
5.1 Regulative requirements for inspection and maintenance 16
5.2 Current industry practice for maintenance- and inspection management of outfitting structures 16
5.3 Identification and monitoring 17
5.4 Assessment of condition and mitigation of degraded structures 17

6 EXAMPLES OF OUTFITTING STRUCTURE FAILUERS 18

7 MANAGING RISKS 20
7.1 General 20
7.2 Risk reducing measures 21

8 CONCLUSION 22

9 RECOMMENDATIONS 23

10 REFERENCES 24

Appendix A Minikonkurranse 4/23 – Risikovurderinger, teknisk sikkerhet, beredskap og analyser – Studie på prosjektering, fabrikasjon og vedlikehold av tertiære konstruksjonselementer og pipesupport

1 EXECUTIVE SUMMARY

In a previous study DNV was asked by the Norwegian PSA to map critical connections on tertiary structures that can result in a dropped object situation (Phase 1) /2/. Dropped objects can result in damage to both equipment and people and can be due to improper design, manufacturing, installation, maintenance and operation. DNV identified and categorized different non-conventional fastening systems, described the methods, and identified typical experience, damage, and integrity challenges in the industry.

The focus in this report (Phase 2) has been on tertiary outfitting structures that can result in a dropped object situation. Tertiary outfitting structures are usually not covered by design or inspection standards, thus there are limited requirements on how these structures shall be joined and maintained.

The scope of work was to define and identify a selection of tertiary structures and pipe supports with reference to relevant standards and industry best practices both in design and operation. The design requirements (including joining methods), material selection and corrosion protection and fabrication were described.

DIS-ISO 24201 is a standard under development that specifies a limited number of tertiary outfitting structures. This standard was used as a basis for identifying relevant outfitting structures that can result in a dropped object. NORSOK L-002 covers design of pipe supports for critical pipes, whereas it appears as there exists no standard for non-critical pipes.

Based on the literature review tertiary outfitting structures were divided into two main groups.

1. Tertiary outfitting structures
   - handrails, ladders, walkways and grating, blast walls, roof plates, pipe supports for critical and non-critical pipes, trays/channels etc.
2. Equipment
   - lamps, antennas, wind cone, signal horns, loudspeakers etc.

The most common joining method is through bolts (bolts with nuts) or welding, however in many cases this is not practical, nor feasible and alternative joining methods are used. Most common material used for fasteners are stainless steel and hot dip galvanized steel.

The reason for dropped objects of tertiary outfitting structures can typically be due to corrosion or excessive loads of the fasteners, either through incorrect design or lack of inspection in operation. A review of incident databases to conclude on the root cause of dropped objects or the extend of tertiary outfitting structure incidents has not been part of this study. Energy Institute, SfS and ABS have developed guidelines and standards to avoid dropped objects both for design and in operation. These guidelines address equipment and some selected outfitting tertiary structures such as handrails, ladders, pipe supports and grating as potential dropped objects.

The main finding is that the inspection of tertiary outfitting structures is often down prioritized since onshore and offshore standards detail integrity management of loadbearing structures. NORSOK N-005:2017 and ISO-19901-09:2019 recommend annual inspection of secondary/tertiary structures by GVI for the complete structure. In addition to limited legislative requirements, where the risk compared to primary and secondary loadbearing structures is considered as low. Poor visibility of outfitting structures in form of limited registers and documentation from design makes planning of specific and targeted inspection difficult. The inspection extent and the inspection methods used limits detection of hazards and the lack of knowledge and competence related to the variety of configurations used, including associated degradation mechanisms and failure modes, leads to under-reporting and reduced priority for mitigation and maintenance.

Based on the study it is recommended to

- develop a best practice on the fastening of tertiary/outfitting components and/or equipment incl. pipe supports for critical and non-critical lines. This should be referred to from NORSOK N-004 and N-005.

- carry out a workshop with the industry, both end-users (oil and gas companies), vendors and construction companies, where current practice around design and operation of tertiary outfitting structures including joining methods should be discussed.
- perform a generic risk assessment on old and new outfitting structures with focus on the identified threats corrosion, overload, incorrect mounting, loss of pretensioning, fatigue, loosening of nuts due to vibration etc. which can form the basis for a risk-based-inspection (RBI) program.
- introduce more specific categories for inspection reporting and maintenance planning as e.g., “dropped object, personal safety barrier” could improve attention and priority for degrading outfitting structures representing hazards.

2 Introduction

In a previous study DNV was asked by the Norwegian PSA to map critical connections on tertiary structures /2/ that can result in a dropped object situation. Dropped objects can result in damage to both equipment and people and can be due to improper design, manufacturing, installation, maintenance and operation. DNV identified and categorized different non-conventional fastening systems, described the methods, and identified typical experience, damage, and integrity challenges in the industry.

In this study the focus has been on tertiary outfitting structures that can result in a dropped object situation. Tertiary outfitting designs are usually not explicitly covered by standards or integrity management systems, thus there are limited requirements on how these structures shall be configured and further managed during operation.

Several studies /17/ -/19/ have been conducted to reduce the risk of dropped objects. Statistical data shows that dropped objects are one of the leading causes of safety incidents. And it has been shown that the major contributing factors to prevent dropped-object incidents are personnel awareness and training, work process, management, equipment design, environment, and securing of equipment and tools.

2.1 SoW

Appendix A and Ref /1/ contains the contract details.

The scope of work is defined as follows:

- Identify risk elements and compensatory measures relevant to the petroleum industry for accidents caused by failure of tertiary structure elements.
- Describe practices for preparing design requirements (including type of fasteners), material selection (including corrosion protection), fabrication and maintenance requirements.
- Identify which national and international standards are used.
- Practice in the maintenance of these structural elements.

3 TERTIARY OUTFITTING STRUCTURES

3.1 Definition type of structures

The group tertiary structure is a broad term, and some operators and designers define tertiary structures as outfitting steel structures. Further in this report, the term tertiary outfitting steel structure will therefore also be used, which is also in agreement with the DIS-ISO 24201 and the industry in general. Table 3-1 lists various types of structures which is divided in two main groups based on functionality: tertiary outfitting steel structure and equipment.

The tertiary outfitting steel structures is usually fastened to the primary structure or to support structures. For instance, some outfitting structures such as electrical, instrumentation, telecom and piping can be fastened to support systems such as cable trays and ladders which are bolted to steel brackets welded to the structure, see Figure 3-1 and Figure 3-2.

Table 3-1 Grouping of outfitting steel structures and equipment.

Grouping	**Examples**
Tertiary outfitting steel structure	Handrails*
	Bumpers
	Safety gate*
	Kick-list
	Stairs*
	Spiral stairs*
	Stair towers
	Vertical ladders*
	Rest platforms, repose
	Grating with supporting structure*
	Manhole hatches
	Ventilation louvres/ducts incl. supports
	Pipe supports for non-critical pipes
	Pipe supports for critical pipes
	Plates for roof, walls and wind walls including supports
	Acoustic curtain/ sound-resistant drapery including supports
	Trays, channels and struts for cable, conduit, and tubing runs including supports
Electrical equipment and instruments	Instrumentation, junction boxes, lights
	Grounding and bonding equipment (e.g., for equipment, pipe flanges, storage tanks, junction boxes etc.)
	Cameras and loudspeakers*
	Antennas and wind cone
	Signage
	Safety net helideck
	Repair systems

* DIS-ISO 24201 covers these tertiary outfitting structures. The recommended fasteners are through bolts (bolts with nuts)

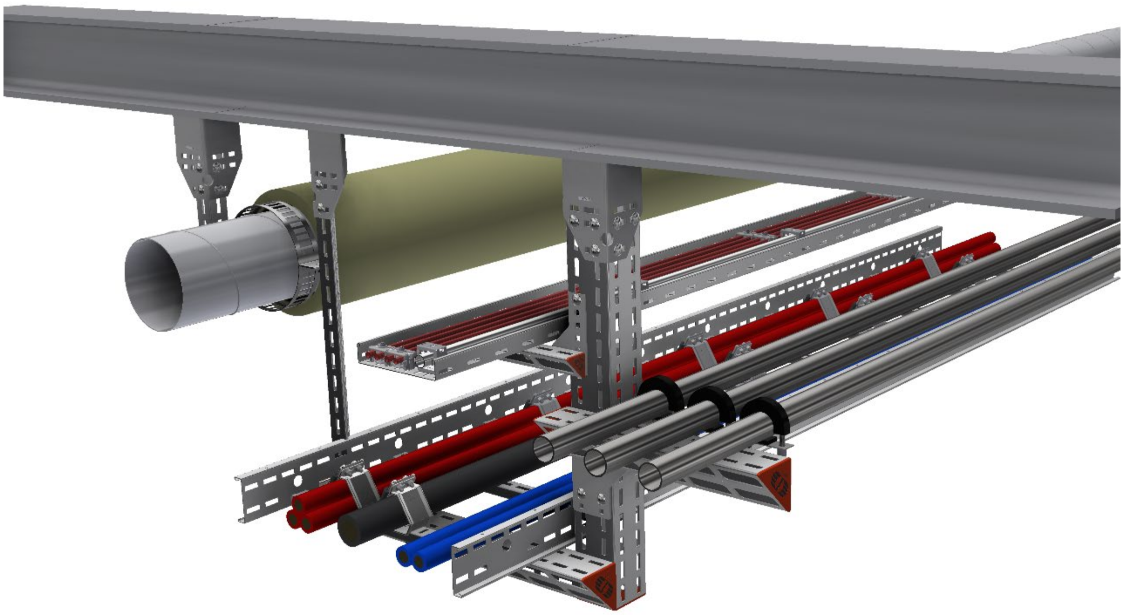

Figure 3-1 Example of support systems for electrical cables and piping. Photos: Permission to use from Øglænd systems

3.2 Types of joining methods and connections

Typical joining methods and connections of tertiary/outfitting structures and equipment are listed in Table 3-2. The main focus is the joining methods and not the outfitting structure in itself. Only systems exposed towards external environment is assessed, meaning structures with HVAC and inside living quarters are not a part of the scope. Some structures, such as stair towers can be assessed as secondary structure based on its size and connection method (through bolting). Conventional bolt with nuts is defined in this report as "through bolts".

Table 3-2 Examples of outfitting structures and joining methods.

Examples tertiary /outfitting structure including supports	Examples joining methods	Evaluations
Handrails	Bolt with nuts ("through bolts"), stud welded to structure, explosion and friction welded connections	Detachment of handrails have been reported.
Bumpers	Bolt with nuts ("through bolts"), explosion and friction welded connections.	Detachment of bumpers have been reported.
Safety gate	Hinged with bolts	This is also called swing gates. Reported to be a typical dropped object.
Kick-list (toe-structure)	Continuously welded	This is not considered as a critical component since it is welded to the structure
Stairs	Stairs are usually fastened with bolt with nuts ("through bolts"), welded	
Spiral stairs	Bolt with nuts ("through bolts"), welded	This component is not considered as relevant as a dropped object due to the size.

Examples tertiary /outfitting structure including supports	Examples joining methods	Evaluations
Stair towers	Bolt with nuts ("through bolts"), stud welded, explosion and friction welded connections	This component is not considered as relevant as a dropped object due to the size. Compared with the other items on this list, stair towers are considerable larger and typically supported on several levels. A stair tower would probably be considered as secondary design by most design companies.
Vertical ladders	Welded to construction.	Reported to be a typical dropped object.
Rest platforms, repose	Bolt with nuts ("through bolts")	Reported to be a typical dropped object.
Grating with supporting structure	Square, M and G clips together with blind bolts (pop rivets, rivet nuts and expansion bolt) and self-tapping screws	Detachment of grating has been reported.
Manhole hatches	Bolted hinges	Reported to be a typical dropped object.
Ventilation louvres/ducts incl. supports		
Pipe supports for non-critical* pipes	Clamps (bolted) and shoes (bolted or welded) towards pipes. Interface towards load bearing structures is usually welded or bolted connections. Other types of fastening methods can be used on the interface towards supporting structures such as trays and ladders.	Trapped water at the piping pipe support interface can result in corrosion. Installation errors of threaded blunt tip studs with stud gun causing loose or loosening of studs. Stainless steel studs may be prone to galvanic corrosion against carbon steel structure if weather seal is compromised. Insulation as dropped object may represent a risk, in particular when heavy from absorbed water.
Pipe supports for critical pipes**	Beam support with and without U-bolts, saddle clamps (bolted) and shoes (bolted or welded). Interface towards load bearing structures is usually welded or conventional bolted connections.	Known incident with fractured pipe supports of pipe running through several modules on FPSO due to high frictional loads and global deformations from wave loads. Trapped water at the piping pipe support interface can result in corrosion. Insulation as dropped object may represent a risk, in particular when heavy from absorbed water.
Plates for roof, walls and wind walls including supports	Wind wall panels must be fastened (usually bolted) to a dedicated support structure – never to the main structure.	Detachment of plates have been reported.

Examples tertiary /outfitting structure including supports	Examples joining methods	Evaluations
Acoustic curtain/ sound-resistant drapery including supports		
Trays, channels and struts for cable, conduit, and tubing runs including supports	Stud welded/ Self-tapping screws/through bolts on supports	Reported to be a typical dropped object.
Instrumentation, junction boxes, lighting	Stud welded/ Self-tapping screws/though bolts	Reported to be a typical dropped object.
Signage	Stud welded/ Self-tapping screws/ though bolts	Reported to be a typical dropped object.
Grounding and bonding equipment	Stud welded/ Self-tapping screws/ though bolts	Reported to be a typical dropped object.
Antennas and wind cone	Stud welded/ Self-tapping screws/ though bolts	Reported to be a typical dropped object.
Safety net helideck		Reported to be a typical dropped object.
Repair	Threaded insert/bushing	

**Non-critical pipes: Low pressure, low temperature piping in low or none -hazardous service. Typically, 2" and below. Piping not subjected to stress- and flexibility analysis, limited or no detailed pipe support design. Support location and technical configuration are often selected on site by installation contractor. Less likely to be maintained by regular inspection or maintenance due to low risk associated with loss of process containment.*

***Critical pipes: Represents piping subjected to regulatory stress- and flexibility analysis due to risk contribution. Analysis provides load input to detailed pipe support design, which contributes to a compliant and robust design with conventional- and well proven fastening methods. Such piping systems incl. support are more likely to be maintained by regular inspection and maintenance due to the increased risk associated with loss of process containment.*

Last decades 316 SS has been the primary material selection for cable trays, pipe supports and racks, brackets and bolts. Such trays and pipe supports can be used for critical or non-critical piping clamps 2" to 8", tubing clamps (up to 1") and HVAC clamps (up to 1.25 m). The so-called starter brackets are either bolted or welded to the structure. In case of welding this is preferably done on stainless steel doubler plates. Bolted brackets can be fixed by any of the below mentioned methods.

Joining methods comprise of welding and the use of different types of fasteners. Fasteners can be divided between through bolted connections and non-through bolted connections (also called non-conventional). Bolt with nuts, so-called through-bolted connection, is the recommended type of connections for securing outfitting structures.

Other joining methods can be explosion welding, friction welded studs, self-tapping screws, blind bolts /expansion bolt. Friction welded bolts and self-tapping screws are commonly used offshore to fix grating, cable trays etc. The studs are completely sealed by the stud washer with a sealing ring during setting.

Figure 3-2 Example of starter brackets for assembly of trays and ladders. Photos: Permission to use from Øglænd systems

3.2.1 Explosion welding

Explosion welding is used for joining dissimilar metals (aka structural transition joints) such as aluminum to carbon steel because this is not possible with conventional arcwelding. Explosive charges are placed along the surface at one of the metals and when detonated a shockwave is created which force the two metals together with a high velocity. This high-speed collision generates heat and pressure that creates a metallurgical bond at the interface without melting. Surface cleanliness and distance between the metals are critical to ensure a good quality. When installing explosion welded parent plates it is important to avoid excessive heat from welding close to the interface because this can cause delamination.

Delamination between steel and aluminum, primarily due to corrosion, has been reported from offshore installations.

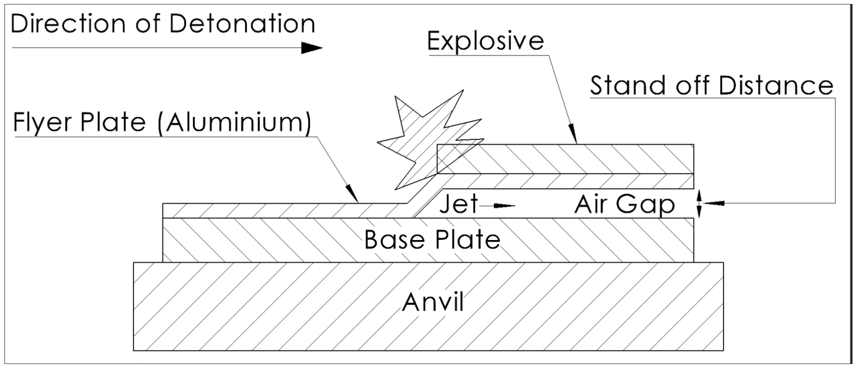

Figure 3-3 Illustration of explosion welding

3.2.2 Friction welded / fusion welded studs

Stud welding process:

- The stud welding process consists of joining the stud to the base metal with friction made by rotation or pressure that creates heat to melt the end of the studs. This will create a permanent connection with the metal. See Figure 3-5.
- Another method is to apply a short, high-current electrode transfer between the stud and base metal. This electrical discharge melts the end of the studs, and a solid connection is made. See Figure 3-4.

It is important to inspect the connection after joining to secure that no defect or lack of fusion is found. Both tension test (proof load), bend testing and hammer testing can be used.

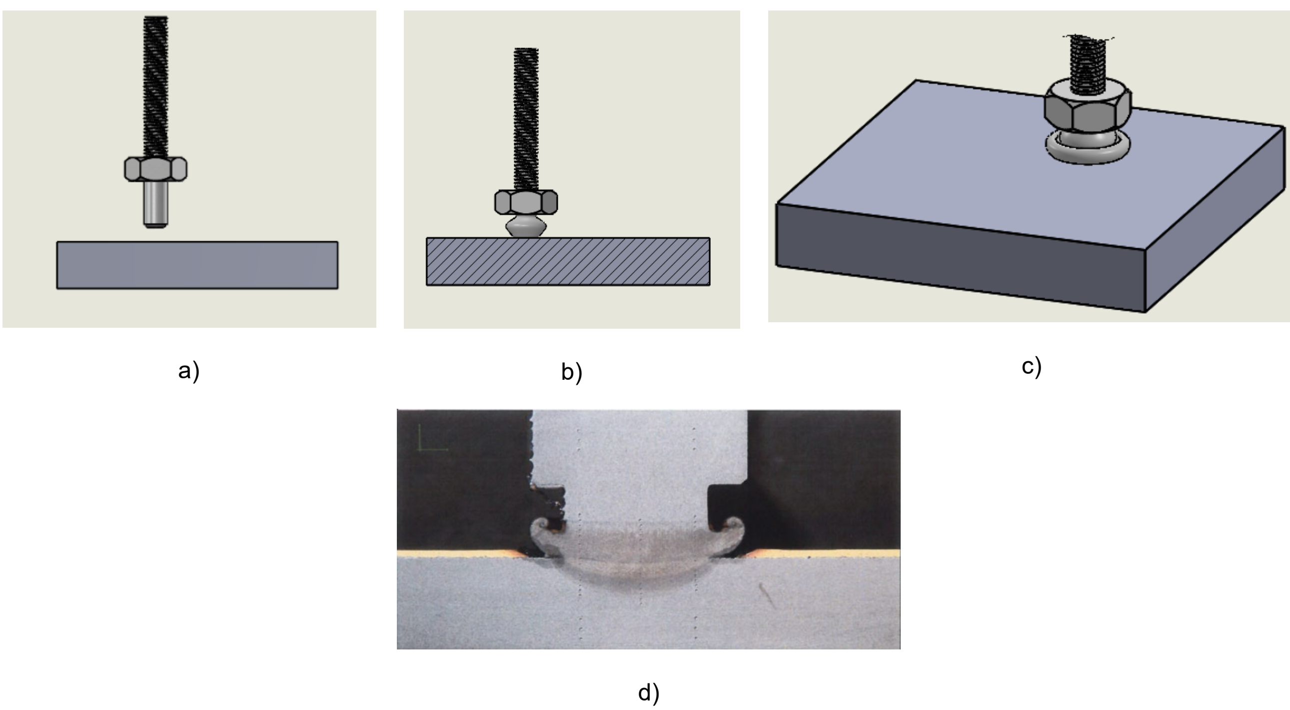

Figure 3-4 Example of stud welding process, where a) the rotating stud is b) pressed into the workpiece c) The heat from the friction process mixes the two materials together. d) A macro of a stud weld.

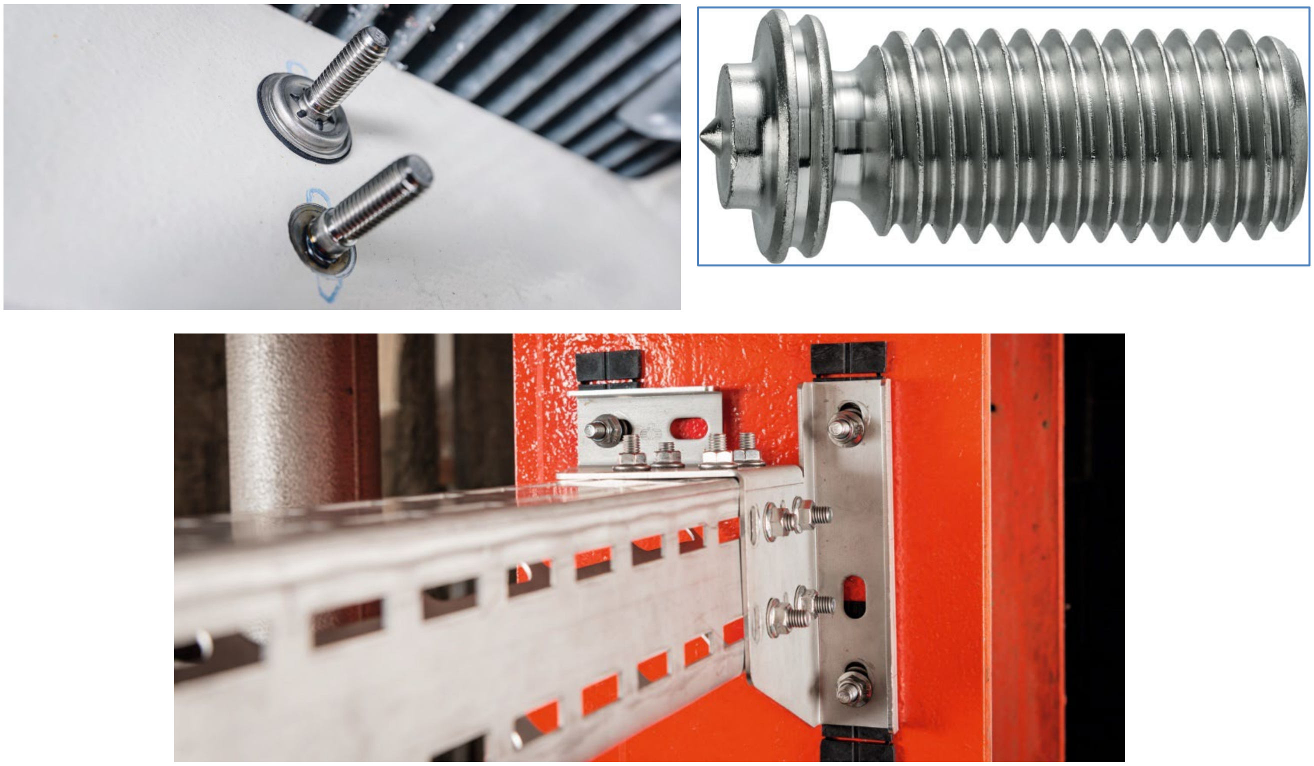

Figure 3-5 Example of fusion welded stainless steel stud with sealing washer. Photos: Permission to use from Øglænd systems

3.2.3 Self-tapping studs

Self-tapping screws are screws that when driven into the material it can tap its own hole. These screws cannot drill through metal and require a pilot hole to be pre-drilled before installation. These types of screws can be categorized into two main groups, thread-forming and thread-cutting. The difference between the two types is how the hole is made. For thread-forming screws the material is displaced while for thread-cutting screws the sharp threads cut the surface and removes the material.

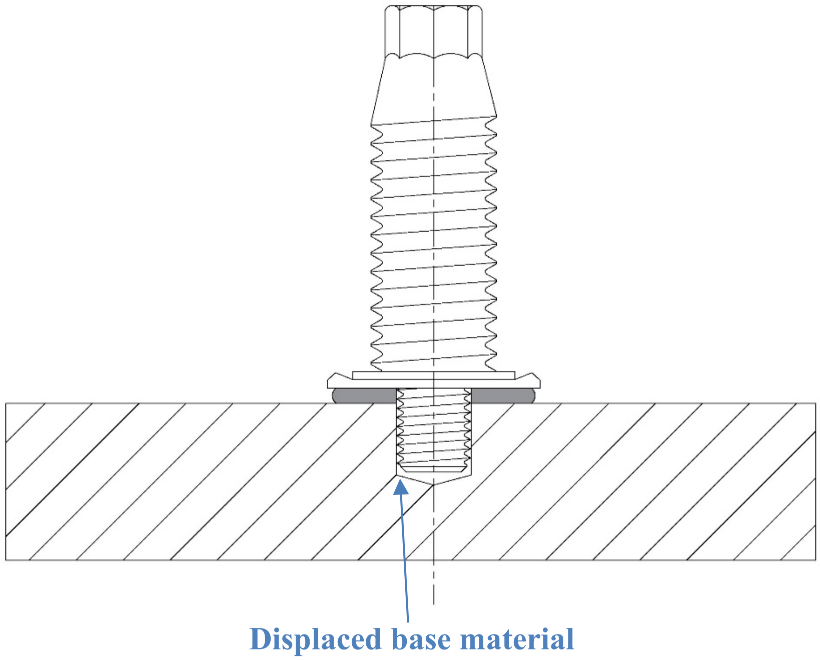

Figure 3-6 Example of a self-tapping screw in a predrilled hole.

3.2.4 Expansion bolt (through hole)

These types of fasteners consist of three main components a cylindrical shaft that is inserted into a pre-drilled hole, a fixed head on one end and a tail that, using a special tool, is “bucked” to expand in diameter, fastening it in place towards the inner wall. The bolt heads can be flush to the structure, counter sunk and lay on top of the surface. The bolt is not reusable.

The blind bolts are often used when access is available from one side only and reduces the need for welding or strapping.

- Perforation of hollow profiles leading to water ingress
- Galvanic corrosion due to the fastener often being stainless steel

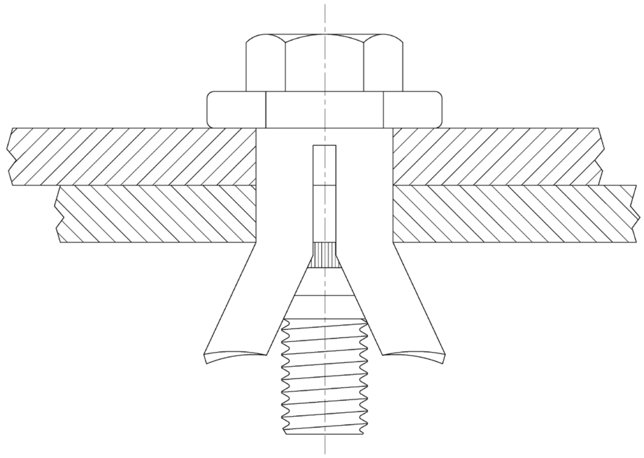

Figure 3-7 Example of an expansion bolt after fastening.

3.2.5 Blunt tip studs (stud gun)

Threaded blunt tip studs is much used on the Norwegian continental shelf (NCS). The blunt tip stud is punched into a predrilled hole with bolt gun, which creates a mechanical press fit / partly friction welded joint.

- Issues with incorrect installation of such studs causing loose or loosening of studs.
- Studs are stainless steel – potential galvanic corrosion issue in case of fastening to carbon steel and loss of sealing in case weather seal is compromised.

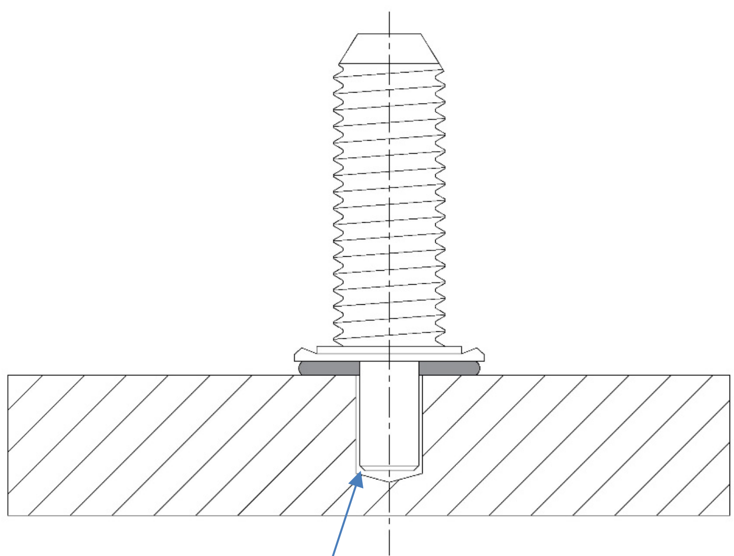

Figure 3-8 Example of a blunt tip stud mounted with a stud gun.

3.2.6 Pipe supports

Design and types of pipe supports are covered in NORSOK L-002, EN 13480 (all parts) and ASME 31.1 and 31.3. NORSOK L-002 covers process, drilling, utility and instrument piping and tubing for offshore oil and/or gas production facilities, i.e. critical pipes.

Pipe supports can be divided into standard beam supports which the pipes rest onto (often secured with a u-bolt), welded supports and saddle-clamps (which is reported to have a higher probability of corrosion).

Below photo (Figure 3-9) shows one example known to DNV with an incident with fractured welded pipe supports of a pipe running through several modules on an FPSO. The likely cause was high frictional loads transferred from pipe to supports, due to global deformations from wave loads.

Figure 3-9 illustrates other types of pipe supports, for non-critical pipes.

v

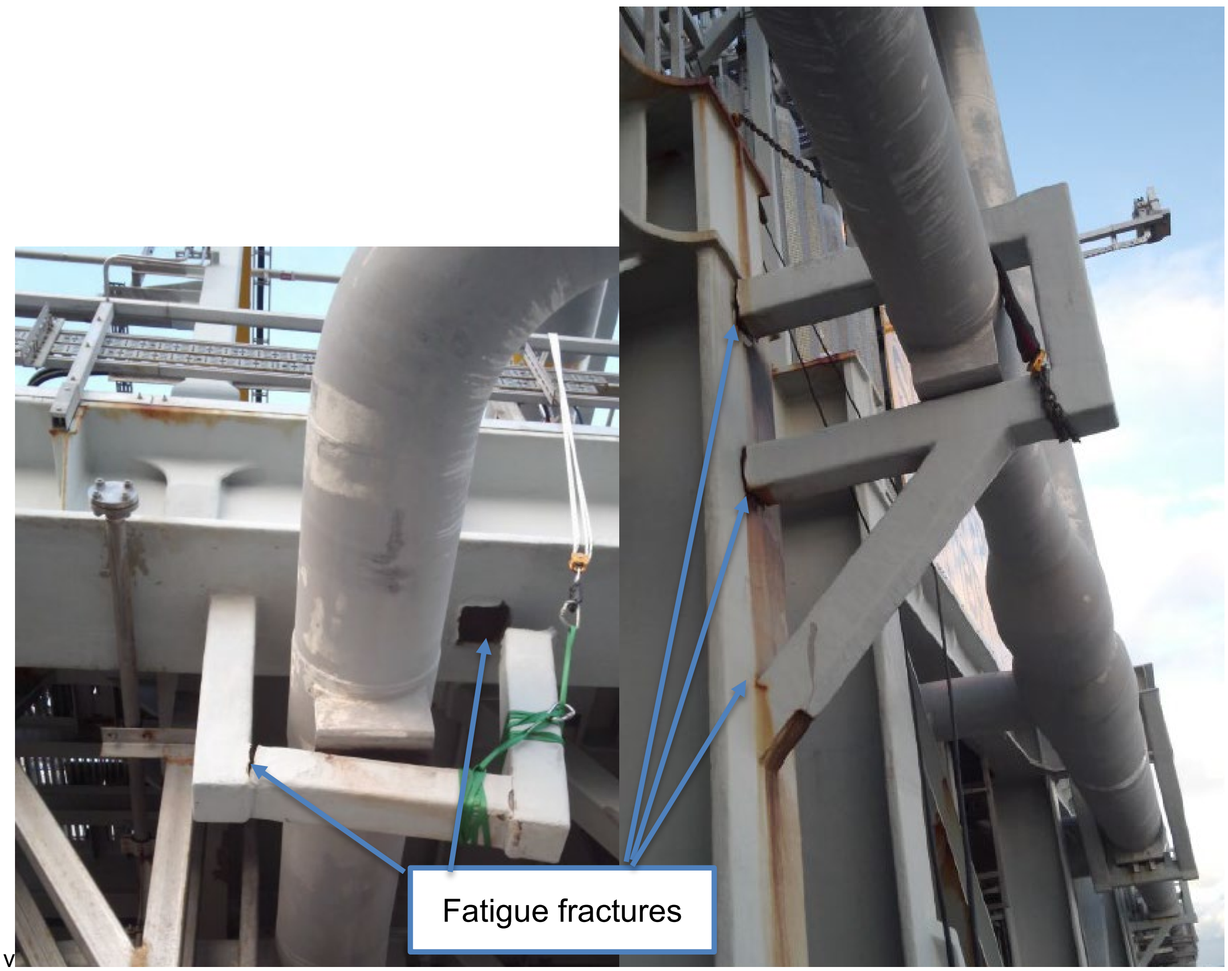

Figure 3-9 Example of two adjacent, welded pipe supports (RHS 150 and RHS200) failed by fatigue. Photos used with permission from operator.

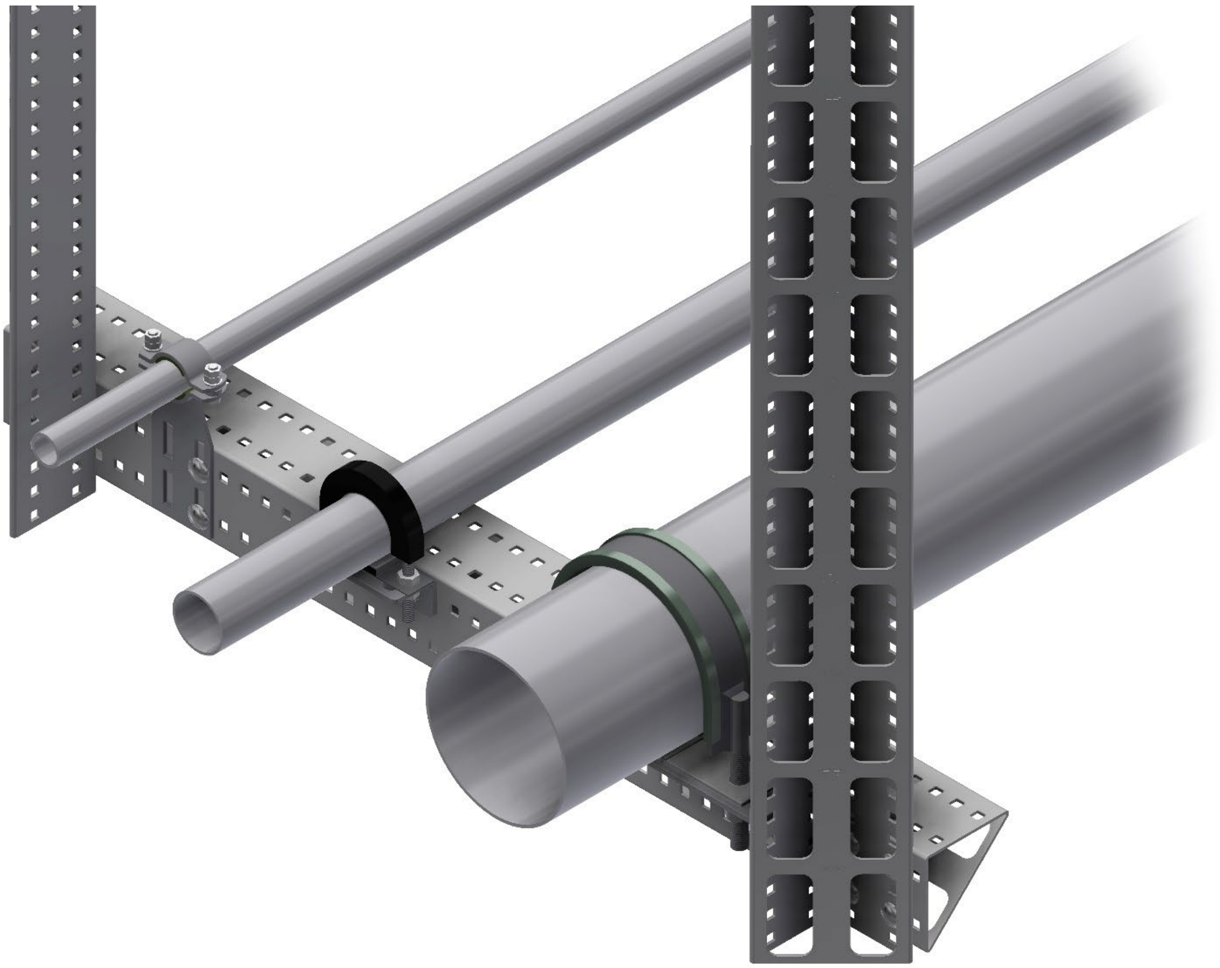

Figure 3-10 Pipe supports. Photos: Permission to use from Øglænd systems

4 DESIGN, MANUFACTURING/FABRICATION AND INSTALLATION

4.1 Design requirements

It has not been a tradition on the Norwegian continental shelf to require standardization of design approaches with regards to load bearing structures. Instead, requirements are put on its functionality. For instance, requirements are given for performance (commonly interpreted as strength) and requirements for serviceability (typically limitations against deflections, vibrations, etc). This means that the designer is given the privilege to choose between different materials (aluminum, steel), connection types (weld, bolts, bearings, grout), plate thicknesses, etc. as long as the structures including connections fulfill the requirements for performance and serviceability. NORSOK N-001, N-003 and N-004 gives general requirements to perform design to fulfill these requirements.

While it is not requirements to standardization in the structural discipline, there have been introduced some semi-standardization requirements in an amendment to NORSOK M-001 to prevent galvanic corrosion. This requirement has been developed as a consequence to the challenges with galvanic corrosion between carbon steel, stainless steel and aluminum observed out in the field. This could be considered as standardization to prevent corrosion.

Designers are given these privileges, but that freedom comes with responsibility. The designer shall fulfill the general requirements above. It is believed that this is performed not so thoroughly, and it is not followed up in the same extent as for the primary and secondary design.

Some designers limit the risk of galvanic corrosion by selecting the same material on the connection systems as the structures themselves.

4.2 Manufacturing/fabrication/Installation

For through bolts the requirements are specified in NORSOK but these are for primary steel (load bearing structures). There are no other offshore standards that specifies other types of fastening methods. EN1090 which regulate the fabrication and assembly of steel and aluminum structures have some requirements, but these are for onshore.

EN1090-2 specifies fasteners for railings, stairs and ladders according to execution class EXC2. EN 1090-2 also gives some requirements towards special fasteners and solid rivets for hot riveting.

Studs or shear connectors other than the stud types for arc stud welding in EN ISO 13918 shall be classified as special fasteners. Other types of special fastening methods are specially tapped holes, or threaded studs. These may be used as equivalent to the use of a bolting assembly provided that the materials, thread forms and thread tolerance comply with the respective product standard. Any procedure tests required for use of special fasteners and fastening methods in non-preloaded or preloaded applications shall be specified.

No requirements exist towards installation of non-conventional bolts for offshore use. The selection of materials and methods is up to the designer and installation companies.

NORSOK M-001 which covers material selection for offshore does not specify requirements to tertiary outfitting steel structures.

5 INSPECTION AND MAINTENANCE

5.1 Regulative requirements for inspection and maintenance

A review of a selection of onshore and offshore standards has been carried out /9/ - /14/. These standards detail design and integrity management of loadbearing structures, while specific requirements or recommendations for outfitting structures are not-, or only briefly addressed.

A short summary of the most relevant standards is given below.

NORSOK-N005: 2017 /9/ lists structures to be considered for “integrity assessment” and specifically mentions “access structures” such as handrails, ladders, walkways and grating and states that the extent of structural inspection should include annual inspection by GVI for the complete structure. The standard mentions dropped objects but focuses on damages on loadbearing structures caused by accidental impact.

ISO 19901-09:2019 /10/ addresses that periodic inspection scope should include visual survey to capture the condition secondary/tertiary structures, such as walkways (handrails, grating) and their supports, lifeboat davit connections, and blast walls including visual survey of personnel safety devices and emergency escape routes.

NS-EN-ISO 19902:2020 /11/

Robustness in relation to dropped objects should be incorporated into the design.

NORSOK N-004 /12/ nothing specific

NORSOK N-006 /13/ nothing specific

NORSOK Z-008 /14/ nothing specific

5.2 Current industry practice for maintenance- and inspection management of outfitting structures

Both inspection and maintenance of structures is throughout the industry managed by a risk-based approach, focusing on structural components or members representing a high consequence if a failure occurs. Primary effort in form of detailed and specific inspection, followed by mitigating actions, is consequently made to loadbearing structures, highly utilized or designed with no, or limited redundancy. These structures are subjected to detailed legislative requirements in design, providing a robust design, allowance for degradation and are based on well proven and familiar technical configurations suited for inspection and maintenance.

Compared to loadbearing structures, the consequence of failure in outfitting structures is far less. This is often reflected in design, fabrication, inspection and maintenance of these types of components and structures. Outfitting structures are normally not tagged and often poorly reflected on general arrangements drawings and relevant design documentation is limited or not available. Such structures are in most cases managed by area- or risk-based fabric maintenance programs often governed by high consequence items and subjected to inspection regimes, commonly limited to general visual inspection (GVI) with the shortcomings and challenges as described in Sec. 5.4.

Despite the moderate attention made towards outfitting structures in the industry, increased focus on features evidently representing personal safety risks, such as handrails, escape routes, grating and stair towers, has been noticed the recent years. This might be credited to the attention caused by actual incidents in the industry and the fact that these specific items to some degree are discussed in standards as objects to be assessed for visual inspection.

5.3 Identification and monitoring

Documentation in form of overviews or registers for outfitting structures is seldom established during design. This combined with poor technical documentation limits the possibility to identify and subsequent ensure that components and configurations that represent risks are represented in- and specifically maintained by the inspection program. The use of 3D models has somehow improved the visualization of such configurations, but is not available, or not of sufficient detail level, on aging installations. Consequently, inspection planning and -execution of outfitting structures is commonly maintained by area based general visual inspection (GVI), where e.g., *general outfitting structures* are used as a collective term to include all such structures. Inspection is usually conducted with negative reporting, i.e., only findings are reported which provides limited historical documentation of inspection extent and general condition.

General visual inspection does normally not have any requirements for proximity to the object subjected to inspection and is mainly conducted without any access enhancing measures as scaffolding or rope access which limit the inspection extent to the accessible objects and parts identified by visual sight. Lack of details specifying the inspection scope and -execution, combined with limited priority, time and resources, affects the coverage and quality of the inspection.

Close visual inspection (CVI) is normally required to be conducted within proximity of an arm's length. During a GVI campaign, CVI, if not otherwise specified, is normally only conducted if indications of degradation are identified.

Degradation mechanisms relevant for explosion welded connections or non-conventional fasteners is not necessarily of conspicuous appearance and both detection and condition assessment will often require increased inspection effort in form of CVI or NDT, seldomly planned and budgeted for in the initial planning.

5.4 Assessment of condition and mitigation of degraded structures

Assessment and mitigation of degradation requires relevant competence and experience to the object subjected to inspection or repair and should preferably be accompanied by pre-defined acceptance criteria for degradation limit state.

Unlike primary loadbearing structures with familiar conventional welding or joint configurations and associated with known degradation mechanisms, outfitting structures utilizes a variety of material and technical solutions, introducing other degradation characteristics requiring different detection approaches and inspection techniques.

Conventional welded and bolted connections are normally not designed with any allowances for degradation providing specific acceptance criteria. Still, years of experience with these configurations has led to an industry practice and understanding of acceptable degradation limits. There is reason to believe that lack of knowledge and experience related to function, degradation characteristics and condition assessment of un-conventional fastenings systems contributes to less detection and -reporting of potential hazards.

Reporting of findings, assessment and further processing into notifications or work orders for repair or maintenance is ensured by inspection and maintenance management systems. These systems do often not have specific categories for reporting, highlighting and maintaining these kinds of configurations and accompanied hazards, which tends to result in a low attention and generic appointed priority for mitigation. Introducing more specific categories for inspection reporting and maintenance planning as e.g., "dropped object, personal safety barrier" could improve attention and priority for degrading outfitting structures representing hazards.

6 EXAMPLES OF OUTFITTING STRUCTURE FAILUERS

Some incidents from PTILs Hendelsesdatabase are listed in DNV report no. 2022-3242 rev. 2. A more detailed study is expected to be carried out in 2024.

DNV has assessed the public available incident databases for UK HSE /15/ and US BSSE /16/ with focus on dropped object offshore. Most of the reported incidents and cause of fatalities are related to loosening of grating. Two most common threats for grating damages are corrosion and wind load lifting the grating during harsh weather conditions, primarily for rigs. No details regarding joining methods are mentioned in these databases.

According to a large standardization study performed by ABS (American Bureau of Shipping) /20/ it was demonstrated that dropped objects are among the top 3 causes of injuries in the work environment and accounted for 14% of fatalities in the US Upstream Oil and Gas Industry from 2003-2014. One of the findings in this study was that prevention of dropped objects is not addressed in the design standards.

The many guidelines and best practices on dropped objects outlines the typical failure modes without explicitly mention the root cause /17/-/19/. The focus is mainly on the recommendations towards mitigations such as the use of recognized fastening systems (e.g. through bolts) and the use of retention systems (cables, safety nets etc.) as a second barrier. However, this might indicate that the use of non-robust joining methods is one of the reasons for the dropped objects.

A summary of typical failure modes has been listed in Table 6-1. These observations are mainly interpreted by DNV based on the documentation on the work performed by Energy Institute and SfS. Most of the dropped objects can be classified as equipment. Larger components such as stair towers are not mentioned.

Table 6-1 Typical failure modes on outfitting structures and equipment

Outfitting structures/Equipment	Typical failure mode
Grating, hatches, doors, access panels	Gravity pin and loop hinges as these can become disengaged due to vibration and environmental loads
Piping and equipment feed throughs	Missing covers or barriers at piping cable or equipment feedthrough point
Pipe clamps	Pipe clamps are prone to vibration and corrosion, resulting in components and pipework becoming loose, damaged and dislodged.
Guard rails	Use of set screws
Toe bord(kick-list)	Missing and incorrectly installed toe boards
Swing gates	hinges with neither the necessary quality of material nor the design strength to serve their intended function over time
Ladders	damage to ladders and safety cages as a result of collisions with mobile equipment. In addition, cracks have been found in safety cages
Signage	Detachment
Lighting units	Not adequately secured against falling or colliding with mobile equipment
Cameras	Subject to dynamic forces, particularly snagging. Lens covers, wipers and motors frequently fail due to collisions or loose fittings
Junction/control box, cabinets	Defective mounting/fastening and to inadequate securing of hatches, doors and covers
Crane boom camera/ Pivoting flood lamps	Fatigue and failure of pivot fixings
Cable trays and ladders	Loose nuts and bolts in the joints and fastenings of cable ducts (electro-steel), probably as a result of vibration and/or faulty installation. The risk of galvanic corrosion should be assessed, and insulation considered where appropriate.
Antennas, light and sensors	Mounted at heights that are exposed to continuous environmental forces. Have become dislodged and fallen considerable distances
Wind walls	Third party damages due to collisions with mobile equipment and incorrect fastening

Dropped objects can be divided in static and dynamic /18/, /19/:

- ***Dropped Object [Static]:*** *Any object that falls from its previous position under its own weight (gravity) without any applied force. For example: a failure caused by corrosion, vibration or inadequate securing.*
- ***Dropped object [Dynamic]:*** *Any object that falls from its previous position due to an applied force. For example: collisions involving traveling equipment or loads, snagging on machinery or stacked items, motion, helicopter downdraft or severe weather.*

Based on the outfitting structures listed in Table 6-1 these can be defined as potential static dropped objects.

7 MANAGING RISKS

7.1 General

Several studies have been conducted the past 20 years to define guidelines in reducing the risk of dropped objects. The organization dropsonline.org, an Aberdeen, UK based member organization was formed in 1998 and consists of over 200 member companies and organizations that contribute to the ongoing development of best practices.

As previously mentioned, Energy Institute (EI) and SfS (Working Together for Safety) have made informative guidelines that give advice to the prevention of dropped objects applicable for rigs and fixed offshore installations. ABS (American Bureau of Shipping), has developed the first international standard addressing dropped object prevention on offshore units and installations as a part of their classification system.

The guidelines do not explicitly mention tertiary structures but divide the components into equipment and outfitting items which have the potential to detach and fall. Pipe supports are only mentioned in the EI document. There exists however some information on pipe supports and potential failures in the litterature.

All of the guidelines focus on the establishment of an Integrity Management System (IMS) to ensure a reduction in the number of dropped objects and prevent future incidents. The integrity management system shall cover the whole life cycle from design to operation and decommissioning. This type of management system has different names such as DO (SfS) , DROP (EI) and DOPP (ABS). An example of an integrity management system taken from DNV RP-F116 is shown in Figure 7-1. The integrity management system consists of an inner circle, in this case called the integrity management process, and the outer supporting elements, such as personnel, organization, plans and procedures. The integrity management process is the core of the integrity management system and is the combined process of threat identification, risk assessment, planning, inspection, monitoring, testing, integrity assessment, mitigation, intervention, and repair.

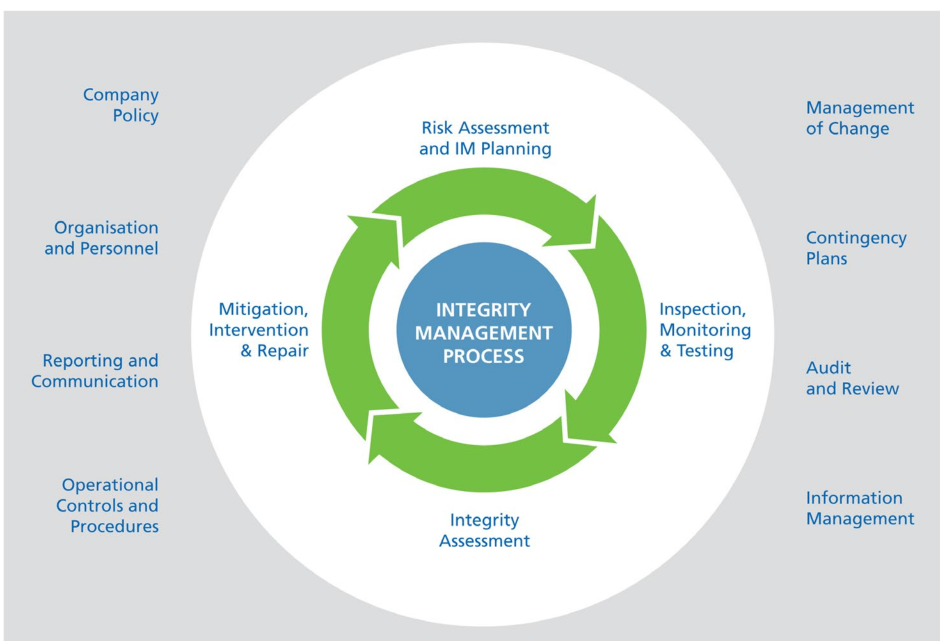

Figure 7-1 Example of an integrity management system

7.2 Risk reducing measures

All the dropped object guidelines recommend carrying out a risk assessment to identify the potential for a dropped object (DO) situation. All type of equipment old and new shall undergo a risk assessment with focus on the identified threats corrosion, overload, incorrect mounting etc.

The risk of a static dropped object situation is dependent on the connection method and the size of the object itself, therefore one risk reducing measure is to evaluate the design of the joining method. Many engineering companies and contractors pay attention to this and have made their own requirements. Typical risk reducing measures is to evaluate the robustness of the design and ABS has for instance the following requirements during this stage:

- Material selection for fastening to avoid corrosion, mechanical properties, load design, lubricant and the use of the correct torque equipment.
- Primary fastening to be bolts, nuts and screws.
- Secondary retention to be used if the equipment is not an integral part of the structure. The use of secondary retention is to prevent loosening of the bolts, nuts, and screws. The retention methods can be specific for non-through bolted (such as lock-wire/cable) and through-bolted connections (the use of castellated nuts, split/cotter pins etc.). Other examples of secondary retention are split pins, retaining plates, securing wires and safety nets.
- Special requirements for specific equipment (not mentioned).
- Design and installation factors minimizing dropped object potential.

After installation the following is identified to be implemented for dropped object zones:

- Equipment and Outfitting Register listing items.
- Risk assessment reports for each listed item.
- An Onboard Drops Prevention Program that covers the required functions.
- Implementation and audit of the onboard dropped objects prevention program by recognized service suppliers.
- A system of record keeping that includes auditing, inspection, accidents reporting, feedback, and lessons learned.

Equipment that poses a risk of dropped object shall preferably be secured using secondary retention. If this is not possible, a securing device shall be added by the supplier, this can for instance be safety net for smaller objects such as lamps, loudspeaker etc.

Most common material used for fasteners is stainless steel, but it is recommended to pay special attention to avoid galvanic corrosion, hence as a general rule, only metals of the same or almost the same nobility should be combined in a corrosive environment. If this is not feasible, electrical isolation shall be implemented.

Energy Institute mentions that pipe clamps are prone to vibration and corrosion, and therefore components and pipework may become loose, damaged and dislodged. It shall therefore be ensured that all pipe clamps are regularly inspected for fatigue, corrosion, missing components (brackets, bolts, locking wire, tab washers). It shall also be ensured that appropriately engineered pipe clamps are used.

8 CONCLUSION

Tertiary structures/ outfitting steel structures including joining methods have been assessed with focus on dropped objects.

Based on the literature review tertiary outfitting structures were divided into two main groups;

1. Tertiary outfitting structures
   - handrails, ladders, walkways and grating, blast walls, roof plates, pipe supports for critical and non-critical pipes, trays/channels etc.
2. Equipment
   - lamps, antennas, wind cone, signal horns, loudspeakers etc.

There exists limited information regarding joining methods of tertiary outfitting structures including pipe clamps in the design standards.

Most common material used for fasteners are stainless steel and hot dip galvanized steel. It is recommended to pay special attention to avoid galvanic corrosion and electrically isolate as specified in NORSOK M-001 for some types of structures.

Currently there are no standards addressing tertiary outfitting structures for design and operation that are compulsory to comply with. DIS-ISO 24201 is a standard under development that specifies some selected tertiary outfitting structures. The recommended selection of fasteners is through bolts (bolts with nuts).

Design and types of pipe supports are covered in NORSOK L-002 and covers process, drilling, utility and instrument piping and tubing for offshore oil and/or gas production facilities, i.e. critical pipes.

Onshore and offshore standards detail integrity management of loadbearing structures, while specific requirements or recommendations for outfitting structures are not-, or only briefly addressed. NORSOK N-005: 2017 and ISO-19901-09:2019 recommends annual inspection of secondary/tertiary structures by GVI for the complete structure.

Inspection and maintenance of outfitting structures are in general subject to low attention in the industry. In addition to limited legislative requirements, this relates to low risk compared to primary and secondary loadbearing structures. Poor visibility of outfitting structures in form of limited registers and documentation from design makes planning of specific and targeted inspection difficult. The inspection extent and the inspection methods used limits detection of hazards and the lack of knowledge and competence related to the variety of configurations used, including associated degradation mechanisms and failure modes, leads to under-reporting and reduced priority for mitigation and maintenance.

Energy Institute, SfS and ABS have developed guidelines and standards to avoid dropped objects both for design and in operation. Common for these guidelines are that they mostly address equipment and only some selected outfitting structures such as handrails, ladders, pipe supports and grating.

The reason for dropped objects can be due to corrosion or excessive loads of the fasteners, either through incorrect design or lack of inspection in operation.

9 RECOMMENDATIONS

It is recommended to:

- develop a best practice on the fastening of tertiary/outfitting components and/or equipment incl. pipe supports for critical and non-critical lines. This should be referred to from NORSOK N-004 and N-005.
- carry out a workshop with the industry, both end-users (oil and gas companies), vendors and construction companies where current practice around design and operation of tertiary outfitting structures including joining methods should be discussed.
- perform a risk assessment on old and new outfitting structures with focus on the identified threats corrosion, overload, incorrect mounting, loss of pretensioning, fatigue, loosening of nuts due to vibration etc.
- improve documentation and registers to enhance visibility of outfitting structures to ensure that necessary integrity management measures are implemented.
- introduce more specific categories for inspection reporting and maintenance planning as e.g., “dropped object, personal safety barrier” to improve attention and priority for degrading outfitting structures representing hazards.

10 REFERENCES

/1/ Konkurransegrunnlag - Minikonkurranse 4/23

/2/ Risk related to falling structures, - hazards and accidents, DNV Report no. 2022-3242 rev. 2

/3/ NORSOK M-001:2014 Materials selection

/4/ NORSOK M-001:2014/A1, AMENDMENT Materials selection Annex B Implementation and use of the standard Guidance for design of dissimilar metal connections, Published: 2021-12-17

/5/ EN1090-2:2018 Execution of steel structures and aluminum structures Part 2: Technical requirements for steel structures

/6/ NORSOK N-001:2020 Integrity of Offshore Structures

/7/ NORSOK N-003:2017 Actions and action effects

/8/ DIS-ISO 24201 Petroleum, petrochemical and natural gas industries — Bulk material for offshore projects — Tertiary outfitting structures

/9/ NORSOK N-005: 2017 In-service integrity management of structures and marine systems

/10/ ISO 19901-9:2019 Petroleum and natural gas industries, Specific requirements for offshore structures,

Part 9: Structural integrity management

/11/ NS-EN-ISO 19902:2020 Petroleum and natural gas industries Fixed steel offshore structures

/12/ NORSOK N-004:2022 Design of offshore structures

/13/ NORSOK N-006:2015 Assessment of structural integrity for existing offshore load-bearing structures

/14/ NORSOK Z-008:2017 Risk based maintenance and consequence classification

/15/ https://www.hse.gov.uk/index.htm

/16/ https://www.bsee.gov/stats-facts/offshore-incident-statistics

/17/ G+/DROPS Reliable securing booklet for offshore wind, Energy Institute June 2019

/18/ Guide for Dropped Object Prevention on Offshore Units and Installations" from ABS

/19/ Handbook Prevention of dropped objects rev. 2018 Working Together for Safety (SfS): Recommended Practice 024E/2018 – Part 1, Part-1-Handbook-Prevention-of-dropped-objects-Rev-4.pdf (samarbeidforsikkerhet.no)

/20/ Preventing Dropped Objects on Offshore Units and Installations, C. Corcoran, D. Stroubakis, A. Sarthy, OTC-28419-MS (2018)

APPENDIX A

Minikonkurranse 4/23 – Risikovurderinger, teknisk sikkerhet, beredskap og analyser – Studie på prosjektering, fabrikasjon og vedlikehold av tertiære konstruksjonselementer og pipesupport

1. Arbeidstittel

Prosjektering, fabrikasjon og vedlikehold av tertiære konstruksjonselementer og pipesupport.

2. Kort beskrivelse av oppdraget

Identifisere risikoelementer, kompenserende tiltak relevant for petroleums-næringen for ulykker forårsaket av svikt i konstruksjonselementer. Beskrive praksis for utarbeidelse av krav til design (inklusive innfesting), materialvalg (inklusive korrosjonsbeskyttelse), fabrikasjon og krav til vedlikehold. Samt identifisering av hvilke nasjonale og internasjonale standarder som benyttes. Praksis i vedlikholdet av disse konstruksjonselementene.

3. Bakgrunn

Petroleumstilsynet jobber bevisst med kontinuerlig forbedring av vår risikobaserte oppfølging av aktiviteter, der oppfølging av konstruksjonssikkerhet er sentralt. Det er forbundet storulykkerisiko med konstruksjoner med fare eller ulykkesindikator (DFU) i RNNP. Konstruksjoner representerer også fare med mindre konsekvenspotensiale. I 2022 fikk vi gjennomført en studie på «Fallende konstruksjoner med hensyn til fare og ulykkesrisiko», ref. 1.

Hjemmelsgrunnlaget for Petroleumstilsynet sin oppfølging er hovedsakelig Innretningsforskriften §§ 11 om laster, lastvirkninger og motstand, og 12 om materialer, Styringsforskriftens kapittel II om risikoreduksjon og Aktivitetsforskriftens kapittel IX. Forskriftskravene er funksjonelle og de anerkjente standardene for å oppfylle sikkerhetsnivå er gitt i veiledningen til forskriftene.

4. Mål med prosjektet og forventet effekt

Målet er å redusere fare og ulykkesrisiko, identifisere risikoelementer, kompenserende tiltak relevant for petroleumsnæringen for ulykker forårsaket av svikt i konstruksjonselementer.

Etablere et analysegrunnlag for en felles tilnærming og læring på tvers. Dette forventes å gi redusert risiko for ulykker.

DNV

5. **Detaljert beskrivelse av oppdraget**

- Definere tertiære strukturer med referane til relevante standarder.

- Identifisere et relevant utvalg av tertiære strukturer og pipesupports og beskrive praksis for utarbeidelse av krav til design (inklusive innfesting), materialvalg (inklusive korrosjonsbeskyttelse), fabrikasjon og krav til vedlikehold. Samt identifisere nasjonale og internasjonale standarder som benyttes i dette arbeidet. Beskrive praksis i vedlikholdet av disse konstruksjonselementene.

- Rapporteringsrutiner og statistikker på relaterte hendelser.

- Identifisere lærepunkter og forbedringsområder.

6. **Samarbeidsform**

Møte ved oppstart avholdes hos leverandør. I prosjektperioden er det krav til månedlige statusmøter på video e.l., for rapportering av fremdrift og tekniske avklaringer. Leverandør er ansvarlig for etablering av agenda og referat fra møtene. Innsamling av data fra aktørene er leverandør ansvarlig for. Dette bes redegjort for i løsningsforslaget.

Utkast til rapport presenteres hos Petroleumstilsynet i Stavanger 14 dager før endelig rapportutgivelse. Eventuelle kommentarer fra Petroleumstilsynet oversendes leverandør sju dager før endelig rapportutgivelse. Utgifter knyttet til leverandørens presentasjon hos Petroleumstilsynet skal inkluderes i prosjektforslagets totalkostnad.

7. **Leveranser**

- Sluttleveransen er en rapport på norsk.
- Presentasjon av arbeidet hos Petroleumstilsynet ved utkast til endelig rapport, presentasjonen (Powerpoint) skal kunne brukes av Ptil.

8. **Rapportering og konfidensialitet**

Rapportutkast og utkast til konferanseinnlegg er konfidensielle. Endelig rapport publiseres på Petroleumstilsynets nettside.

9. **Økonomisk ramme**

Øvre økonomiske ramme for prosjektet er kr. 600 000 eks. mva. inkl. eventuelle reisekostnader forbundet med gjennomføring av oppdraget.

10. Forventet oppstart/avslutning av oppdraget

27.09.23 - 11.12.2023

11. Forlengelse/utvidelse av oppdraget

Ptil skal ha mulighet til, innenfor oppdragets arbeidsbeskrivelse, å forlenge/utvide oppdraget i tid og kostnad.

12. Referanser

1. DNV, ASSESSMENT OF NON-CONVENTIONAL FASTENING SYSTEM Risk related to falling structures, - hazards and accidents, 2023. (www.ptil.no/fagstoff/utforsk-fagstoff/prosjektrapporter/2023/fallende-konstruksjoner-vurdering-av-fare--og-ulykkesrisiko/)

About DNV