ASSESSMENT OF NON-CONVENTIONAL FASTENING SYSTEM

Risk related to falling structures, - hazards and accidents

Petroleumstilsynet

Report No.: 2022-3242, Rev. 2
Document No.: 1763794
Date: 2023-02-28

Project name: Assessment of non-conventional fastening system

DNV AS Energy Systems
Materials & Structural Int Advisory - Oslo-4100-NO
Veritasveien Høvik 1363
Norway
Tel: 945 748 931

Report title: Risk related to falling structures, - hazards and accidents
Customer: Petroleumstilsynet,
Professor Olav Hanssens vei 10
4021 STAVANGER
Norway
Customer contact: Morten A. Langøy
Date of issue: 2023-02-28
Project No.: 10385338
Organization unit: Materials & Structural Int Advisory - Oslo-4100-NO
Report No.: 2022-3242, Rev. 2
Document No.: 1763794
Applicable contract(s) governing the provision of this Report:
Avrop nr: 06725 – 01-2022 - 992989 – saksnr. 2022/1418

Objective:

Prepared by:	Verified by:	Approved by:
Brit Graver Principal specialist	Digitally signed by Løken, Sondre Date: 2023.02.28 15:02:48 +01'00' Sondre Løken Head of Section - Materials Advisory	Digitally Signed By: Gustav Heiberg Location: Høvik, Norway Signing Date: 01.03.2023 Contact Info: +47 67579900 Gustav Heiberg Head of Section – Structural Integrity
Tone Hasle Principal Engineer		

Keywords:
Non-conventional fasteners, tertiary components, galvanic corrosion, dropped object, fatigue, overload

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	16.12.2022	First issue			
1	03.02.2023	Final revision			
2	28.02.2023	Final revision after updated comments			

Table of Contents

1 EXECUTIVE SUMMARY

The Petroleum Safety Authority (PSA) has requested a project study to identify experiences with explosion welding between steel and aluminum and "non-conventional" fastening of tertiary components, and to identify threats and risk-reducing measures.

DNV has identified and categorized different non-conventional fastening systems, described the methods and identified typical experience, damage, and integrity challenges in the industry. The non-conventional fastening methods can be divided in welding and non-welding, as listed in Table 1-1.

A review of selected standards and best practices shows that there are limited requirements towards non-conventional fastening of tertiary items. The focus for an operator is mainly on structural bolted connections and traditional welding. NORSOK M-001 Amendment has some requirements towards selection of material and how to avoid galvanic corrosion between steel and aluminum by electrical insulation however, these are mainly for through-bolts. To DNVs understanding the most common fastening material is stainless steel alloy 316.

The review of industry experience, selected incidents from PSA's Incidents database ("Hendelsesdatabasen") and Investigation reports ("Granskningsrapporter") has identified that galvanic corrosion between the fastener and the tertiary component and overload/fatigue due to wind are the most common threats leading to dropped objects.

The challenge is that tertiary components can be fastened to structural items and DNV is aware that blind bolts have been used in RHS profiles leading to water ingress and internal corrosion of the structural steel member. NORSOK M-001 Amendment 2021 gives requirements towards this.

It appears as no regulations exist for non-conventional fastening system, whereas there exist some regulations for explosion and friction stir welding. Some operators have qualified non-conventional fastening systems for use on tertiary components, but this appears more as an exception.

Most inspection programs are based on risk assessments, where the components listed in Table 7-1 normally will obtain much lower risk than other structural elements. Consequently, they may be given less priority when planning for and selecting areas for inspection.

Table 1-1 Connection methods and tertiary components to be fastened

Connection methods	Tertiary components
• Explosion and friction welded connections	• Bumpers • Railings
• Stud welding (friction welded, arcwelding, resistance or capacitor discharge) • Blind bolts /Expansion bolt Blind threaded insert /riv-nut • Self-tapping screws • Clips • Nails and screws **- not evaluated**	• Railings • Stairs • Door frames • Metal and fiberglass gratings to steel and aluminum • Cable, conduit and tubing connectors to steel and aluminum • Trays, channels and struts to steel and aluminum for cable, conduit and tubing runs • Instrumentation, junction boxes, lighting • Pipe hangers • Signage • Grounding and bonding equipment (e.g., for equipment, pipe flanges, storage tanks, junction boxes etc.)

2 INTRODUCTION

2.1 Background

Structural components, often defined as tertiary, such as bumpers, handrails, fixed armatures, stairs and cable trays are usually not considered as part of the risks related to major accidents. However, the consequence of a falling object or man-overboard situation is as critical as a hazardous leakage and may results in causalities.

The Norwegian PSA has therefore asked DNV for a mapping of critical connections that can result in a dropped object. DNV will identify different connection types, threats and risk-reducing measures.

2.2 Scope of work

Appendix A and Ref /1/ contains the invitation to tender from the Norwegian PSA. The scope of work was modified in kick-off meeting dated 03.11.2022.

The purpose of the study is to identify experiences with explosion welding between steel and aluminum and "non-conventional" fastening for tertiary components, and to identify threats and risk-reducing measures.

PHASE 1 – Mapping and information gathering

- identify and describe explosion welding between steel and aluminum (e.g. welding shape, microstructure) and "non-conventional" connections
- identify relevant requirements and standards and scope in use in maritime, oil and gas and possibly other industries.
- identify typical experience, damage and integrity challenges in the industry (eg galvanic corrosion, brittle fracture).

PHASE 2 – Systematization and reporting

- Based on the findings, DNV must identify and systemize relevant threats linked to design, execution and operation, including degradation mechanisms such as galvanic corrosion.
- These threats will form the basis for identifying lessons learned and areas for improvement
- Recommendations for further work, if relevant

PHASE 3 – Reporting and presentation

Other joining methods relevant for offshore/maritime will also be considered, for example;

- Other welding methods such as friction stir welding (FSW), magnetic pulse welding (MPW), ultrasonic welding (DNV – evaluate whether these are relevant)
- Non-conventional connections between railings and steel, grating and steel, suspension of fittings, sound, ventilation, stair towers etc. which are not conventional bolting. This can be Hilti, Hollo, stud welding etc.
- Only connections with steel as one of the materials are part of the scope of work, e.g. steel against steel and steel against aluminum.
- The focus of the work is on connections with danger associated with falling objects or man overboard

3 CONNECTION METHODS

3.1 Welded connections

3.1.1 Introduction

Welding of dissimilar materials with different melting points requires other joining methods than conventional arc welding. Joining aluminum to steel is commonly welded together with explosion welding where a controlled detonation generates a high pressure between the metals that fuses them together at an atomic level. Joining steel to aluminum can also be done with the force of friction. Use of preproduced Bi- or Trimetal elements in maritime and offshore industry to form a transition between dissimilar metals has been used for some years. The quality may derivate depending on both manufacturing, installation, and surface treatment.

3.1.2 Explosion welding

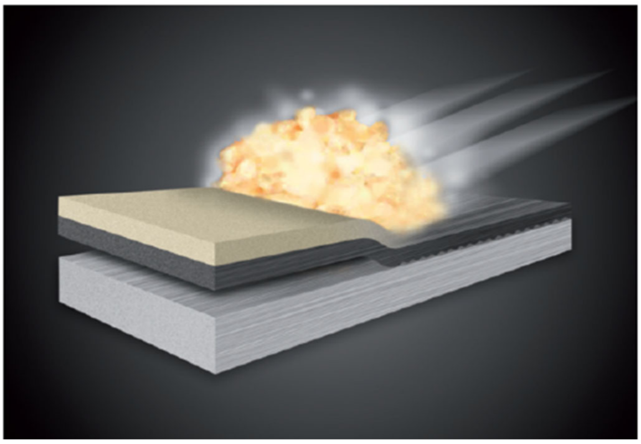
Explosion welding has a history back to First World War when military personnel noticed that when exploding bombs cause metals to fuse together. After the war the process was developed further in lab conditions to be perfected for conventional manufacturing purposes.

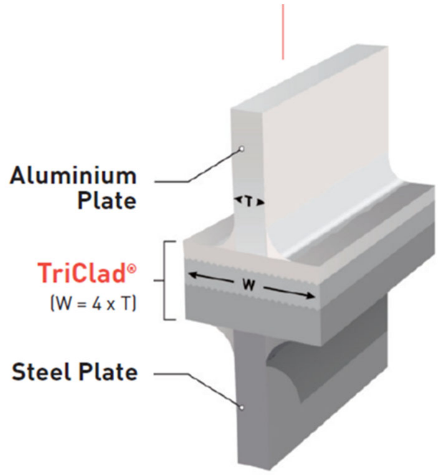
Explosion welding is performed with a controlled compression force created by detonation of explosives to fuse plates together. After ignition the joining plates are moved together with a high speed so that plastic deformation fuses them, see illustrations in Figure 3-1. The surface of the plates, distance between the plates and the angle in addition to the detonation energy is crucial for the result. The surface shall be clean from any contaminations such as grease, oil, oxides or paint. The angle and the distance are also very important parameters in addition to the detonation energy. This will vary due to materials and dimensions.

Prefabricated Bi-or Trimetal elements have been used for many years in the maritime industry. This consists of an explosion welded carbon steel to aluminum and is typically used to join hull to superstructures or decks. Typically, there are 3 layers; steel, an intermittent layer of pure aluminum and on top alloyed aluminum, typically A5056 or A5083. The pure aluminum is softer and acts like a buffer layer.

In installation precautions must be taken to the following factors:

- Welding closer than 3mm from fusion line between aluminum and steel is not recommended and the temperature in this area should be kept below 300°C. Aluminum has good heat conductivity which means that there is an elevated risk of delamination of the pure aluminum layer when welding or gas cutting is performed close to the Bi/Trimetal
- After installation, it is important to apply proper surface treatment (e.g. coating) and maintain this regularly.





a) b)

Figure 3-1 a) Illustration of explosion welding. b) Triclad, where aluminium is joined with a steel plate Illustrations from NobleClad TriClad brochure.

The advantage with explosion welding is that it is a fast process with no spatter and no arc flash, hence the surface finish is very good. In addition, there is little or no deformation in the process. The weld has in many cases the same yield strength as the base material

The process has some safety concerns and facilities must be in such a condition that the risks are limited for handling, noise and the controlled detonation in this process.

For the final product there will be a possibility of galvanic corrosion and care must be taken in installation and maintenance. Read more in the chapter regarding corrosion.

As in all other welding applications, a controlled process is important to achieve a correct quality and this shall be follow up with inspection. Good control is also important at installation and as mentioned before; be careful with welding and gas cutting close to the Bi/Trimetal because of risk of delamination which will further lead to initiation of galvanic corrosion. Correct surface treatment and maintenance of this is crucial for the result. Additional information can be found in Refs. /9/-/12/.

Magnetic Pulse Welding is another joining method, see Figure 3-2. Developments have been done to minimize the risks with explosion welding by removing the explosion and replacing it with Magnetic Pulse welding. This gives the same kind of joining as a plastic deformation/ fusion. There are some limitations with respect to thickness of the workpieces. Sufficient electrical conductivity will induce eddy currents and build up magnetic pressure and will produce a process suitable for line production of dissimilar joints.

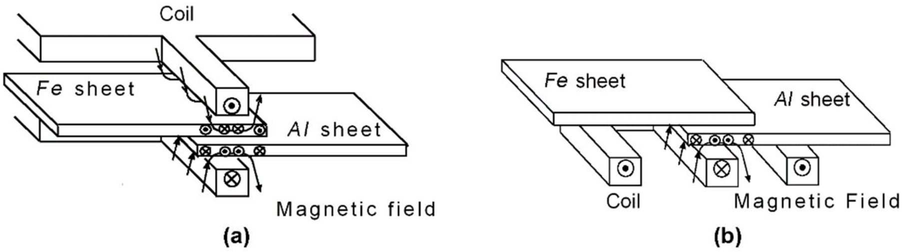


Figure 3-2 a) MPW coil structure where a) is a double layer, H shaped flat coil , and b) is one layer E shaped flat coil taken from Ref. /13/

3.1.3 Friction welding

Friction welding is another solid phase joining technique. This is a process which works by rotating a stud between two workpieces which are joined to each other under a compressive axial force, see Figure 3-3. This friction produces heat, and the interfaces plasticise together and the joint is at an atomic level.

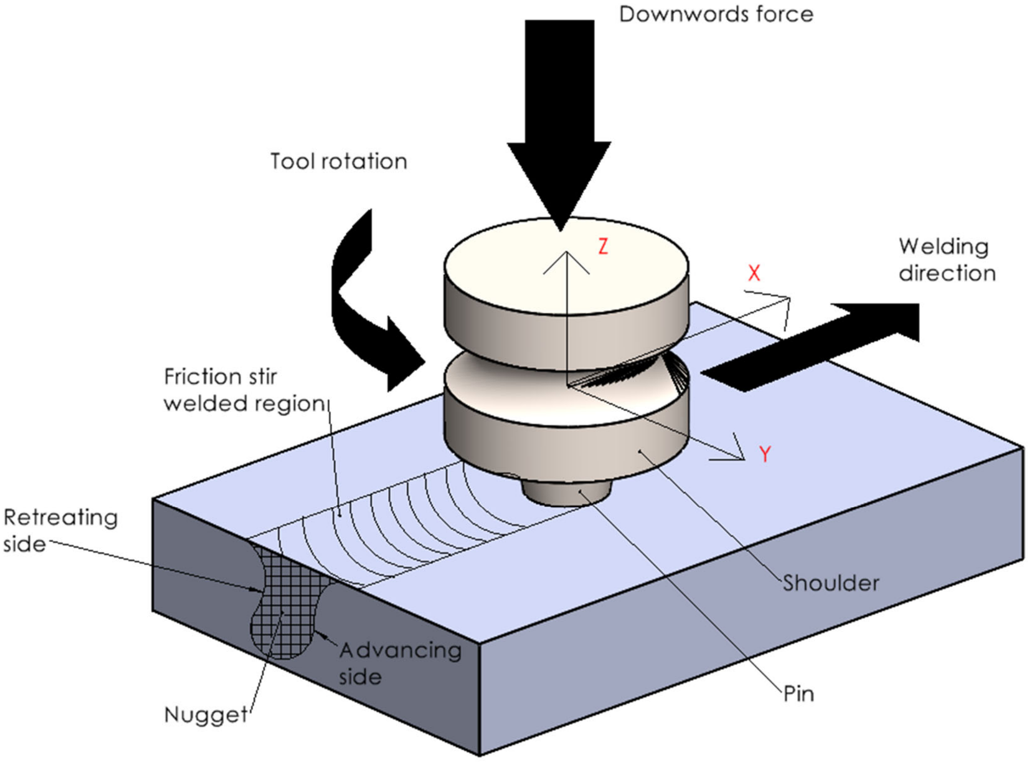
There are four different processes of friction welding;

- Friction Stir welding
- Friction spot welding
- Linear friction welding
- Rotary friction welding.

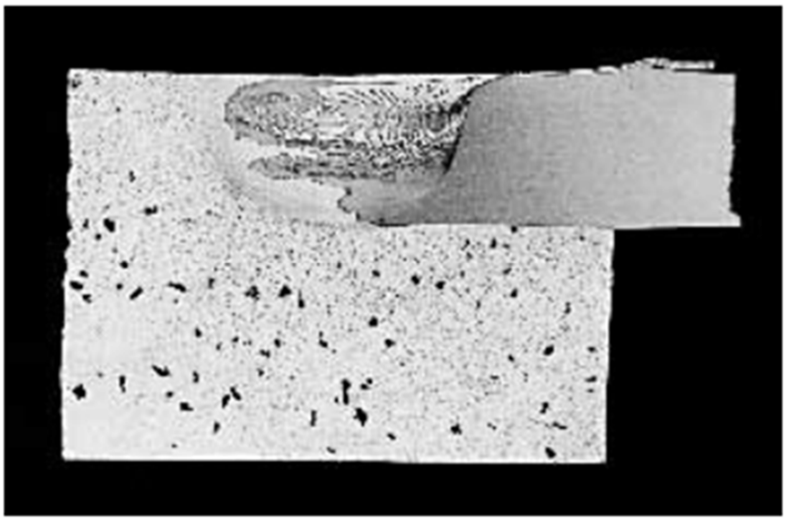
The first two methods use a special tool to generate friction heat and mechanical mixing. The linear and rotary friction welding do not require a non-consumable tool because in this case the workpieces are oscillated relative to each other under a compressive force. Friction Stir Welding was invented and patented by The Welding Institute (TWI) in 1991. This technique is mostly used for joining aluminum to itself in larger structures like helicopter decks.

The advantage is that no or little distortion will occur since there is no melting of the materials, only mechanical joining. And that it is possible to join dissimilar materials with different melting points since there is no melting in this process. The process produces a high weld quality with mechanical properties as good as parent material. The yield strength will decrease when aluminum is welded with a melting technique, but with a friction stir process the strength will stay unchanged. Because of no or little distortion the fatigue properties are also excellent.

Friction stir welding can be used for copper, lead, magnesium, zinc and titanium as well as for steel and aluminum



a)



b)

Figure 3-3 a) Friction stir welding principle b) Macro of a friction stir welded joint (Part of thermomechanical zone (TMAZ))

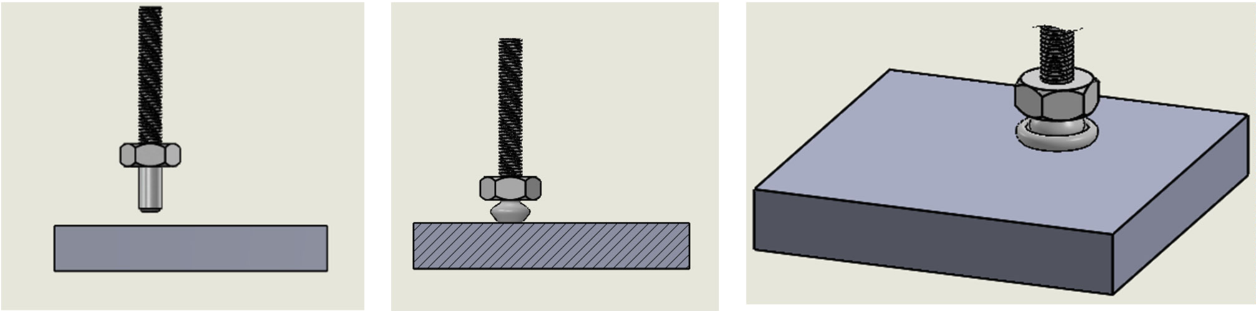
3.1.4 Stud welding

Stud welding is a general term to describe how to join a stud to a workpiece. The processes can be arcwelding, resistance, friction or capacitor discharge.

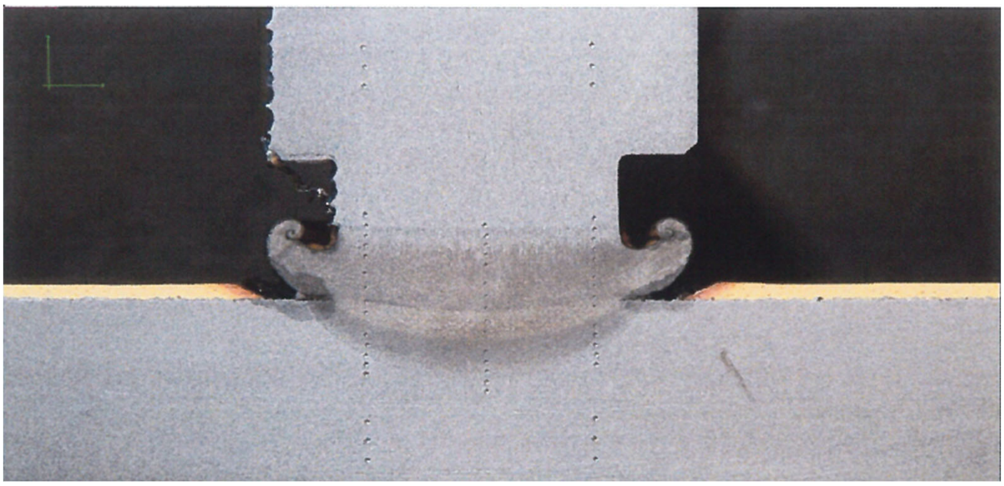
Arcwelding is done by heating the stud and creating an arc between the stud and workpiece, the pieces are then put together with a low pressure.

Capacitor discharge is performed with the heat that comes from a rapid discharge of electrical energy from a bank of capacitors.

Friction stud welding is the same process as described above in Sec. 3.1.3. Friction heat from the rotating stud that is pressed on to a workpiece will mix the two materials together. The advantage is the quick process with good quality if performed correctly. As for all other techniques it is important to follow the procedure and have the welding gun in a 90-degree angle. Inspection with NDT is difficult or not possible, but some tests can be done. The tests can be a sound check and/or a 5% bending test. That is to test and bend one of every 20 studs. For qualification of such welds tensile, macro and hardness testing can be done. Hardness can be high in the base material where the stud is pressed in.



a) b) c)



d)

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.

Friction welded bolts are commonly used offshore to fix grating, cable trays etc. The threaded studs are fasteners with male threads for attachment on one end and a friction welded tip on the other end for embedment into the structural steel of a minimum steel thickness (usually 8 mm), see Figure 3-5.

![DNV]

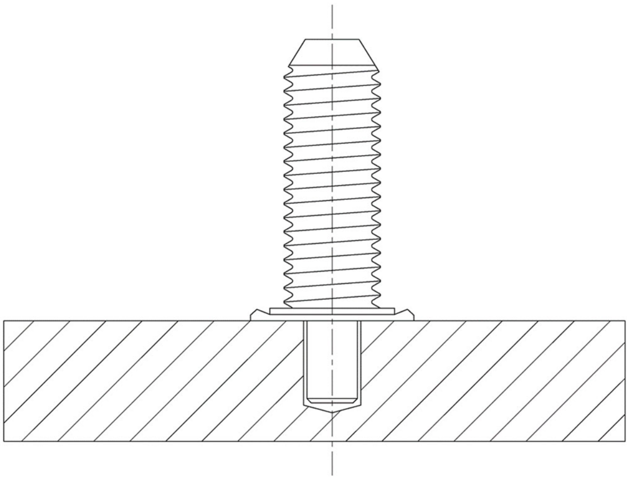
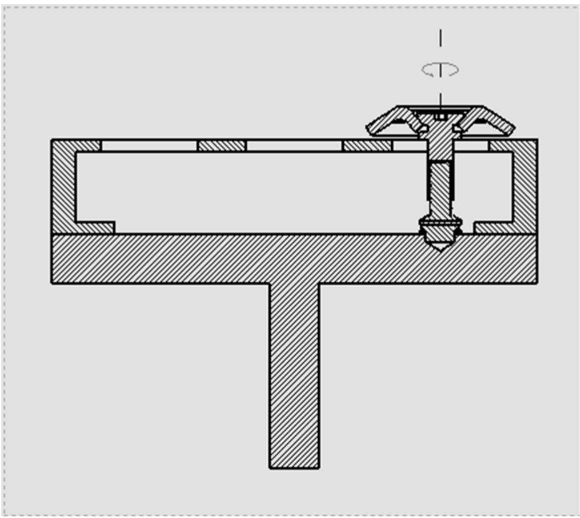


Figure 3-5 Example of a friction welded bolt with a predrilled hole

Friction welded studs are often used for fastening gratings a disk is threaded on top of stem, Figure 3-6. There exist different types of clips (see also Sec. 0) and usually the vendors deliver both the stem and the clip. The material can either be duplex coated carbon steel or stainless steel.



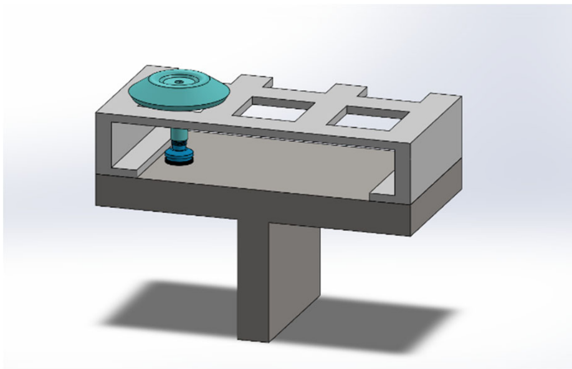


Figure 3-6 Example of friction welded fastener for grating

3.2 Fasteners and connection methods

3.2.1 Bolts and nuts

See PSA report /3/ for bolted connections with bolts and nuts. See Figure 3-7 for examples of horizontal bolted connections.

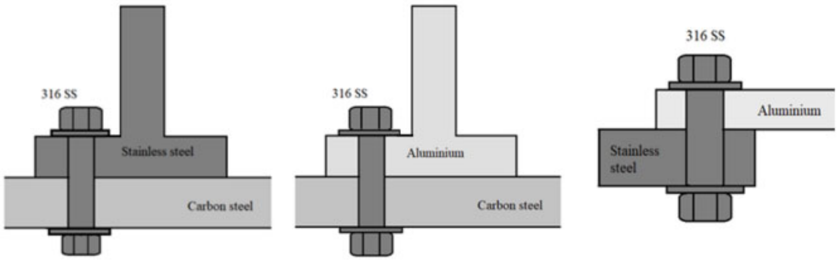


Figure 3-7 Typical horizontal bolted connections/3/

3.2.2 Self-tapping screws

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. The type of fastening system can be both perforation and non-perforation.

The self-tapping screws are used to fasten materials in areas where welding or drilling for bolting is permissible, e.g., gratings, installation channels, installation rails, junction boxes and lightning, control panels, cable trays, cable channels, checker plates. This type of fastening is commonly used in the ship and shipbuilding environment and on offshore Structures. For outdoor applications (mainly the stainless-steel fasteners) the intended use comprises connections for predominantly static loads (e.g., dead loads).

Figure 3-8 shows a threaded stud which are set into a pre-drilled pilot hole and the drill entry point is then completely sealed by the stud washer during setting. If sealing ring is used, the sealing ring can be in an elastomeric material such as chloroprene rubber.

For thinner plates the stud can be set into a through hole. In this case a rework of the protective surface on the backside is potentially needed, usually by applying coating or a sealer.

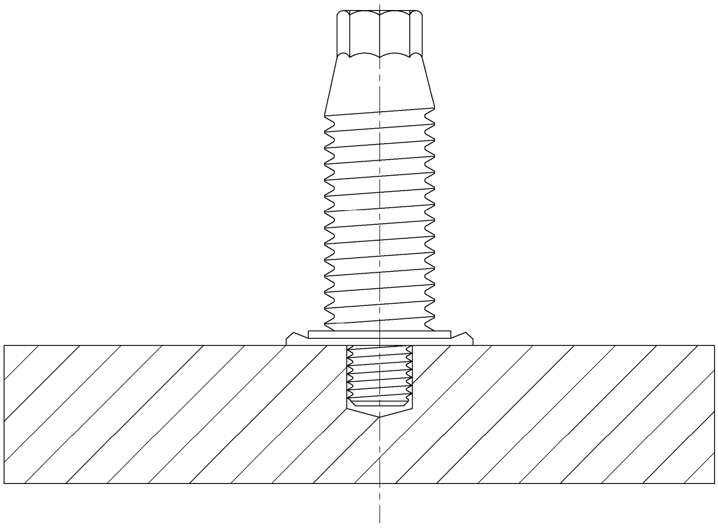


Figure 3-8 Example of a self-tapping screw in a predrilled hole

Table 3-1 Examples of typical plate thicknesses for some self-tapping screws

Base material	Base material thickness [mm]	type of bore hole
Steel	≥6	Pilot hole
Aluminium	≥6	Pilot hole
Steel	6 > t ≥ 3	Drill-through
Aluminium	6 > t ≥ 5	Drill-through

The stud materials can be stainless steel and carbon steel with duplex-coating Zn-alloy and a topcoat.

3.2.3 Pop rivets, rivet nuts and expansion bolt (blind bolts)

There are a lot of different types of blind bolts on the marked. 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.

Typical materials are aluminum, carbon steel and stainless steel. These can be coated by different types of coating systems, including galvanization for carbon steel.

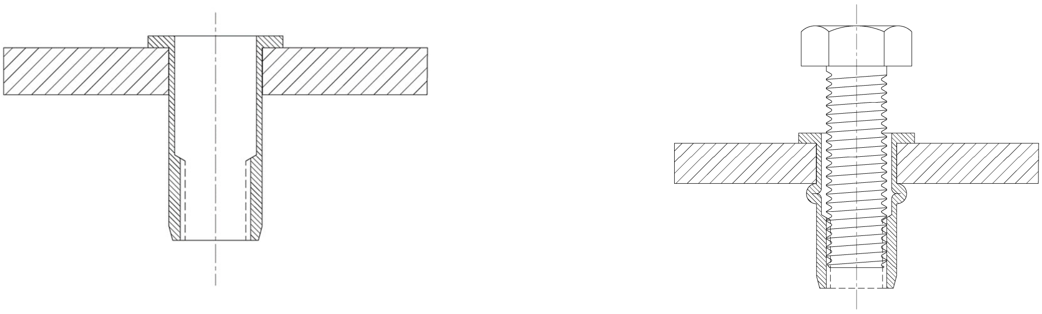
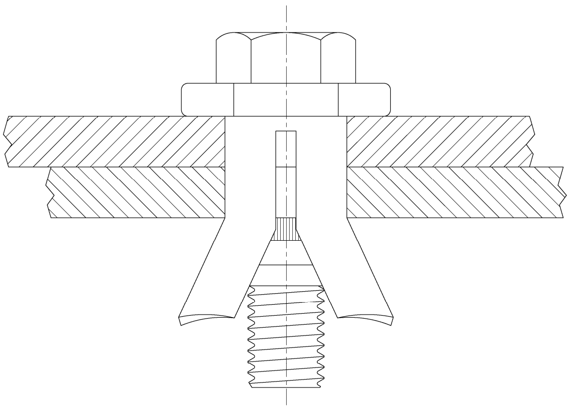
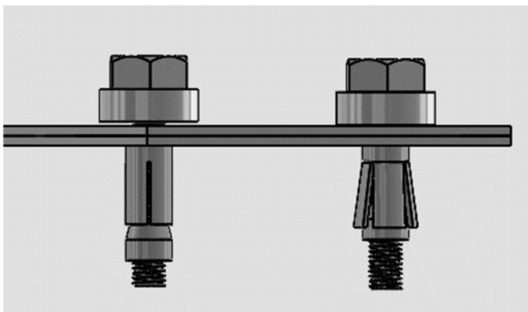


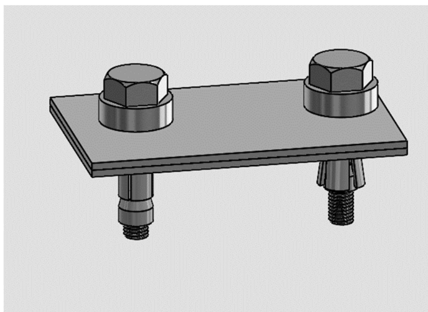
Figure 3-9 Example of blind rivet-nut without and with bolt



a)



b)



c)

Figure 3-10 a) – c) examples of an expansion bolts during and after fastening

3.2.4 Grating Clips

Grating fasteners or clips are used to attach gratings to a structural member. These clips can be in various shapes, depended on how the grating shall be secured. Saddle clips, butterfly, M-clip, square clip , L-clip, C-clip are some types of fasteners that are fastened with a stud that is driven into the structural member either self-tapping/drilling or friction welded, see Figure 3-11. Usually, the vendor will deliver the clip with the stud.

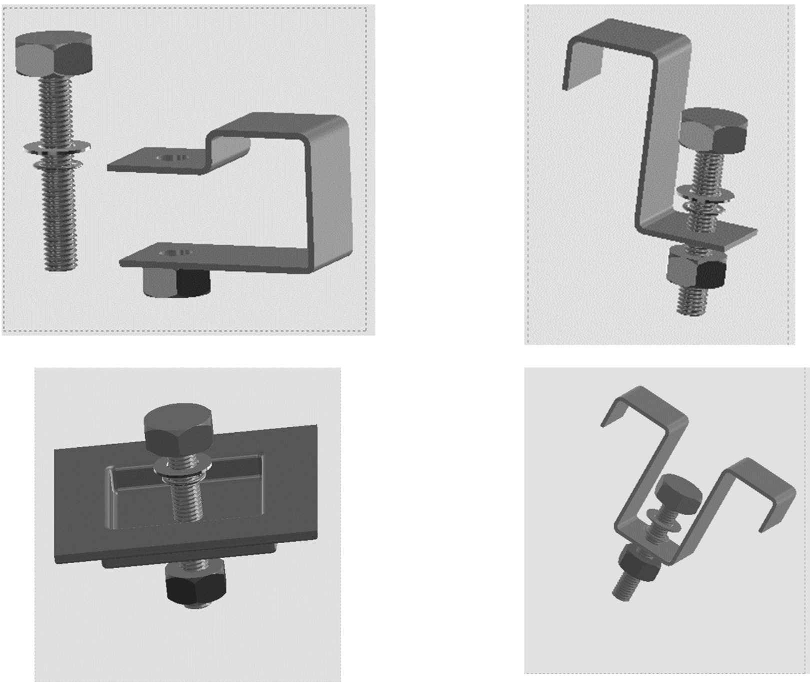


Figure 3-11 a) C- clips, b) L-clip, c) square-clip and d) m-clip with studs

Other types of grating fasteners are for instance G clips which is a type of clamp connector that does not perforate the steel structure, see Figure 3-12.

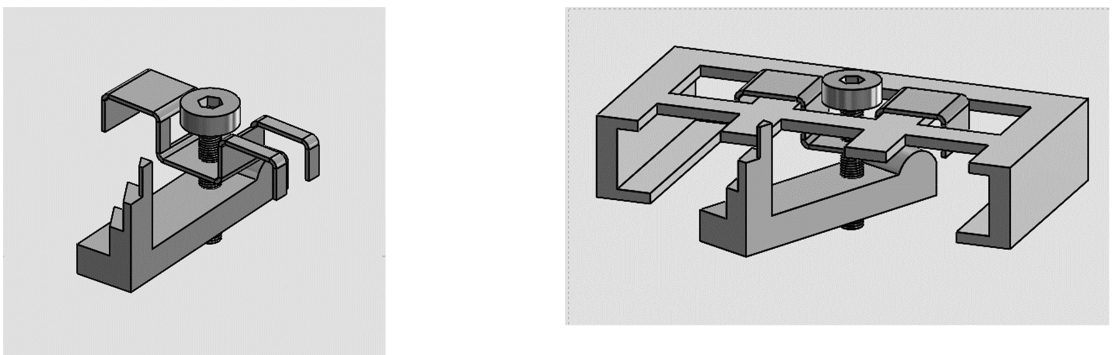


Figure 3-12 Grating G-clips without and with grating

3.2.5 Threaded insert /threaded bushing

These systems can be used as repair of damaged threads. A coiled-wire or a solid type of thread is inserted to create internal screw threads, see Figure 3-13. This is a permanent repair solution.

The materials can be stainless steel and carbon steel.

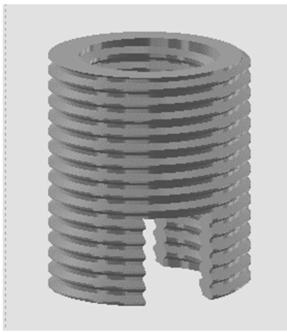


Figure 3-13 Examples of threaded insert /threaded bushing. Left picture is coiled-wire thread and right picture is solid thread.

4 EXPERIENCE WITH CONNECTIONS EXPOSED TOWARDS MARINE ATMOSPHERE

4.1 Explosion welding

An incident with delamination of footplates on aluminum rails were reported to the Norwegian PSA /7/. The footplate was a part of a bumper in aluminium and located on an offshore installation. A full failure investigation was carried out. Aluminum rails welded to explosion welded Trimetal had loosened from deck and caused a risk situation. Root cause was not fully investigated, but one suggested element is that heat transfer from welding to close to fusion line between steel and aluminum may cause delamination which can further lead to galvanic corrosion. Damaged or improper coating due to lack of regular maintenance can also be part of the failure. The buffer layer with pure aluminum is not fully seawater resistant and can corrode when exposed to spray of saltwater.

4.2 Galvanic corrosion between self-tapping screws and ventilation grid

This incident happened in a HVAC area and was reported to the Norwegian PSA. However, the system was exposed towards marine atmospheric air, bringing salts and moist.

Self-tapping screws in non-galvanic material were used to install a ventilation grid without isolation between the screw and ventilation grid. This led to galvanic corrosion and resulted in the ventilation grid falling down onto the deck. The materials are unknown. There was no secondary retention for the ventilation grid.

The investigation identified that neither the installation requirements, nor the guidelines from SfS.024 Handbook for securing permanent equipment with bolted connection, had been followed. These components should have been installed using 316 Stainless steel Bolt & Nut, and with further wire net/mesh rather than a lamella grid.

4.3 Shelter plate on drilling rig

A shelter plate on a rig had fallen down during a storm with strong winds was reported to the Norwegian PSA. The plate was fastened by pop-rivets on both ends and had been installed when the rig was built (about 10 years ago). When inspecting the rivets there were clear signs of galvanic corrosion, where the fasteners had corroded. Fasteners were not according to the guidelines from SfS.024 Handbook for securing permanent equipment with bolted connection and were also not a part of an inspection regime. The recommendation in SfS.024 is to use through bolts with nuts and locking rings.

4.4 Galvanic corrosion between aluminum handrails and steel structure

On an offshore installation tack welded 316 studs loosened due to insufficient welding and subsequent galvanic corrosion between 316SS and the carbon steel structure. The studs were used to fasten handrails in aluminum towards the carbon steel structure.

4.5 PSA Incidents database (Hendelsesdatabasen)

The Incidents database is a database where all incidents reported by the operators to PSA are recorded. DNV has reviewed some selected incidents made available by the Norwegian PSA /2/. The criteria for the reporting were heavy objects that could cause a third-party damage. Twenty-three incidents that were related to dropped objects had been reported and the weight on the objects ranged from 0.7 kg to 47.2 kg. The fastening type and the damage cause were unknown in most situations, however in some cases corrosion was reported to be the root cause. The incidents often occurred after storms or heavy winds.

Table 4-1 Reported incidents from operators and rig owners to the Norwegian PSA 2020-2022

Number	area	fastening system	structure material	bolt material	Component material	component	Damage cause	Risk	weight (kg)
1	drilling module	weld	unknown	none	unknown	drain pipe	corrosion	dropped object	6
2	scid deck	unknown	unknown	unknown	unknown	cover	unknown	dropped object	20
3	drilling module	unknown	unknown	unknown	unknown	door on control panel	unknown	dropped object	16
4	pipe deck	bolts	unknown	unknown	unknown	brackets	vibrasion	dropped object	7,5
5	unknown	unknown	unknown	unknown	unknown	wind wall	unknown	dropped object	10
6	Upper - Lower deck	unknown	unknown	unknown	unknown	hand rails	unknown	man over board	47,2
7	pipe deck	unknown	unknown	unknown	unknown	HVAC roof plate	unknown	dropped object	7,26
8	Area M14	weld	steel	none	steel	handel on deice system valve	weld defect	dropped object	4,5
9	TK 904	bolts	unknown	unknown	unknown	cover plate	corrosion	dropped object	8
10	unknown	unknown	unknown	unknown	unknown	signage	unknown	dropped object	2,05
11	landing area	pop rivets	stainless steel	aluminium	steel	signage	galvanic corrosion	dropped object	0,7
12	Top	unknown	unknown	unknown	steel	cover plate on cable tray	unknown	dropped object	6,85
13	living quarter	unknown	unknown	unknown	aluminium	wall plate	unknown	dropped object	7
14	messanin deck	unknown	unknown	unknown	unknown	protection structure for light	unknown	dropped object	71
15	mob-båt deck	unknown	unknown	unknown	aluminum	grating	unknown	dropped object	1
16	M18M	unknown	unknown	unknown	unknown	drip tray (temporary)	unknown	dropped object	1,48
17	riser gantry control cabin	unknown	unknown	unknown	unknown	AC hatch	unknown	dropped object	12,6
18	E500	bolts	unknown	unknown	unknown	bolt for exhaust pipe clamps	unknown	dropped object	1
19	Crane area	unknown	unknown	unknown	unknown	bar holding wind cone with light	fatigue	dropped object	15
20	Antenna Deck	unknown	unknown	unknown	unknown	metal part from wind cone	unknown	dropped object	0,7
21	level 11 Cold box	unknown	unknown	unknown	unknown	lid from electro cabinet	corrosion	dropped object	1,8
22	unknown	unknown	unknown	unknown	aluminum	cover on windwall	unknown	dropped object	7
23	drilling deck	pop rivets	unknown	unknown	unknown	Shelter plate	corrosion	dropped object	12

5 RULES AND REGULATIONS

5.1 Introduction

A review of some selected onshore and offshore standards and best practices has been carried out with focus on non-conventional fasteners and tertiary components. The identified standards are design standards, which to some extent covers some of the tertiary components in this study such as handrails, ladders and staircases, wind walls, access platforms and aluminium structures /5/. Other tertiary components such as cable trays, signage etc. as described in Sec. 4 , appears as not covered by these standards.

5.2 Offshore Standards

The governing standard for material selection is NORSOK M-001 /4/ including addendum from 2021 /5/.

In general, NORSOK M-001 give guidance on how to select proper bolt materials and how to avoid galvanic corrosion between dissimilar materials in the design phase for pressure equipment and structural use.

In the addendum to NORSOK M-001 from 2021, there is a particular focus on bolting of handrails, ladders and staircases, wind walls, access platforms and aluminium structures bolted with stainless steel bolts. The recommended fastening material is stainless steel with sufficient electrical insulation to avoid galvanic corrosion. In addition, adequate slope and drain to avoid water being trapped shall be accounted for in design and different metallic materials shall be separated by suitable isolation to avoid galvanic corrosion.

It is also specified that bolted connections made by drilling holes in hollow sections such as rectangular hollow section (RHS) or squared hollow structures (SHS) profiles or similar are not permitted. Further, it is specified that if stainless steel bolts or screws are threaded into carbon steel, a suitable thread sealant shall be applied to the threads to prevent ingress of water and corrosion of the threads.

NORSOK Standard M-102 covers bolting of aluminium structures towards steel or aluminium, and what type of bolt material to be used. The recommendations for bolt materials are aluminium, stainless steel 316 or galvanised steel in internal dry environment and 316 stainless steels in marine atmosphere.

In general, these standards only cover design and new-build and not modifications or repairs where welding or hot working is not allowed.

There are no specific requirements towards non-conventional connections. For non-conventional welding NORSOK M-001 specifies that familiarisation and qualification programs might be required if the fabrication contractors have limited experience.

It is noted that an iso standard (ISO/DIS 24201) is under development covering tertiary outfitting structures.

5.3 Onshore standards

EN1090 which is an onshore standard for the build construction for structural component. The standard specifies that stairs and railings whose sole function is to prevent a person from falling are not structural products because they do not support (part of) the structure /6/. This means there are no requirements towards non-conventional fastenings.

EN1999 covers technical requirements for execution of steel structures and aluminum structures.

The standards give recommendations towards bolt materials for structural applications.

EN1999-1 Appendix D.3.3 gives some recommendations towards bolted, riveted, welded and high strength friction grip bolted joints for structural purposes.

5.4 DNV offshore recommended practices and standards

DNV certifies ships according to ship classification rules. There are limited requirements towards non-conventional connections and tertiary components.

DNV-ST-0342 Craft

Sec 2.2.1.5.5 specifies that blind rivets shall not be used in shell plating or stressed joints.

Sec. 2.2.1.7.1 specifies for other joints that joints with through-bolts shall be designed as riveted joints. Self-tapping screws are only allowed above waterline in joints carrying insignificant loads.

Several DNV standards specifies that for bolt connections considered as secondary shall be made from suitable materials.

DNV-ST-0358 Offshore gangways

Fasteners (bolts, nuts and washers) in marine environment shall normally be hot-dipped galvanized or sherardised with coating thickness min. 50 micrometre. If special thread profiles or narrow tolerances prohibit such coating thickness, bolts/nuts may be supplied electro-plated or black provided properly coated/painted after installation. Pickling and electro-plating operations shall be followed by immediate hydrogen-relief (degassing) treatment to eliminate the risk of hydrogen embrittlement.

5.5 Ship classification rules

DNV certifies ships according to ship classification rules. There are limited requirements towards non-conventional connections, however for explosion welding there are some rules.

4.4. Ship rules RU-SHIP Pt.2 Ch.4 Sec.5

1.5.3 - welding of clad products

In case of explosion bonded steel-aluminium transition joints, the qualification of the WPS for the steel part to the steel structure and for the aluminium part to the aluminium structure shall each follow the requirements of this section. Furthermore, the recommendations for welding given by the manufacturer of the transition joint shall be observed.

1.5.4 - Friction stir welding

For friction stir welding of aluminium, ISO 25239 shall be applied.

In addition, DNV has several ITG for different areas to secure consistency and quality for the inspectors. One example is Internal Technical Guideance 0454 for Materials, Welding and Non Destructive Testing.

5.6 Industry best practice

“Samarbeid for sikkerhet (SfS)” has developed a Recommended practice 024N/2018 – del 1 /8/ which summarizes the relevant requirements for how to secure tools, fixed and loose equipment. For fixed equipment different bolting systems are listed and recommendations are given towards these. The handbook divides the components in structural items (grating, railings, windwalls), electro and instrument (light-fixtures, cameras, cable trays, wind cone) and other structures (signage etc.). The best practice does not explicitly mention type of fasteners which can be used. The Best Practice recommends using through bolts as far as possible and to avoid galvanic corrosion. No information regarding non-conventional fasteners is mentioned.

5.7 Operator/vendor best practice

This section is based on contact with selected operators, vendors, sub-suppliers, DNV inhouse experience and literature review.

Some operators have regulations much similar to NORSOK M-001 addendum 2021. This is however for new build and covers mainly handrails, ladders and staircases, wind walls, access platforms and aluminium structures. Some operators informs that in operation the use of alternative fasteners is not regulated and is evaluated by the purchaser/engineer.

In the maritime industry there are cases where vendor specific self-tapping screws and grating fasteners have been type approved as an alternative to welding. The type-approval documentation is extensive and covers both mechanical integrity and corrosion.

Some sub suppliers of items such as cable trays etc. have received instructions from the operators on types of non-conventional fasteners. The items to be fastened are also divided into 3 categories; non-engineer (lightning fixture), load specific items and tailor-made engineered items. The sub supplier requires training of personnel to carry out the job on site. There is a high focus on electrical insulation between the bolt and the structure and to apply coating/grease to avoid trapped water.

Reliable vendors of non-conventional bolting can deliver all types of materials and coatings. They can also perform tests and document the durability if required.

6 THREAT ASSESSMENT AND DEGRADATION MECHANISMS

6.1 Component classification

Table 6-1 shows how the different tertiary components are grouped according to SfS Best Practice 024N/2018 – del 1 /8/. DNV have added some extra components such as roof plates, ventilation grids and bumper. The best practice recommends installing wires to secure the objects to the underlying structure.

Table 6-1 Item group, item/component and requirement towards fastening SfS Best Practice

tertiary components group	tertiary components	Recommended fastening type
Structures	Grating and hatches	– Through bolted or threaded connection is recommended fixing method – Clips should consist of as few parts as possible
	Pipe and equipment feedthroughs (sleeve)	No information
	Railings	– Through bolted or threaded connection is recommended fixing method – set screws are not a recommended solution for permanent railings
	Kicklist	No information
	Wind walls	– Through bolts with large washers and lock nuts. – Wind wall panels must be attached to their own support structure, never in main structure
	Ladder	No information
	Stairs	No information
	Swing gate	– Hinges should preferably be integrated as a part of swing gate
	Bumper (DNV added)	No information
	Roof plates, ventilation grids, panels (DNV added)	No information
	Sign frame/ signage	– Sign frames should be fixed with through-bolts with locking nuts – Fastening bolts towards bracket and structure are equipped with a secondary barrier
Electro and instrument	Floodlights	– The light fixture's and possibly associated transformer's fastening bolts towards bracket and structure are equipped with a secondary barrier
	Lighting fixture	– fastening bolts towards bracket and structure are equipped with a secondary barrier
	Navigation lanterns	– fastening bolts towards bracket and structure are equipped with a secondary barrier
	CCTV cameras	– The camera housing is attached to the bracket and structure in such a way that fastening bolts can be securely locked
	Crane equipment	– fastening bolts towards bracket and structure are equipped with a secondary barrier
	Loudspeaker	– fastening bolts towards bracket and structure are equipped with a secondary barrier
	Junction box, cabinets and covers	– fastening bolts towards bracket and structure are equipped with a secondary barrier
	Cable tray	– only recommended bolt connections – the potential for galvanic corrosion must be assessed and insulation should be implemented
	Windsocks, antennas, sensors	– Two fixing brackets or a minimum of 3 bolts – All bolts shall be through hole – Set screws are not allowed
Other types of equipment	Racks and storage	– Racks and storage units must be secured/fastened to permanent structures in an appropriate and durable manner
	Sign frame/ signage	–

6.2 Threat assessment and typical damages

Table 6-2 contains an overview of different threats towards non-conventional fasteners and welding. The main structure is defined to be either steel (i.e. structural members) or aluminium (i.e helidecks, living quarters etc.).

Table 6-2 Threat assessment including typical damages for non-conventional fasteners

Threat	Description	Typical damages	Mitigation
Design error	Incorrect material selection and design	Corrosion Overload Poor water tightness resulting in water ingress – In hollow structure leading to corrosion or ice-load – at the interface between fastener and structure/component leading to corrosion	Robust material selection Electrical insulate the metals Establish robust procedures for non-conventional fasteners in operation
Fabrication / manufacturing	Incorrect explosion welding in new build	Lack of fusion	QA/QC
	Incorrect NDT in new build	Lack of fusion	QA/QC
Installation	Fasteners installed not according to description	Reduced service life due to galvanic corrosion structural damages	The fasteners are to be installed and inspected using installation procedures and tools recommended by the manufacturer
Corrosion	Galvanic corrosion between fastener and structure/component	Metal loss resulting in loss of tension	Ensured that the drill entry point is sealed if no drill through Drill through hole in thin base material might require rework of the protective surface on the backside
	General corrosion of fasteners	Metal loss resulting in structural degradation of bolt	Correct selected material
	Corrosion in non-inspectable profiles due to bolt penetrations	Metal loss resulting in loss of structural integrity	Covered by Norsok M-001 addendum 2021.
3rd party	Impact damage	Detached fastener due to overload	
Structural	Overload where the bolts are not designed for the application	Detached fastener	Establish procedures for recommended loads, maximum loading in tension, shear, moment and torque.
	Fatigue in bolt due to vibration (wind or process variations)	Detached fastener	Establish procedures for recommended loads, maximum loading in tension, shear, moment and torque.
Natural hazard threats	Extreme weather	Overload	Establish procedures for recommended loads, maximum loading in tension, shear, moment and torque.
	Ice loads	Hole in hollow profiles due to perforation might lead to frost cracking due to trapped water	Covered by Norsok M-001 addendum 2021.
Incorrect operation	Incorrect maintenance	Corrosion	Procedures for inspection and maintenance
	Lack of inspection and following up	Corrosion	Procedures for inspection and maintenance

7 DISCUSSIONS

A review of selected standards and best practices shows that there are limited requirements towards non-conventional fastening of tertiary items. The focus is mainly on structural bolted connections and traditional welding. NORSOK M-001 Amendment has some requirements towards selection of material and how to avoid galvanic corrosion between steel and aluminum by electrical insulation.

Table 7-1 summarizes the identified connections methods and tertiary components and is based on a DNV inhouse experience and SFS Best Practice on Prevention of dropped objects.

Non-conventional fasteners can be delivered in different types of materials, but the most common materials identified are stainless steel, coated carbon steel and galvanized carbon steel. Further, the components to be fastened are usually in coated carbon steel, galvanized steel or aluminum.

Based on the review of the reported incidents and failure investigation reports, it appears as galvanic corrosion and fatigue/overload are the threats that has resulted in falling objects. Galvanic corrosion can either occur between the main structure and the fastener, or between the fastener and the item to be fastened. To DNVs understanding the most common fastening material is stainless steel alloy 316.

In one case regarding explosion welded aluminum towards steel, galvanic corrosion of the aluminum occurred leading to dropped object. In this case the root cause was not determined, but one theory was that heat transfer from welding to close to the fusion line between steel and aluminum had caused delamination which further led to galvanic corrosion. Another theory was that damaged or improper coating due to lack of regular maintenance led to bare metal exposure and galvanic corrosion.

Most inspection programs are based on risk assessments, where the components listed in Table 7-1 normally will obtain much lower risk than the main hydrocarbon systems. Consequently, they may be given less priority when planning for and selecting areas for inspection.

Table 7-1 Connection methods and tertiary components to be fastened

Connection methods	Tertiary structures
• Explosion and friction welded connections	• Bumpers • Railings
• Stud welding (friction welded, arcwelding, resistance or capacitor discharge) • Blind bolts (pop rivets, rivet nuts and expansion bolt) • Self-tapping screws • Clips • Nails and screws **- not evaluated**	• Railings • Stairs • Door frames • Metal and fiberglass gratings to steel and aluminum • Cable, conduit and tubing connectors to steel and aluminum • Trays, channels and struts to steel and aluminum for cable, conduit and tubing runs • Instrumentation, junction boxes, lighting • Pipe hangers • Signage • Grounding and bonding equipment (e.g., for equipment, pipe flanges, storage tanks, junction boxes etc.)

DNV is aware that blind bolts have been used in RHS profiles leading to water ingress and internal corrosion of the structural steel member. NORSOK M-001 Amendment 2021 gives requirements towards this.

In the maritime industry type approval is sometimes used for non-conventional fastening systems. The type approval gives limitations towards the structural capacity, materials selection and corrosion protection.

PSA’s Incidents database (“Hendelsesdatabasen”) contains limited information regarding the root cause of the dropped objects.

8 CONCLUSIONS

Two main types of connection methods used for fastening of tertiary components has been assessed, that is welded and non-welded connections (non-conventional fasteners);

- The welding comprises of stud, explosion and friction welding. These connections are used for joining aluminum and steel together and is performed in the construction phase since this involves hot work.
- Non-conventional fasteners are used if hot work is not allowed, typically in operation. Non-conventional fasteners are grouped into stud welded bolts, self-tapping screws, blind bolts, clips and threaded inserts. This type of fastening system comprises of joining tertiary components in stainless steel, aluminum and coated carbon steel usually towards a steel structure. Nails have not been evaluated, but that doesn't mean it is not used.

It appears as no regulations exist for non-conventional fastening system, whereas there exist some regulations for explosion and friction stir welding.

Some operators have qualified non-conventional fastening systems for use on tertiary components.

Review of industry experience has identified that galvanic corrosion between the fastener and component and overload/fatigue due to wind as the most common threats leading to dropped objects.

Fasteners such as self-tapping screws and blind bolt types should not be used in primary load bearing structures, such as RHS/SHS where the steel wall can be penetrated resulting in water ingress.

Tertiary components are usually not a part of an inspection plan.

9 RECOMMENDATIONS

9.1 Design

Procedure or qualification of non-conventional fasteners should be carried out in the design phase prior to installation of tertiary components, with focus on material selection, galvanic corrosion and structural integrity.

Insulation between different materials to avoid galvanic corrosion shall be qualified.

When designing constructions with the use of Tri/Bimetal it is important to avoid welds or design that require gas cutting close to the fusionline of the aluminum because of high risk of delamination. Coating system shall be qualified and applied according to recognized standards.

Design of tertiary components should also have the same attention when it comes to technical solutions with regards to welding and fastening systems to secure dropped objects. Extra important is selection of correct material when it comes to dissimilar joints. Overmatching alloyed consumables for joining stainless steels to carbon steel is one example, in addition to correct material in bolts, screws or rivets when dissimilar materials are joint together.

9.2 Fabrication

Welding should be according to a qualified procedure with qualified personnel and sufficient follow up even when it is considered as a tertiary component. From experience it is quite often that when the operator, foreman or inspector know that this is a connection with low criticality the quality goes down. A recommendation is that more attention should be given to these connections.

With regards to bolting, screwing and other joining methods in fabrication it is important that correct material and fastening process is followed as described in the design.

9.3 Operation and maintenance

Non-conventional fasteners and components that can be classified as tertiary should be included in an inspection regime.

Establish robust procedures for non-conventional fasteners in operation.

Welded connections considered as tertiary components should be part of an inspection routine. Responsibilities to who and when the inspection is performed should be clearly defined. Action should be taken when someone “sees something” that could lead to objects falling down or in other way result in hazardous situations. Handrails, cable trays, pipe support and signs that are close to fall dawn or loosened do not fix themselves.

9.4 Further work

It is recommended to get in dialogue with the industry to map type of connections used in the field and how these have been selected.

It is recommended to define clearer requirements particularly:

- for the type, material and assembly of fasteners, and
- maintenance and integrity management

10 REFERENCES

/1/ Konkurransegrunnlag - Minikonkurranse 3/22 - Risikovurderinger, teknisk sikkerhet, beredskap og analyser - Fallende konstruksjoner med hensyn til fare og ulykkesrisiko, saksnr. 2022/1418, Revidert 09.09.2022 13.14.42

/2/ Email from Bahram Momeni ptil to Brit Graver DNV Eksempler på hendelser med fallende konstruksjonsdeler dated 17.11.2022

/3/ REVIEW OF STRUCTURAL CONNECTIONS OF DISSIMILAR METALS – PREVENTION OF GALVANIC CORROSION; PRACTICE AND EXPERIENCE, doc. no. Z-Pt-201 rev. 03. https://www.ptil.no/contentassets/2be164e3a83c47a6be00badecc8d40d6/review-of-structural-connections-of-dissimilar-metals--prevention-of-galvanic-corrosion---practice-and-experience

/4/ NOROSK M-001: 2014 Materials selection

/5/ 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

/6/ https://www.en1090.no/CE_merking_av_stalkonstruksjoner.htm

/7/ OKEA, Failure analysis and inspection of explosion welded aluminium rails, Draugen, 10.06.2022 Målfrid Guldstein, Engineer Material / Inspection

/8/ Offshore Norge: Håndbok Beste praksis Forebygging av Fallende gjenstander rev. 2018, Anbefaling-024N-2018-Del-1-Håndbok-Forebygging-av-fallende-gjenstander.pdf (samarbeidforsikkerhet.no) 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)

/9/ TriClad® Structural Transition Joints NT300 rev 2, NobelClad, https://www.nobelclad.com/en/resources/NobelClad-TriClad-Product-Sheet

/10/ Welding Guide for Detacouple® Aluminum / Steel Transition Joints, July 2011, Dynamic Materials, https://unitedmarine.com.tr/triclad/

/11/ Explosion-bonded metals for marine structural applications, Charles R. McKenney and John G. Banker, July 1971, Marine Technology

/12/ Shockwave Metalworking Technologies BV (SMT), https://smt-holland.com/#/explosive_cladding

/13/ Application of Magnetic Pulse Welding for Aluminum Alloys and SPCC Steel Sheet Joints, T. AIZAWA, M. KASHANI, AND K. OKAGAWA, Welding Journal, May 2007, Vol. 86

APPENDIX A

Minikonkurranse 3/22 – Risikovurderinger, teknisk sikkerhet, beredskap og analyser - Fallende konstruksjoner

1. **Arbeidstittel**
   Fallende konstruksjoner med hensyn til fare og ulykkesrisiko.

2. **Kort beskrivelse av oppdraget**
   Undersøke bakenforliggende årsaker, med fokus på det tekniske, for fallende konstruksjoner. Målet er å redusere fare og ulykkesrisiko, identifisere risikoelementer, kompenserende tiltak og vedlikhold relevant for petroleumsnæringen. Beskrive hvilken praksis som benyttes i forskjellige relevante næringer og eventuelt hvilke nasjonale og internasjonale standarder den bygger på og erfaring fra drift.

3. **Bakgrunn**
   Petroleumstilsynet jobber bevist med kontinuerlig forbedring av vår risikobasert 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. Det er disse som ønskes belyst i denne oppgaven. Disse konstruksjonene karakteriseres ofte som hjelpestruktuer, men svikt kan gi fatale konsekvenser for enkeltpersoner. Her er det forbindelser som ikke er sammenføyd med tradisjonell sveising som ønskes undersøkt. En av disse er eksplosjonssveiste plater av aluminium og stål. Hjemmelsgrunnlaget for Petroleumstilsynet sin oppfølging er hovedsakelig Innretningsforskriften §§ 11 om laster, lastvirkninger og motstand, og 12 om materialer og Styringsforskriftens kapittel II om risikoreduksjon. Forskriftskravene er funksjonelle og de anerkjente standardene for å oppfylle sikkerhetsnivå er gitt i veiledningen til forskriftene.

4. **Mål med prosjektet og forventet effekt**
   Identifisere utfordringer med forbindelser og identifisere egnede tiltak. En felles tilnærming og læring på tvers kan gi redusert risiko for ulykker.

5. **Detaljert beskrivelse av oppdraget**
   Identifisere og beskrive sammenføynigsmetoder, utover tradisjonell sveising, som eksplosjonsplater, med tekniske utfordringer og drift, som galvanisk korrosjon.
   Gå gjennom relevante krav i maritim, olje og gass og evt. andre industrier. Samle industrierfaring/skader/integritetsutfordringer. Identifisere relevante standarder som benyttes. Identifisere lærepunkter og forbedringsområder.

6. **Samarbeidsform**
   Møte ved oppstart avholdes hos leverandør, eventuelt Teams. 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 språk. Eventuelt om leverandøren finner det formålstjenlig kan engelsk benyttes etter avtale med Petroleumstilsynet.
   - Presentasjon av arbeidet hos Petroleumstilsynet ved utkast til endelig rapport, presentasjonen skal kunne brukes av Ptil.

8. Rapportering og konfidensialitet

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

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.