G+ Safe by design

Workshop report: Hydraulic torqueing and tensioning systems

G+ Global Offshore Wind
Health & Safety
Organisation

In partnership with

energy institute

G+ SAFE BY DESIGN
WORKSHOP REPORT: HYDRAULIC TORQUEING AND TENSIONING SYSTEMS

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CONTENTS

Annexes

LIST OF FIGURES AND TABLES

Page

Figures

Tables

1 EXECUTIVE SUMMARY

This G+ Safe by Design workshop was focused on the issues associated with hydraulic torqueing and tensioning on the main flange connections and the associated large fasteners and tooling. The workshop, comprising several data gathering and data analysis activities, was held in London on 5 March 2019. The workshop format was developed to explore hydraulic torqueing and tensioning system issues with a focus on the Safe by Design (SbD) principles.

Across the workshop, many common and interrelated issues and associated recommendations were identified, and these are shown in 1.1.

1.1 RECOMMENDATIONS

- Industry-wide knowledge sharing of torqueing/tensioning issues encountered, how these were solved, what works and what doesn't, could help to improve the current operation and maintenance (O&M) activities and future wind turbine generator (WTG) designs, both in terms of health and safety (H&S) and cost. Additionally, the development of a guidance document using the information obtained from these issues and consideration of good practices in other industries could be useful.
- WTGs and transition pieces (TP)s may not always seem to be fully considered as 'places of work' during the design process. Several ergonomic hazards were identified that could be designed out of future WTGs and TPs. Therefore, it could be beneficial to facilitate further engagement of original equipment manufacturers (OEM)s, owners and operators and technicians to share feedback from issues/accidents attributed to these design features.
- Musculoskeletal disorders caused by manual handling and use of the equipment, often in restricted space, were identified as a significant issue. This issue is not unique to hydraulic torqueing/tensioning and is a challenge facing the industry. The G+ is about to publish a case study based on the analysis of reducing manual handling and ergonomics related incidents in the offshore wind industry which will be followed by a guidance document for manual handling. In addition to that, a G+ SbD workshop, or other initiative exploring this topic more fully and sharing the output could be valuable.
- During the safe by design workshops, bolt torqueing and tensioning tool manufacturers described improved or innovative products which offer the potential to reduce hazards, either associated with manual handling, ergonomics, transport or positioning of the tools. It is recommended that methods to improve the visibility of G+ member organisations and their procurement teams to these potential solutions are explored. It is suggested that having an understanding at the point where purchasing decisions are made of how a slightly more expensive product may reduce risks, and the value that these offer, has the potential to lead to safer projects in future.

- During the safe by design workshops, it was identified and highlighted that improved quality assurance/quality control on bolted connections drastically reduces the exposure due to reduced problems/interventions associated with the bolting activities. Various solutions were identified including, but not limited to:
  - More bolting and testing in prefabrication (rather than offshore).
  - Introduction of torque testing techniques (ultrasonic testing).
  - Smart bolts (with tension/torque ID).
- Innovations such as alternative power (electric rather than hydraulic), remote control, or robotic solutions may require demonstration to build track record and industry confidence. The opportunity to facilitate trials or demonstrations of new technology should be explored. For example, do any G+ member organisations have an onshore mock-up of foundations which could be used as a demonstration environment? Are any test facilities available, if not what capabilities should they have, and which organisations could develop them? Related to this, mechanisms enabling the experience of early adopters to be shared would be valuable and should be explored.
- Task-specific training could be very useful to ensure competency during operations. The G+ could review the current training landscape to determine if there are any opportunities for improvement based on the outputs of this workshop, including items such as roles and responsibilities, and competency tracking.
- Tracking tool use, maintenance and calibration was identified as an area of opportunity to reduce these factors contributing to tool failure. Incorporating the need for this tracking to be built into future tool designs could be of benefit for the industry. The G+ could gather insight from the industry and publish a set of recommended requirements.
- The G+ could perform a cost-benefit analysis of permanently storing spare parts and/or tools for bolt tensioning and torqueing on WTG (i.e. the benefit of being more able to perform work/less down-time versus additional inspections and maintenance offshore).

2 BACKGROUND AND INTRODUCTION

2.1 BACKGROUND

The G+ Global Offshore Wind Health and Safety Organisation (G+) comprises the world's largest offshore wind developers who have come together to form a group that places health and safety at the forefront of all offshore wind activity and development. The primary aim of the G+ is to create and deliver world class health and safety performance across all its activities in the offshore wind industry. The G+ has partnered with the Energy Institute (EI) to develop materials including good practice guidelines to improve health and safety performance. Through sharing and analysis of incident data provided by G+ member companies, an evidence-based understanding of the risks encountered during the development, construction and operational phases of a wind farm project has been developed. This information has been used to identify the health and safety risk profile for the offshore wind industry.

In 2014, the Crown Estate asked the G+ to take over the running and delivery of their SbD workshops. The Crown Estate had run a number of these previously covering topics such as diving operations, lifting operations, wind turbine design and installation and the safe optimisation of marine operations.

By bringing the Safe by Design workshops into the G+ work programme, the G+ aims to explore industry operations and technologies with a focus on SbD principles. The G+ workshops examine the current design controls relating to a topic, discuss where current design has potentially failed, identify opportunities for improvement and then seek to demonstrate the potential risk reduction to be gained from these new ways of thinking and operating.

To date, seven workshops have been held under the auspices of the G+, covering: marine transfer/access systems; escape from a nacelle in the event of a fire; lifting operations; service lifts; davit cranes; WTG access/egress, and WTG access below the airtight deck. The outputs from six of these workshops have been made available in reports which can be downloaded from the G+ website, to be used as a reference by the industry.

https://www.gplusoffshorewind.com/work-programme/workshops

2.2 INTRODUCTION

From data analysis and feedback received by the G+, hydraulic torqueing and tensioning was identified as an area that should receive additional focus. Therefore, under the direction of the G+ Focal Group, a SbD workshop on hydraulic torqueing and tensioning systems was held on 5 March 2019 in London, UK.

The outputs from this workshop are documented in this report.

3 METHOD/ATTENDANCE/AGENDA

3.1 METHOD

A one-day workshop was held on 5 March 2019 in London, bringing together stakeholders from across the industry to consider the issues associated with hydraulic torqueing and tensioning in a WTG in the offshore environment. This was focused on the large structural flange connections, but many of the issues and recommendations made are common to torqueing and tensioning throughout a WTG. After opening remarks from Marcus Peters, Head of HSSE, Offshore Technologies, Wind Construction & New Markets, E.ON Climate & Renewables GmbH, two scene-setting presentations were delivered on 'Typical bolted connections' and 'MP/TP bolting operations'. To conclude the opening session, and allow a smooth transition to the workshop exercises, a short overview of these was provided, as shown.

Exercise 1 – Hazard identification (HAZID)

- Brainstorming techniques were used to identify the hazards associated with hydraulic torqueing and tensioning systems.
- Three main areas were covered, with each of the three workgroups covering one of these areas:
  - Storage, transportation and handling.
  - Operation of the tools.
  - Tool maintenance.
- This was followed by identification of the main hazards associated with these activities. The most significant activities and hazards were explored further in Exercise 2.

Exercise 2 – Hazard risk analysis (Bow tie)

- Bow tie analysis of the most significant hazards identified in stage 1 was conducted.
- This involved selecting a top failure event from the hazards analysed and identifying the threats, consequences, controls and mitigations associated with the hazard/top failure event.

Exercise 3 – Hierarchy of control

- In the final exercise, the most significant hazards were analysed further with respect to the hierarchy of control.
- This resulted in suggestions for how each of these activities/hazards could be eliminated or substituted.

The attendees were split into three groups and participated in each of these exercises.

At the end of the day the initial findings and conclusions were presented to the attendees in a plenary session, before concluding the workshop.

Note – the full results and details of the workshop exercises are shown in Annex A of this report.

3.2 AGENDA

Workshop opening remarks
Marcus Peters, Head of HSSE, Offshore Technologies, Wind Construction & New Markets, E.ON Climate & Renewables GmbH

G+ incident data – what is the evidence telling us?
Beate Hildenbrand, Technical Manager – Offshore Wind, Energy Institute

Typical bolted connections
George Walker, Associate Engineer, Arup

MP/TP bolting operations
Edward Gilhead, Foundation Engineer, E.ON Climate & Renewables GmbH

Workshop exercises introduction and overview
Gordon Stewart, SHEQ Manager, Offshore Renewable Energy Catapult

Workshop exercises
Each exercise led by a Catapult facilitator*; Owen Murphy, Craig Stout and Roberts Proskovics*

Plenary session – Presentations on key findings/outputs from workshop

Closing remarks
Marcus Peters, Head of HSSE, Offshore Technologies, Wind Construction & New Markets, E.ON Climate & Renewables GmbH

3.3 ATTENDANCE

Ollie Bartoszewwicz	Alltorc
George Walker	Arup
Soeren Baek	CIP
Pete Andrews	Echobolt
Marcus Peters	E.ON
Steven Heald	E.ON
Edward Gilhead	E.ON
Moritz Eggers	E.ON
Sebastian Godwin	E.ON
David White	E.ON
Garry Bradford	EDF RE
Lee Cameron	EDF RE
Remy Menage	EDF RE
Chris Dixon	EDPR/Moray East
Beate Hildenbrand	Energy Institute
Kate Harvey	Energy Institute
Kishan Kansara	Energy Institute

Mark Rockliff	Equinor
Eke Warren	Equinor
Philip Anthony Wells	Equinor
Rick Sykes	Equinor
Lisa Mallon	GE
Matt Brooks	GEE-FORCE
Ruth McArdle	HSE
Gerry Muir	HSE
Beth Rawson	HSE
Trevor Johnson	HSE
John Lindsay	Hytorc
Neil Murphy	Hytorc
Michael Wilkinson	Hytorc
Roy Dickson	Innogy
Colin Schroder	ITH UK
Paul Anthony Naughton	MHIV
Craig Stout	ORE Catapult
Gordon Stewart	ORE Catapult
Owen Murphy	ORE Catapult
Roberts Proskovics	ORE Catapult
Niels Tharald Bust Peterson	Ørsted
Claus Frandson	Ørsted
Stefano Morosi	Ørsted
Pat McCann	SPR
John Roger Connors	SPR
Anders Mikkelsen	SGRE
Kevin Welsh	SGRE
Roland Gutbrod	SGRE
Rosie Atkinson	SSE
Scott Perkins	SSE
Rene Schade	Vattenfall
Alan Johnson	Vattenfall
Tony Lyon	Xceco

ANNEX A
DETAILED WORKSHOP NOTES

A.1 WORKSHOP EXERCISE 1: HAZARD IDENTIFICATION (HAZID)

A.1.1 Purpose

The purpose of this exercise was to identify activities and hazards associated with the storage, transport and handling of tools, use of tools, and maintenance of tools for hydraulic torqueing or tensioning. These tools are used for structural bolted connections in offshore wind turbine substructures. The hazards were discussed and participants in each of the work groups described current control measures which were in place to control the hazards. Potential solutions or improvement ideas and behavioural factors were also discussed. The hazards identified in this exercise were prioritised by the work groups and the highest priority hazards were taken forward for further analysis in the bow tie sessions which followed.

A.1.2 Outputs

A.1.2.1 Evidence

See Tables A.1 – A.3 for the results of the HAZID exercises across the three areas as described in A.1.1.

Table A.1: Storage transport and handling of tools hazard identification

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Defects induced by inadequate or inappropriate storage	– Clearly defined and delegated responsibilities – Equipment testing and calibration – Pre-use checks	– Purpose designed transport bags or cases – Dedicated storage locations – Defined 'owners' for equipment	– Complacency – Poor culture – 'someone else's job' – No time allocated for teams to store equipment properly
Omissions caused by lack of ownership (storage, during transfer and at point of work)	– Clearly defined and delegated responsibilities – Pre-use checks	– Purpose designed transport bags or cases – Smart lifting bags – Defined 'owners' for each stage in the process – Direct supervision	– Complacency – Poor culture – 'Someone else's job' – No time allocated for teams to clean or maintain tools after use or transport

Table A.1: Storage transport and handling of tools hazard identification (continued)

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Manual handling injuries	– Mechanical aids, such as small cranes – Training – Dismantle tools into smaller components – Lifting equipment – Observe good practice guidelines	– Design tools to be transported in small parts easily – Design tools to interface with mechanical aids – lifting points, wheels, handles, rollers	– Procurement pressures to buy lowest cost rather than best value or most appropriate – Failure or reluctance to use mechanical lifting aids provided – bravado – Lifting aids may not always be practical
Dropped objects – personal injuries	– Lift plan – Training – PPE – Safety culture	– Purpose designed transport bags or cases – Design of structures to include lifting points/cargo routes and exclusion zones – Industry focus, improvement drives or development of best practice	– Rushing
Dropped objects – equipment damaged	– Lift plan – Training – Pre-inspection of lifting equipment	– Purpose designed transport bags or cases – Design of structures to include lifting points/cargo routes and exclusion zones	– Rushing – Incorrect rigging of equipment
Musculoskeletal injuries caused by ergonomics of equipment	– Mechanical aids, such as small cranes – Training	– Redesign of tools – Improve design of working areas/ environment	– Procurement pressures to buy lowest cost rather than best value or most appropriate
Lifting operations – lifting equipment failure	– Lift plan – Training – PPE – Statutory inspections of lifting equipment – Pre-use checks	– Review and reflect on G+ davit cranes SbD report	

Table A.1: Storage transport and handling of tools hazard identification (continued)

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Slips and trips – hydraulic oil leak	– Spill kits – Training – Good housekeeping – PPE	– Redundancy in tool design to mitigate leaks	– Not allowing sufficient time to keep work area clean or to clean tools
Environmental – hydraulic oil leak	– Spill kits – Training	– Redundancy in tool design to mitigate leaks – Design of working area to reduce possibility of oil released to environment	– Procurement pressures to buy lowest cost rather than best quality
Unclear who owns risk at different stages of transportation	– Lift plan	– Purpose designed transport bags or cases – Smart lifting bags – Defined roles and responsibilities	– Complacency – Poor culture – 'Someone else's job'
Inadequate tool control causing wrong equipment to be used	– Pre-use checks – Safety culture – Record keeping	– Staff empowerment, sense of pride in job	– Procurement pressures to buy lowest cost rather than best value or most appropriate – Tools being passed from team to team with no inventory or contact with stores
Equipment failure as a result of failing to conduct periodic inspections	– Pre-use checks – Safety culture – Audit	– Fail to safe designs – Supervision – Specific training to cover pre-use checks and basic in-field maintenance of tools – Structured training levels	– Tools being passed from team to team, no inventory or contact with stores

Table A.1: Storage transport and handling of tools hazard identification (continued)

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Misuse of equipment when fault finding	– Requirement to 'stop and ask' – Proactive safety culture	– Trained/competent person to fault find – Follow manufacturer's instructions	– Time pressure or urgency to 'get the job done' – 'Make do and mend' with good intentions
Equipment failure resulting from using incorrect equipment	– Supervision – Training	– Assessment of competence – Audit and supervision	– Time pressure or urgency to 'get the job done' – Tools being passed from team to team – Procurement pressures to buy lowest cost rather than best value or most appropriate
Risks introduced by incorrect tool assembly	– Supervision – Training	– Assessment of competence – More direct supervision – Specific training qualifications	– Time pressure or urgency to 'get the job done'

Table A.2: Use of tools hazard identification

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Working at height, falls from height	– Training – Check and maintain records of competence – Observe good practice guidelines	– Design of working environment or maintenance regime to reduce requirement to work at height	– Failure to follow working procedures – Failure to use correct PPE for working at height
Dropped objects	– Training – Lifting bags and equipment – Exclusion zones – PPE	– Good practice guidelines or cultural improvement initiatives	– Failure to follow working procedures

Table A.2: Use of tools hazard identification (continued)

Hazard	**Current control measures**	**Potential solutions/ improvement ideas**	**Unsafe acts/ behavioural aspects**
Electricity	– Training – Work authorisation systems/safe systems of work – Exclusion zones	– Design of working environment to avoid interaction with electricity	
Crushed fingers/limbs	– Robust RAMS – Training – Written procedures – PPE	– Specific training – Categorisation of training by relevant equipment or implied level of competence	– Failure to follow working procedures
Manual handling	– Dismantle tools into smaller components – Training – Lifting equipment – Observe good practice guidelines	– Automation and robotic methods	– Lack of awareness of good practice guidance – Failure to follow working procedures
Confined spaces	– Training	– Feedback from technicians to design process – Design changes to eliminate the use of structural bolted connections – Design changes to eliminate the presence of confined spaces	– Failure to follow working procedures
Bolt failure – release of energy	– Supplier control – Visual inspections – NDT – Training	– More specific training – Categorisation of training by relevant equipment or implied level of competence – Design changes to eliminate the use of structural bolted connections – Exclusion zones	– Failure to follow working procedures

Table A.2: Use of tools hazard identification (continued)

Hazard	**Current control measures**	**Potential solutions/ improvement ideas**	**Unsafe acts/ behavioural aspects**
Tool failure – mechanical release of energy	– Supplier control – Pre- and post-use checks – Training – Check and maintain records of competence	– More specific training – Categorisation of training by relevant equipment or implied level of competence – Design changes to eliminate the use of structural bolted connections	– Failure to follow working procedures – Misuse of tools
Tool failure – hydraulic injection	– Pre-use checks – PPE – Gloves, goggles, coveralls	– More specific training – Categorisation of training linked to specific equipment or implied level of competence – Design changes to eliminate the use of structural bolted connections	– Failure to follow working procedures
Exposure to noise	– Training – Monitoring and control of exposure time		
Complacency and human factors	– Safety culture	– Enable feedback of experience into designs – Supervision	– Rushing – Keen to get the job done
Difficult communications – noisy environment	– Hand signals – Experience of team	– Remote control of tools	
Difficult communications – language barriers	– Hand signals – Experience of team	– Minimum defined levels of competence – Standardisation of equipment and training	

Table A.2: Use of tools hazard identification (continued)

Hazard	**Current control measures**	**Potential solutions/ improvement ideas**	**Unsafe acts/ behavioural aspects**
Trip hazards	– Hose and cable management systems – Training – Good housekeeping	– Use non-hydraulic tools e.g. electric power – Design structures with installation/ maintenance in mind – Design structures to eliminate confined spaces – Design structures to eliminate structural bolted connections – Adequate lighting	– Failure to follow working procedures
Hazardous fluid – slips trips and falls	– Appropriate footwear	– Design of flooring to reduce risk, e.g. grating vs flat surface – Use non-hydraulic tools e.g. electric power	
Working on an asset with reduced structural integrity	– Supplier control	– Consider merits of owning vs renting tools and equipment – Consider who best owns the risk of using specialist tools e.g. experienced subcontractor	
Hand/arm vibration	– Monitor and control exposure time – Training	– Reduce duration or frequency of tasks – Remote controlled equipment – Mechanical aids or remove requirement to use hands on tools directly	– Failure to follow instructions on manufacturer's exposure time/ work instructions/ HAVS tool-specific exposure reference sheets

Table A.3: Maintenance of tools hazard identification

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Manual handling injuries	– Training – Management commitment and ethos – Lifting aids and equipment – Standardised packing	– Early selection of tools in design process – Better tool packaging – Increase awareness of what is available on the market – Investing in lighter/ smaller/better tools – Feedback to, and interaction with, tool manufacturers Exchange of operational experience – Risk based analysis to justify reduced bolt maintenance frequency	– Working to unrealistic time scales – Rushing – Fatigue – Financial constraints, for example PPE in place of better tools – Good practice/bad habits – Small team dynamics/culture – Unwillingness to report incidents/ reporting culture – Relevance of training
Poor tool control and calibration resulting in equipment failure	– Pre- and post-use checks – Inspection register – Good record keeping – Full inspection and maintenance history – Approved tooling list – Calibration policy – Approved vendors – Training – Packing lists	– Provide adequate spares at the point of work – Refresher training – Robust verification of competence before starting work or undertaking maintenance	– Working to unrealistic time scales – Rushing – Fatigue – Good practice/bad habits – Small team dynamics/culture – Unwillingness to report incidents/ reporting culture – Relevance of training

Table A.3: Maintenance of tools hazard identification (continued)

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Release of high-pressure hydraulic fluid	– Quality control – Tool selection – Pressure testing – Design for maintenance – Design for transport – Adequate storage equipment – Use of correct storage – Standardising inspection and maintenance requirements	– Better tool packaging – Clearly defined roles and responsibilities – Whip checks fitted on the hoses	– Financial constraints, for example PPE in place of better tools
Misuse of equipment causing release of energy	– Personnel expertise – Skills – Competence – Training – Audit of these – Correct equipment provided – Effective RAMS for work – Effective supervision – Safety culture – Management drive to remove complacency	– Design of tools removes opportunity for misuse or mis-maintenance – Provide adequate spares at the point of work – Early selection of tools in design process – Management willingness to accept that we can always improve – Feedback to, and interaction with, tool manufacturers – Robust verification of competence before starting work or undertaking maintenance – Exchange of operational experience	– Working to unrealistic time scales – Rushing – Fatigue – Financial constraints, for example PPE in place of better tools – Good practice/bad habits – Small team dynamics/culture – Job-specific training, or some pre-work verification of knowledge – Unwillingness to report incidents/ reporting culture – Relevance of training

Table A.3: Maintenance of tools hazard identification (continued)

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Difficult ergonomics	– Design of environment should reflect requirement for access for maintenance – Design of tools should reflect working environment – for example include mechanical or lifting aids	– Feedback to, and interaction with, tool manufacturers – Specific lifting points and equipment integrated in tool design – Specific cargo routes and lifting points included in turbine design – Ideally, design turbines and structures which do not have confined spaces – Exchange of operational experience	– Working to unrealistic time scales – Rushing – Fatigue – Financial constraints, for example PPE in place of better tools – Good practice/bad habits – Small team dynamics/culture – Unwillingness to report incidents/ reporting culture – Relevance of training
Noise and vibration	– Tool selection – Monitoring of exposure to noise and vibration – PPE	– Containment and acoustic enclosure – Tooling integrates technology enabling remote control or monitoring	– Fatigue – Good practice/bad habits – Small team dynamics/culture
Working environment	– Regulations – for example confined spaces – Design of environment should reflect requirement for access for maintenance	– Design of environment should reflect requirement for access for maintenance – Management willingness to accept that we can always improve – Ideally, design turbines and structures which do not have confined spaces	– Fatigue – Financial constraints, for example PPE in place of better tools – Good practice/bad habits – Small team dynamics/culture

Table A.3: Maintenance of tools hazard identification (continued)

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Difficult or poor communications	– Discipline – Appropriate RAMS for the work – Defined/structured methods of work	– Containment and acoustic enclosure – Automation and mechanical assistance built into tooling – Alternative tooling drive to replace hydraulic pumps with electrical – Alternative means of communication such as visual indicators, alarms, and radio replacements – Robotics and autonomous systems	– Working to unrealistic time scales – Rushing – Fatigue – Financial constraints, for example PPE in place of better tools – Language barriers
Maintenance ineffective at preventing failures as not reflective of transit	– Standardising inspection and maintenance requirements	– Better tool packaging – Exchange of operational experience	– Good practice/bad habits – Small team dynamics/culture – Relevance of training
Maintenance ineffective at preventing failures as not reflective of marine environment	– Pre-use checks – Modifications and retrofit of equipment – Standardising inspection and maintenance requirements	– Better tool packaging – Robust verification of competence before starting work or undertaking maintenance – Exchange of operational experience	– Good practice/bad habits – Small team dynamics/culture – Relevance of training
Manufacturing defect leading to mechanical or integrity failure	– Vendor qualification and selection – Standardising inspection and maintenance requirements		– Corporate procurement resistance to better value (but higher upfront cost) equipment

Table A.3: Maintenance of tools hazard identification (continued)

Hazard	Current control measures	Potential solutions/ improvement ideas	Unsafe acts/ behavioural aspects
Slips and trips on oil leaks	– Housekeeping – Cultural improvement – Point of work risk assessment – Spill kits – Correct PPE (footwear)	– Exchange of operational experience	– Working to unrealistic time scales – Rushing – Fatigue – Unwillingness to report incidents/ reporting culture

A.1.2.2 Analysis and findings

The three hazard identification exercises conducted by the three separate working groups focused on a specific phase of activities. These were:

1. Storage, transport and handling of tools.
2. Use of tools.
3. Maintenance of tools.

The groups each identified a wide range of potential hazards which have been summarised in Tables A1 to A3. It is noteworthy that despite the focus on different phases of activities, and the fact that workshop discussions occurred simultaneously without any conferring from one group to the other, that some hazards were identified by all groups. These represent consistent themes of the potential hazards associated with hydraulic bolt torqueing and tensioning equipment for substructure bolted connections. They have been summarised in A.1.2.2.1 to A.1.2.2.3.

A.1.2.2.1Manual handling and ergonomics

The tools and equipment associated with the tensioning and torqueing of large structural bolts are by necessity large and powerful. In introductory presentations, M72 bolts were described as weighing around 20 kg without nuts or washers. The groups discussed how bolts themselves were often already on the limits of acceptable masses for manual handling, typical sizes starting at M56 with M72 considered common, and that generally tools and equipment were heavier still (Figure A.1 and Figure A.2). It was also apparent that with a continuing upwards trend in sizes of offshore wind turbines, the number and masses of these fasteners is likely to continue to increase.

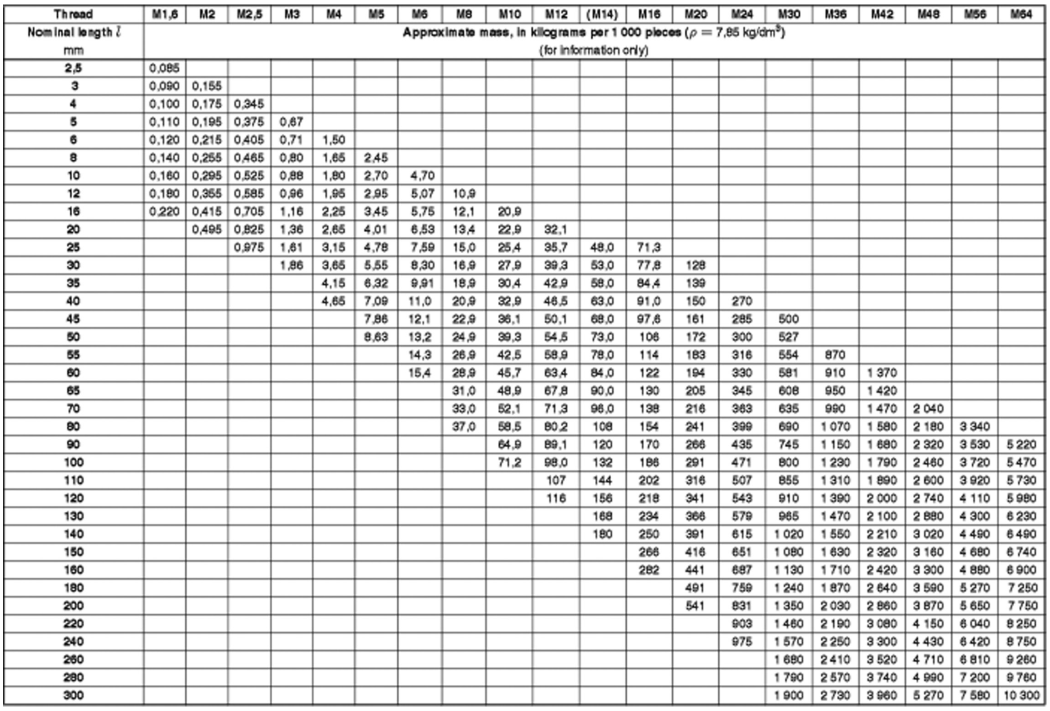
The bulky equipment required to perform torqueing or tensioning of these large fasteners needs to go through a variety of transport and handling tasks to complete the tensioning/ torqueing work. It will be handled in stores both as goods in and good out. Some or all this movement may avoid manual handling through use of forklifts, pallet trucks or overhead cranes, depending on the facility. It will then be transferred to and from a vessel, onto and off a turbine/transition piece and then lowered/raised to the lower decks/working platforms. The final step in this journey is likely to utilise non-permanent lifting equipment or systems which are likely to be rigged and removed specifically for the purpose of transporting equipment to and from the lower working platforms in the foundation.

The tools themselves may not have been designed for the specific handling and transportation necessities of the offshore wind industry. The theme of manual handling and ergonomic injuries was discussed in each workshop. Because of the variety of transport and handling methods used, it was suggested that packaging and lifting equipment may not always be of the optimum design for the task. Equipment may commonly be decanted to/from generic lifting bags which were well suited to lifting from a davit crane but may not protect the equipment from salt spray during vessel transit, and did not prevent the tools and equipment moving around, meaning that impact damage of tools which are loose in lifting bags was possible.

Potential improvements

- The sourcing or design of more appropriate tools and transport cases/bags. Ideally, these solutions should be afforded the opportunity to incorporate the direct feedback of user's experience.
- When considering further mitigations to manual handling hazards, the use of mechanical aids was also discussed. These could be powered or purely mechanical systems such as levels, wheels, springs and rollers which enabled the tools to be positioned, used and moved without significant physical exertion.
- Other potential methods of reducing manual handling and ergonomics hazards included improving the design of the working environment itself to reduce ergonomic challenges such as reach, headroom or otherwise restricted working areas. The trade-off between a structural design which was cost-efficient to manufacture and one which included a working environment which minimised ergonomic hazards was discussed. It was felt that because of a relatively low frequency of access across the windfarm lifetime it was possible that ergonomic features of the lower desk working areas were overlooked or at least not given much priority in design optimisation.
- The reduction of, or means to monitor or control, noise was also cited as a potential way of reducing hazards. Noise has the potential to contribute to hazards in two distinct categories. Noise can be hazardous and potentially damaging to a person's hearing. Further hazards related to difficult communications may also be induced when using powerful equipment in a noisy environment.

Figure A.1 is an extract from Annex A of BS EN ISO 4762:2004 which provides approximate masses. Note that fasteners of relevance to the subject matter discussed in these workshops tend to go beyond the lower right-hand side of this table, and hence will be heavier still. Nonetheless, this figure provides an insight into some likely masses for fasteners of this type.



Thread	M1,6	M2	M2,5	M3	M4	M5	M6	M8	M10	M12	(M14)	M16	M20	M24	M30	M36	M42	M48	M56	M64
Nominal length l mm	Approximate mass, in kilograms per 1 000 pieces ($\rho = 7,85$ kg/dm^3) (for information only)																			
2,5	0,085																			
3	0,090	0,155																		
4	0,100	0,175	0,345																	
5	0,110	0,195	0,375	0,67																
6	0,120	0,215	0,405	0,71	1,50															
8	0,140	0,255	0,465	0,80	1,65	2,45														
10	0,160	0,295	0,525	0,88	1,80	2,70	4,70													
12	0,180	0,355	0,585	0,96	1,95	2,95	5,07	10,9												
16	0,220	0,415	0,705	1,16	2,25	3,45	5,75	12,1	20,9											
20		0,495	0,825	1,36	2,65	4,01	6,53	13,4	22,9	32,1										
25			0,975	1,61	3,15	4,78	7,59	15,0	25,4	35,7	48,0	71,3								
30				1,86	3,65	5,55	8,30	16,9	27,9	39,3	53,0	77,8	128							
35					4,15	6,32	9,91	18,9	30,4	42,9	58,0	84,4	139							
40					4,65	7,09	11,0	20,9	32,9	46,5	63,0	91,0	150	270						
45						7,86	12,1	22,9	36,1	50,1	68,0	97,6	161	285	500					
50						8,63	13,2	24,9	39,3	54,5	73,0	106	172	300	527					
55							14,3	26,9	42,5	58,9	78,0	114	183	316	554	870				
60							15,4	28,9	45,7	63,4	84,0	122	194	330	581	910	1 370			
65								31,0	48,9	67,8	90,0	130	205	345	608	950	1 420			
70								33,0	52,1	71,3	96,0	138	216	363	635	990	1 470	2 040		
80								37,0	58,5	80,2	108	154	241	399	690	1 070	1 580	2 180	3 340	
90									64,9	89,1	120	170	266	435	745	1 150	1 680	2 320	3 530	5 220
100									71,2	98,0	132	186	291	471	800	1 230	1 790	2 460	3 720	5 470
110										107	144	202	316	507	855	1 310	1 890	2 600	3 920	5 730
120										116	156	218	341	543	910	1 390	2 000	2 740	4 110	5 980
130											168	234	366	579	965	1 470	2 100	2 880	4 300	6 230
140											180	250	391	615	1 020	1 550	2 210	3 020	4 490	6 490
150												266	416	651	1 080	1 630	2 320	3 160	4 680	6 740
160												282	441	687	1 130	1 710	2 420	3 300	4 880	6 900
180													491	759	1 240	1 870	2 640	3 590	5 270	7 250
200													541	831	1 350	2 030	2 860	3 870	5 650	7 750
220														903	1 460	2 190	3 080	4 150	6 040	8 250
240														975	1 570	2 250	3 300	4 430	6 420	8 750
260															1 680	2 410	3 520	4 710	6 810	9 260
280															1 790	2 570	3 740	4 990	7 200	9 760
300															1 900	2 730	3 960	5 270	7 580	10 300

Figure A.1: Typical bolt masses, credit BS EN ISO 4762:2004 Annex A

Figure A.2 is an extract from guidance on manual handling. Whilst limits are not the only element of a robust approach to manual handling hazard identification, and there is much more detail to the guidance and best practice, the diagram does provide some useful context. Firstly, it highlights that lifting fasteners with masses of 20 kg by hand is likely to be acceptable over a very small range of movement, and even then, likely by men only. Further, it illustrates how, when working in a relatively constrained space where the range of working heights may be limited by the physical design of the structure itself, a reduced limit is recommended as the distance from the ideal lifting location increases.

Figure A.2: Manual handling, available at: https://www.internationalworkplace.com/az-guides/manual-handling-guide

A.1.2.2.2 Uncontrolled release of energy

Tools and equipment used for torqueing and tensioning of large structural bolts are almost always hydraulically powered. Hazards associated with this source of power, such as failures of hoses or couplings which can release harmful jets of fluid, or the slip and trip hazard posed by smaller leaks were discussed.

Arguably the most severe potential injury possible as a result of this type of release of energy was hydraulic injection injury, which was cited as a consistent cause of concern. This type of injury will almost always require urgent medical treatment by surgical professionals, and the increased time to evacuate a casualty who may be working below the airtight deck offshore was described as having the potential to increase the severity of injuries.

The groups described through anecdotal evidence that at present, minor leaks when using hydraulic tooling were almost inevitable. It was felt that this may be because equipment is either badly made and/or badly specified for the task or environment. However, often failures resulting in an uncontrolled release of energy were likely to be caused by misuse or harsh treatment of equipment, or because tools were not looked after and had to withstand rough treatment when in transport and in use.

The uncontrolled release of energy could also include mechanical failure or the ejection of parts. This was described as having been experienced by some members of some of the discussion groups. Hazards identified by failures such as the fracture when under tension of hydraulic tensioning heads or of bolts themselves included impact of parts or debris moving at high velocity with people, with the potential to cause severe injury. The need for adequate separation distances between energised parts and teams conducting the work was discussed as a potential mitigation. However, physical space can be at a premium when working inside the foundation, or tools may require direct visual observation when in operation, which can mean that people are required to be in closer proximity to these energised systems than would perhaps be considered ideal.

A.1.2.2.3 Attitude, ownership and culture

All the groups discussed either a lack of clarity or a lack of ownership or responsibility for the tools and equipment as a potential contributor to defects, resulting in failure of the equipment. Mechanical or hydraulic failure were cited as having the potential to release energy and cause injury. Defects induced by rough treatment, incorrect handling or misuse were described as having the potential to contribute defects which could make such failures more likely. It was clear that a range of people would handle and use the equipment, and that a relatively basic care or maintenance task such as cleaning may be missed as a large team may each assume it to be somebody else's responsibility. Allocation of tools, inventory and record keeping of tasks such as pre-use checks or basic maintenance were discussed areas with the potential to be improved. Participants described an uncertainty over who was responsible for the care, appropriate handling and use of tools, particularly when large projects comprise several teams and rely on a large amount of pooled equipment.

Participants in the working group also described the potential for improved designs of the tools themselves. For example, if equipment is bulky or difficult to move but does not have a carry handle it may be much easier to use hose fixings as a handle than trying to position only by hand. Often such misuse may take place with the best of intentions, or with the intent of working more quickly or more efficiently. It was thought unlikely that users were deliberately mistreating equipment to the extent that it would fail, but rather that designs could probably be improved if they incorporated the experience of front-line users.

A.1.2.2.4 Training, competence and verification

To be confident that those handling and using tools and equipment are likely to use it correctly a sufficient level of competence will be required. Workshop participants described a patchy landscape of training qualifications and experience which could be used to consider an individual sufficiently competent to conduct or supervise hydraulic torqueing or tensioning works. It was felt that there was potential for hazardous misuse of equipment, often with the best of intentions, arising from a lack of awareness or competence. Workshop participants described the generic nature of any training, and the differences between specific tools or tool manufacturers as potentially contributing to hazards. For example, if a user had received training using a particular type of tool from one manufacturer, they may then go on to use a completely different type with different controls in the future. It was felt that a user could also probably work for quite a long time with one particular system, for example if an installation campaign lasts for several months, giving good familiarity with a particular type of tools, which may lead to accidental misuse of different tools on subsequent projects.

Potential improvements

- A more robust scrutiny of training or experience, direct supervision or audit of the various phases of the work (transport of tools, use of tools and maintenance of tools) or potentially a review of what training syllabuses are relevant to this area.
- Some participants discussed, and were in favour of, formalising the training, and authorisations to be more specific about which users are permitted to conduct which task. For example, it was suggested that training could be structured around several levels. These levels would ensure that there was much clearer delineation of who was capable, competent and authorised to conduct various tasks. For illustration these levels could include: basic user; functional tester; light/in-field maintenance and workshop maintenance, all of which may require different skills and competence.
- The frequency of any refresher training and variance in approach from one project to the next were also mentioned and again it was suggested as potentially prudent to review these; anecdotes were provided which suggested that someone could be deemed to be competent when in fact their original training was provided several years ago and/or of relevance only to a particularly type or manufacturer of tools.

A.1.2.2.5 Procurement

All the work groups discussed the trade-off between quality and capability of tools and the overarching corporate requirement to procure for the lowest possible cost. In some cases, hazards associated with hydraulic tools could be eliminated or reduced by using more expensive systems, for example those which used either electric power supply and/or were equipped to enable remote control from a safe area. Other innovations which could add to the cost but reduce exposure to risk included mechanical lifting aids or roller systems which reduced or eliminated some of the manual handling requirements.

Related to procurement, it was evident that there was a variety of approaches to management of potential risks associated with the equipment by placing the risk either in-house or with suppliers or subcontractors. The ability to better manage risks and potential hazards arising by considering whether to purchase tools and equipment, to rent them or to source labour and equipment together from an experienced contractor was discussed. This could be viewed as a key decision that should be made at the start of the project. Interestingly there was no consensus on what the best approach was, each having pros and cons. It was noted that at times the lowest cost may not always be the best value; for example, more expensive tools may be more robust, fail less frequently or last longer. Similarly, risks could be reduced by engaging the manufacturer of the equipment to provide maintenance and spare parts.

A.1.2.3 Recommendations and outputs

The following thoughts, considerations and recommendations were developed during Exercise 1. The refined report recommendations are shown in the Executive Summary in section 1.

- It is recommended that the G+ review the current training standards and syllabus(es) in this area considering the workshop outputs presented in this report. Specifically, it is recommended that consideration is given to:
  - Whether training is relevant to all tools and manufacturers currently used in the offshore wind industry.
  - Whether training content provides any delineation between operation and maintenance of the tools, and whether a separate or additional training scope, for example for workshop maintenance/stores persons, would be worthwhile.
  - What tool manufacturers' input has been used in the development of training standard(s).
  - Whether there is a risk that an individual may be deemed competent despite holding a training qualification which is either several years old, or which is relevant to equipment of a different type/manufacturer.
  - Whether training material covers the appropriate packing, transport and handling of the tools.
- It is recommended that consideration is given to circulating a safety bulletin or guidance note on the topic covered by this workshop. Specifically, this could include:
  - Link to this report summarising the SbD workshop.
  - Recommendation that the client in charge of bolt torqueing or tensioning work should clearly define which members of the team have which responsibilities and at which times. The aim of this clarification is to avoid situations where team members may see checks or maintenance tasks as somebody else's job.
- This document could also include some reminders of potential damage mechanisms and hazardous consequences which could arise following incorrect transport and handling of tools.
- It is recommended that mechanisms for site technicians to provide feedback of their direct experience to project design teams are investigated.
- It is recommended that the G+ good practice guidelines for manual handling are circulated to workshop participants and that the existence and relevance of these guidelines are communicated to project design and site teams.

A.2 WORKSHOP EXERCISE 2: HAZARD RISK ANALYSIS – BOW TIE

A.2.1 Purpose

The purpose of this exercise was to investigate a top failure event that could occur from a hazard being realised. The working groups were provided with a top failure event for one of the most significant hazards identified in Exercise 1. The groups brainstormed the threats (that can cause the failure event to happen), consequences (which can result from the failure event occurring) and the controls and mitigations. These details were captured on a wall-mounted bow tie template.

A.2.2 Outputs

A.2.2.1 Evidence

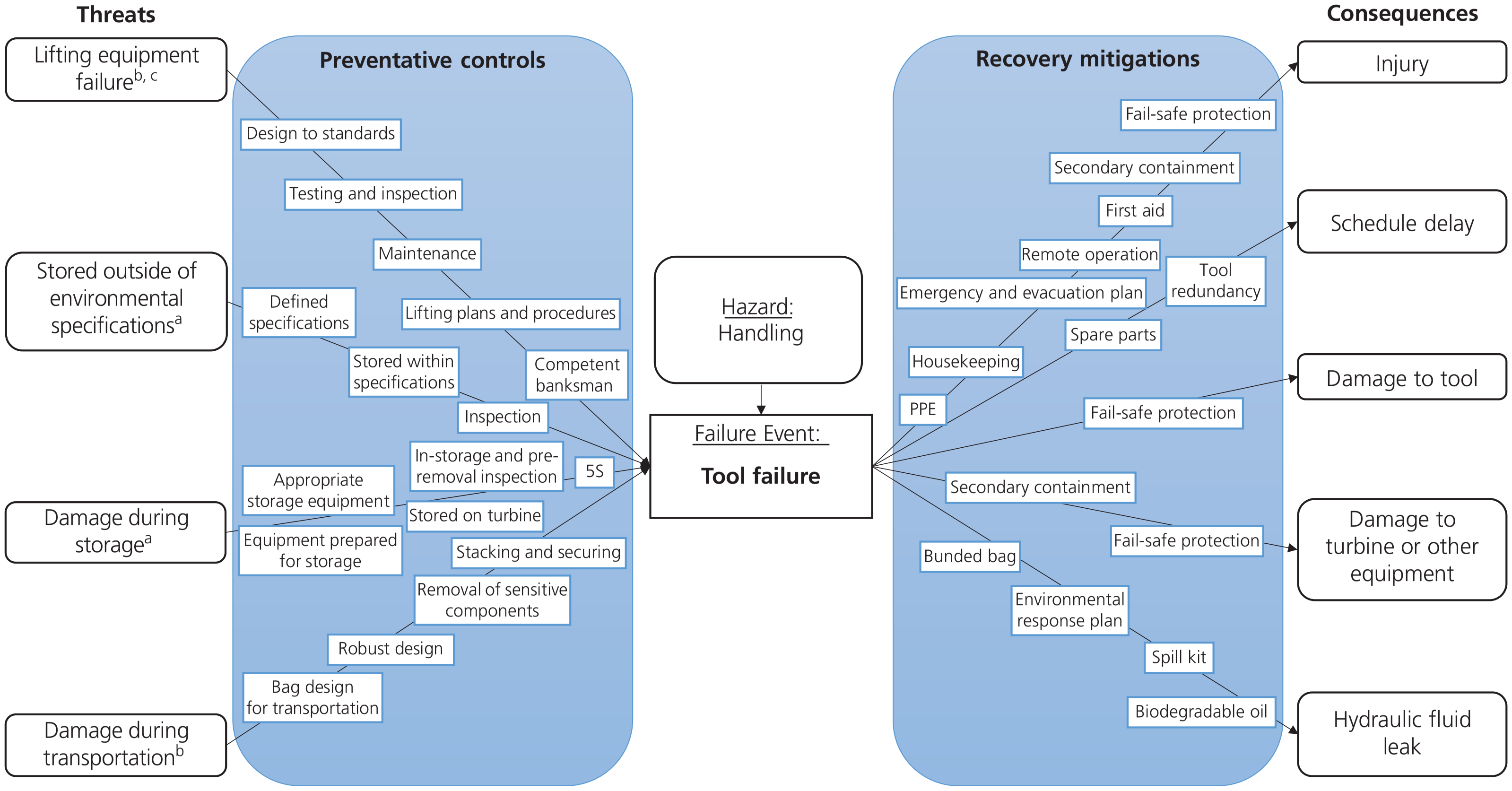
The three groups each analysed a different hazard and top failure event using the bow tie methodology, and each group completed a bow tie diagram.

Bow tie diagrams were created for the following:

- Area: Storage, transportation and handling. Hazard: Handling. Failure event: Tool failure.
- Area: Operation of the tools. Hazard: Operation of the tools. Failure event: Tool failure.
- Area: Tool maintenance. Hazard: Inadequate maintenance regime. Failure event: Release of high-pressure hydraulic fluid.

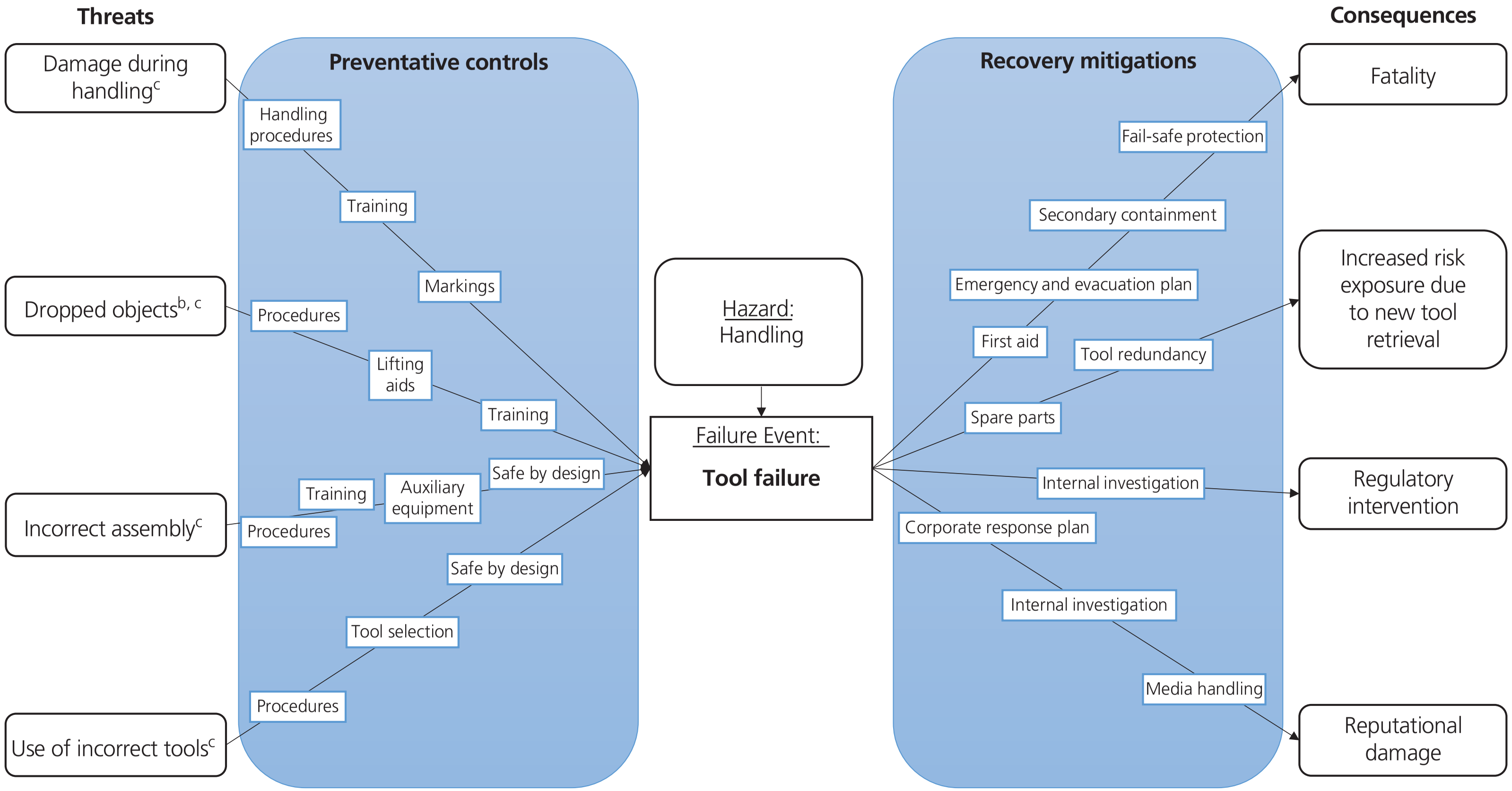
The bow tie diagrams are shown in Figures A.3 to A.8.

Note: For Figure A.5, Figure A.6 and Figure A.7, preventive control and recovery mitigation measures that are not associated with any specific threat and consequence (i.e. do not intersect threat to consequence path) are applicable to all threats and consequences, respectively.



a – storage; b – transport; c – handling and * – indicates suggested improvements

Figure A.3: Tool failure in handling bow tie (a – storage; b – transport; c – handling) (1/2)



a – storage; b – transport and c – handling

Figure A.4: Tool failure in handling bow tie (a – storage; b – transport; c – handling) (2/2)

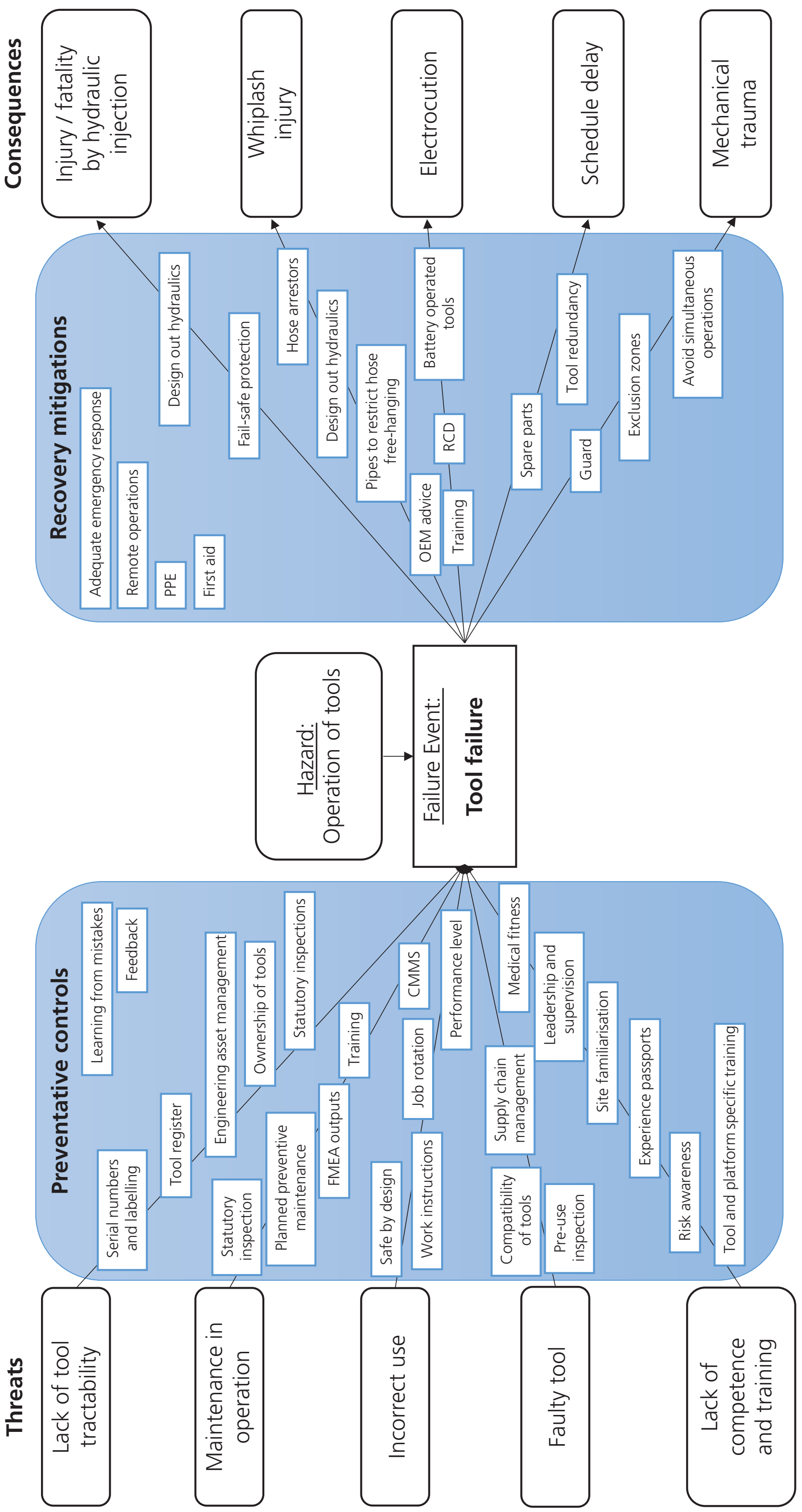


Figure A.5: Tool failure in operation bow tie (1/2)

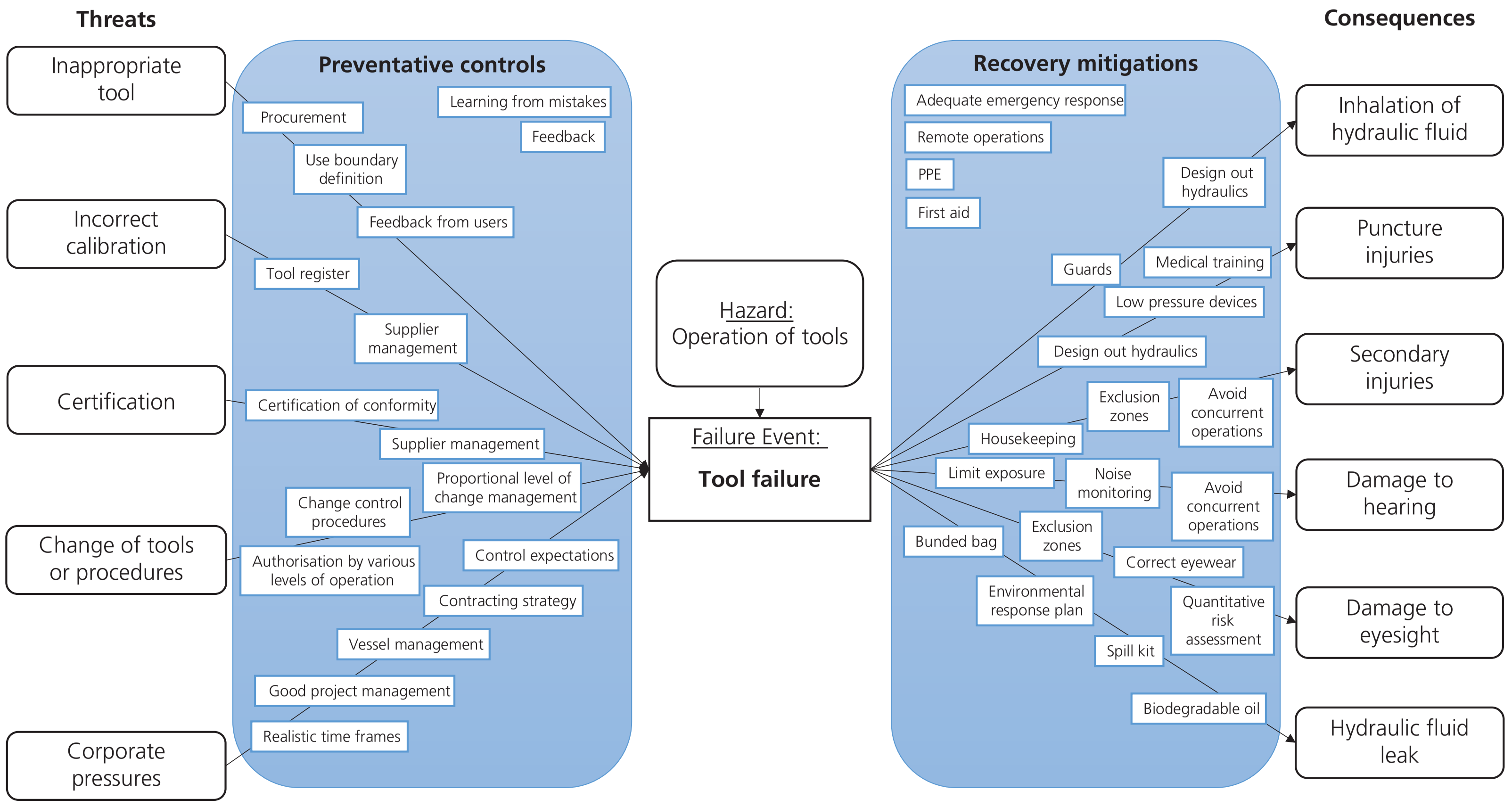


Figure A.6: Tool failure in operation bow tie (2/2)

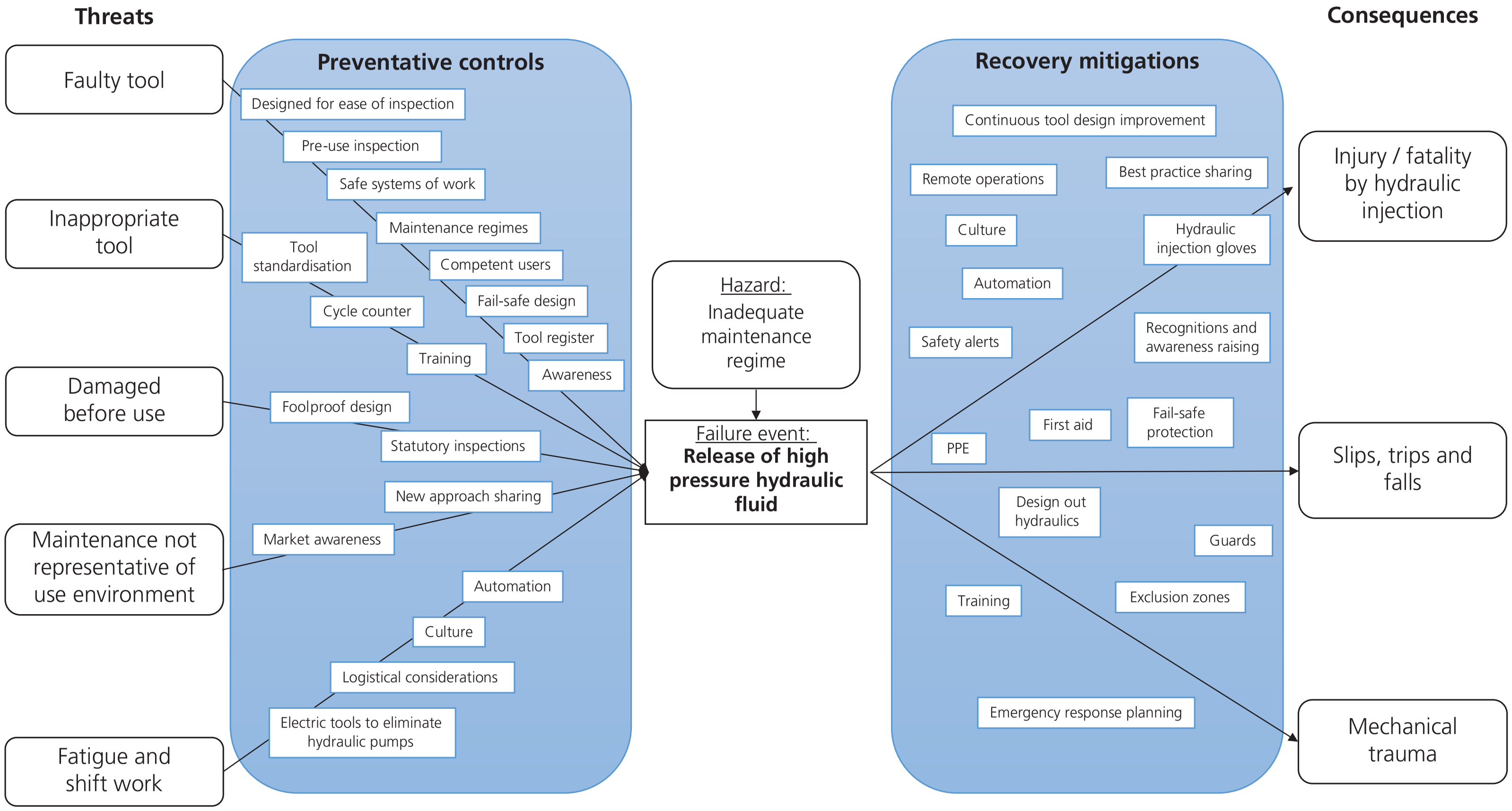


Figure A.7: Release of high-pressure hydraulic fluid bow tie (1/2)

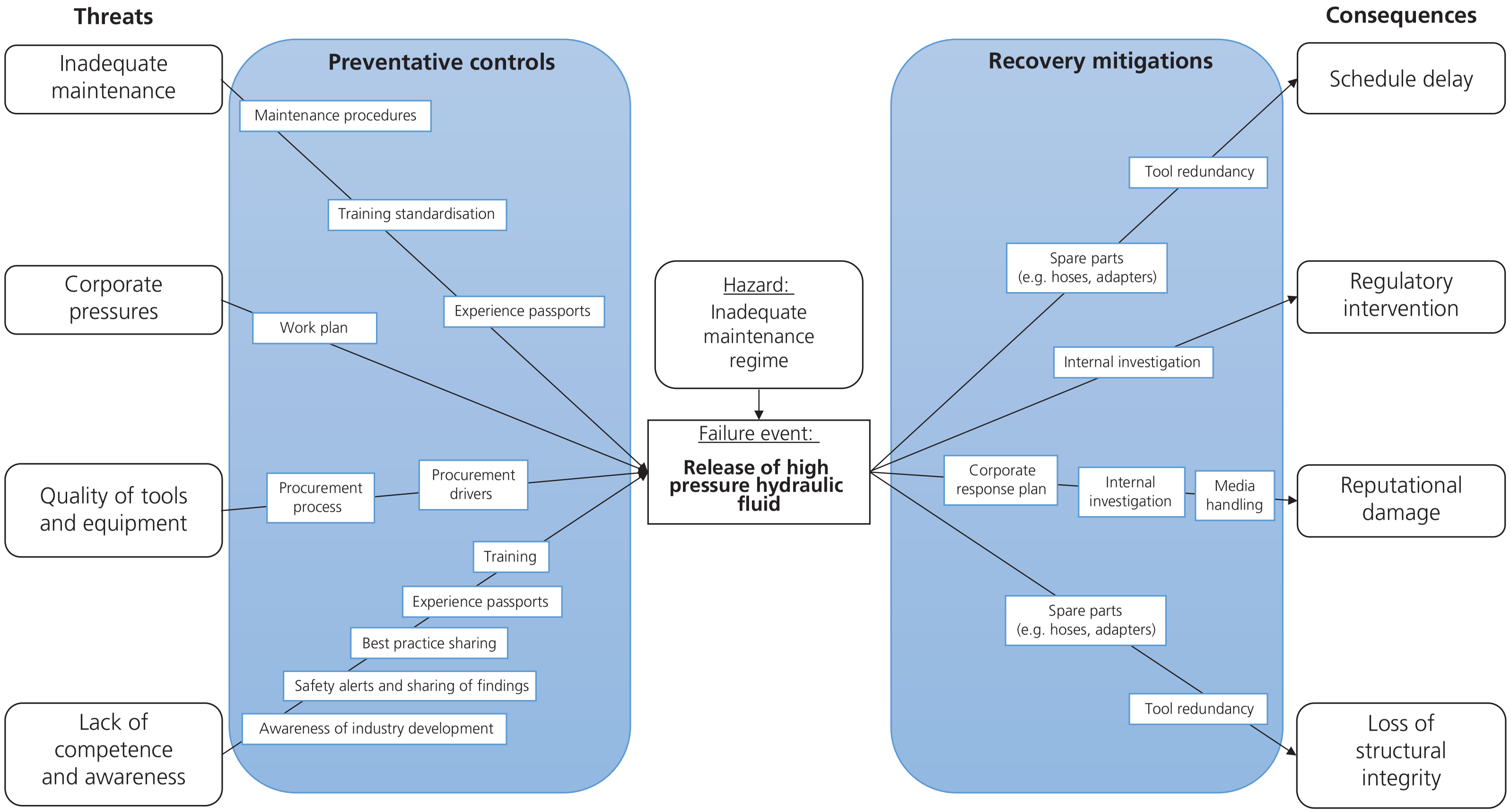


Figure A.8: Release of high-pressure hydraulic fluid bow tie (2/2)

A.2.2.2 Analysis and findings

The bow tie diagrams clearly illustrate the group discussion areas for each failure event. The key findings for each hazard and failure event, as well as general findings, include the following:

- **Hazard:** Handling (storage, transportation and handling). **Failure event:** Tool failure.
- Most of the bolt torqueing and tensioning tool failures in storage, transportation and handling discussed can be prevented by developing and applying procedures, performing equipment inspections and maintenance, ensuring that technicians are trained and competent, and have access to the right tools for the job.
- Tool damage could be reduced by removing sensitive components (e.g. gauges and sensors) during transportation and using markings, such as 'This way up' on bags or 'Hold here' on tools, during storage, transportation and handling. Markings could also help improve H&S by ensuring that equipment is handled correctly, reducing probability of injuries and dropped equipment.
- Workshop participants felt that bags used for tool storage, transportation and handling could be improved to prevent tool and environmental damage (e.g. use of bunded bags to capture hydraulic fluid leaks).
- **Hazard:** Operation of the tools. **Failure event:** Tool failure.
- Guards, exclusion zones and avoidance of simultaneous operations were some of the most common mitigations suggested by workshop participants for various types of H&S consequences.
- No consensus was reached on whether use of torqueing and tensioning tools can lead to damage to hearing, with workshop participants expressing contradictory opinions, which could be as the result of different tools being used.
- **Hazard:** Inadequate maintenance regime. **Failure event:** Release of high-pressure hydraulic fluid.
- Hydraulic injection can lead to life-changing and potentially fatal consequences. Whilst numerous preventive control and recovery mitigations were suggested, from procedural to changing tool design, hydraulic injection resistant gloves were seen by the workshop participants as one of the easiest to implement solutions to prevent hydraulic injection injuries.
- Improving recognition and awareness of hydraulic fluid hazards and potential consequence of these, as well as best practice sharing, is an easy and inexpensive way of educating and potentially preventing hydraulic injections.
- General findings.
- Storing spare parts and/or tools for bolt torqueing and tensioning on vessels or permanently on WTGs was suggested in all groups as means to mitigate most non-H&S related consequences associated with the transport of tools.
- Substitution of hydraulic tools for electric tools can eliminate hydraulic fluid and hose whiplash injuries, as well as reduce the probability of other types of H&S (e.g. slips, trips and falls, puncture injuries) and environmental consequences. If battery-based solutions are used, these would also eliminate the requirement for a transportable power supply.
- Corporate pressures at different levels was identified by workshop participants as a less visible yet still present threat that needs to be managed by having realistic time frames, good project management and controlled expectations based on evidence and historical data.

A.2.2.3 Recommendations and outputs

The following thoughts, considerations and recommendations were developed during Exercise 2. The refined report recommendations are shown in the Executive Summary in Section 1.

- It is recommended that the G+ create an information sharing mechanism to facilitate the distribution of best practice, learnings from mistakes and feedback from technicians with respect to bolt tensioning and torqueing-related activities and tools.
- As an independent and impartial group, the G+ could perform a cost-benefit analysis of permanently storing spare parts and/or tools for bolt tensioning and torqueing on WTG (i.e. the benefit of being able to perform work versus additional inspections and maintenance offshore).

A.3 WORKSHOP EXERCISE 3: HIERARCHY OF CONTROLS

A.3.1 Purpose

The purpose of this exercise was to apply the top two levels of the hierarchy of controls (elimination and substitution), as shown in Figure A9, to the hazards identified in Exercise 1. Each group chose the significant hazards from Exercise 1 and applied the hierarchy of control to each, starting with elimination and followed by substitution.

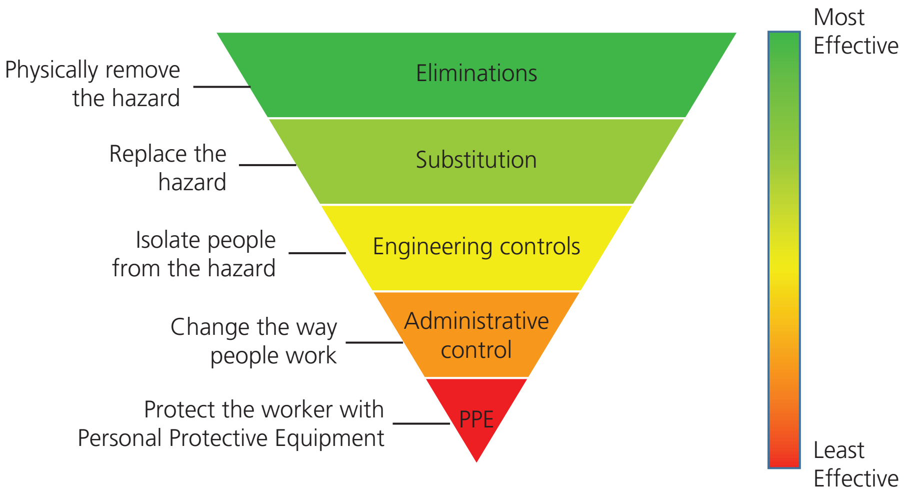


Figure A.9: Hierarchy of controls by IOSH

A.3.2 Outputs

A.3.2.1 Evidence

Some hazards have been identified in multiple activities. These activities are shown in Table A.4 and colour-coded, as shown here:

Use of tools (operation of the tools)	🟦
Tools' maintenance	🟩
Storage and transportation and handling	🟧

It should be noted that there may be overlap and/or duplication in the eliminations and substitutions for each activity stated in Table A.4. This is since similar eliminations and substitutions have been recommended, by each of the exercise groups, for several hazards. Similarly, there may be information captured in one activity that may be applicable to others. These factors have been highlighted in the recommendations provided from this exercise.

Table A.4: Hierarchy of controls

Hazard	**Activity**	**Elimination**	**Substitution**	**Additional comments**
Manual handling and ergonomics	Use of tools	Automation and use of robotics Eliminate flanged connections QC of bolted connection at installation to reduce/remove maintenance checks Ultrasonic preload measurement (and other remote checks)	Replace hydraulic tools for electric alternatives Design bolts and tools to allow the use of mechanical lifting aids Design of platform levels Use of reaction washers Read G+ good practice guidelines for manual handling Use of smaller tools (e.g. lightweight pumps)	Automation could include self-installing turbines Increasing the size and weight of bolts/tools may actually be beneficial to safety as the requirement for mechanical lifting aids becomes a necessity rather than a luxury Consider WTG locations as 'place of work' during design process
	Storage and transportation	Design changes – WTG	Improved collaboration between foundation and WTG OEM designs Tool/equipment securing during transportation and/or storage Pre-installation of bolts Keep equipment on-site/WTG for the whole design life	Design changes could include TP-less designs, or a change in connection design – thus reducing the requirement for vast tool/bolt storage Improved collaboration would ensure technician safety is considered in the installation and O&M processes

Table A.4: Hierarchy of controls (continued)

Hazard	Activity	Elimination	Substitution	Additional comments
Competency and training	Use of tools	– Automation and use of robotics – Foolproof design (inherently safe)	– OEM handover training in specific use of tools and processes – Tracking of technician competency and match competency to specific jobs using a colour coded system – Task-specific training is required to ensure adequate knowledge of tasks prior to operational intervention – Use of experience passports	– There is learning to be gained from other industries – such as the use of colour coded systems to ensure personnel training/competency is matched to specific tasks – Task-specific training should be organised by the appropriate body and all training programmes should be accredited and audited – Feedback of incident data (to the G+ and the wider industry) is required to prioritise training and address key issues – Foolproofing design – designing tools so they are generic to the application (bolt size/type) would reduce tool misuse
	Maintenance of tools	– Foolproof design (inherently safe)	– Training – Design for easy checks and easy to use equipment/tools – Tool design – sacrificial parts/fail to safe – Positive culture – Supervision	– In this case, competency and training relates to the personnel conducting maintenance of tools and/or equipment – See 'use of tools' comment on foolproofing design

Table A.4: Hierarchy of controls (continued)

Hazard	Activity	Elimination	Substitution	Additional comments
Tool failure	Use of tools	– Eliminate flanged connections	– Use of smart bolts – 'Plug and play' tool design would eradicate improper use of tools due to incompetency – Integrate tool cycle counters to track how often tools are used	– Tracking the use of tools (i.e. how many cycles they have been put through) should be a focus in tool design
	Maintenance of tools	– Design tools to accept ID labels to track individual tool maintenance – don't rely on case labels – Colour code tools to control component maintenance, tool use and to track component failure	– Traceability and tracking of all tools at all sites – QR codes on tooling – Audits – Use of smart bolts	– Tool failure as a result of this activity is primarily due to inadequate tool control (such as control of tool use, rotation and calibration) – Use of smart bolts may reduce frequency of tool use/maintenance – Use of smart bolts could enable the ability to compile a database of bolt conditions – Implementing Smart Bolts throughout bolted connections could prove to be financially unrealistic. However, cost savings could be found in reduced checks/maintenance – Introducing a sense of tool ownership may reduce tool misuse and reduce tool failures

Table A.4: Hierarchy of controls (continued)

Hazard	Activity	Elimination	Substitution	Additional comments
	Storage and transportation	– Outsource storage to bespoke parties – Design to use materials that are not prone to corrosion/damage		– For this activity, tool failure causes as a result of corrosion, mechanical and structural damage
Equipment damage	Storage and transportation	– Design changes – Automation and robotics (such as the use of drones for transportation) – Removal of sensitive components	– Use of bespoke bags for equipment/tools – Tools and equipment used interchangeably – spread the workload of tools	– In this case equipment damage occurs during transportation – Use of bespoke bags would reduce tools damage during transportation/lifting activities – Design changes could include TP-less designs, or a change in connection design
Dropped objects	Use of tools	– Ensure bolted connections require no working at height to access	– Ensure no personnel/activity below any height related activity – Design larger hatches to enable safe working and easy lifting	
Release of high-pressure hydraulic fluid	Maintenance of tools	– Consider location as 'place of work' during design – Eliminate flanged connections – Use of electric tools	– Design to have bolted connections not in confined areas	– In this case the release of high-pressure hydraulic fluid occurs as a result of mechanical failure of tool(s) due to poor maintenance

Table A.4: Hierarchy of controls (continued)

Hazard	Activity	Elimination	Substitution	Additional comments
Noise and vibration	Use of tools	– Automation and robotics	– Use of electric tools – Ensure sufficient maintenance of tools – Benchmarking/ prioritising selection of tools (not just based on cost) – Use of bolt tensioning over torqueing – Consultation and sharing of data/ information	– There is some uncertainty around the levels of noise present when using hydraulic tools
Lack of ownership of risk	Storage and transportation	– Improved risk transfer – Design tools that cannot be used after a specified number of cycles/ uses		– Improved risk transfer could, for example, mean placing more emphasis on tool providers for ensuring safe working practices

A.3.2.2 Analysis and findings

Across all the activities and hazards discussed, four key approaches to hierarchy of controls were noted:

- Remove/reduce the need for hydraulic torqueing and tensioning activity by:
  - Eliminating flanged connections from design.
  - Ensuring QC of bolted connections at installation to reduce requirement for return visits or checking as part of an ongoing maintenance regime.
  - Using ultrasonic preload measurement (or other remote checks).
- Automate processes and embrace the use of robotics, including:
  - Use of smart bolts for remote maintenance checks.
  - Use of reaction washers.
  - Use of drones for tool/equipment transfer.
- Improve training and competency tracking; specific recommendations include:
  - Task-specific training to ensure competency in an operational environment.
  - Training specific to offshore activity processes and selection/use of tools should be provided during OEM handover.
  - Tracking of competency, by using a passport/colour-coding methodology, could be implemented to match technician competency to specific tasks.

- Implement design changes, such as:
    - Tool-specific design changes, such as integrating tool use/cycle counters and bespoke lifting bags, could reduce the likelihood of tool failure. Hydraulic tools could also be substituted for electric alternatives.
    - Turbine-specific design changes such as improving platform designs, use of anchor points for assisted lifting and considering WTGs as 'places of work' during design could eliminate ergonomic hazards.

There is a consensus that designing to eliminate the need for hydraulic tooling would be beneficial to the industry. However, this would not eliminate all associated hazards as flanged connections are used throughout the already existing offshore fleet. Therefore, substituting hydraulic tooling for electric alternatives could be a feasible design change, as would implementing more anchor points and safety features on the tools and in the working environment (the WTG) already in place.

It should be noted that the elimination or substitution of certain hazards can introduce new hazards to specific activities. An example of this would be the substitution of hydraulic tooling for electric alternatives, which would introduce the associated hazard of electrocution. These new hazards should always be identified and considered when evaluating the impact of the changes recorded in this section.

A.3.2.3 Recommendations and outputs

The following thoughts, considerations and recommendations were developed during Exercise 3. The refined report recommendations are shown in the Executive summary in Section 1.

- Task-specific training could be beneficial to ensure competency during operations and relevant training programmes should be organised, accredited and audited by the appropriate body. The G+ could influence the content of this training by collecting and comparing safety data throughout the industry to help identify areas/activities to focus on.
- Relevant learning could be gained from other industries regarding competency tracking and training practices. The G+ could commission a study into these practices from other industries and, in collaboration with Owners and Operators, produce good practice guidelines on this topic for the offshore wind industry.
- WTGs and TPs do not seem to be wholly considered as 'places of work' during the design process. Several ergonomic hazards were identified that could be designed out of future WTGs and TPs. It could be beneficial to facilitate the engagement of OEMs, Owners & Operators and technicians to share feedback from issues/accidents attributed to these design features.
- Tracking tool use, maintenance and calibration was identified as an issue relating to tool failure. Emphasising the need for these aspects to be incorporated into future tool designs would be of benefit for the industry. This could be realised by a body, such as the G+, gathering insight from the industry and publishing a set of recommended requirements specific to hydraulic tooling.

ANNEX B
PRESENTATIONS

B.1 PRESENTATION 1 – ARUP – TYPICAL BOLTED CONNECTIONS

B.1.1 Executive summary

This presentation was provided to highlight the design drivers behind monopile (MP) to TP bolted flange considerations and the requirement for re-tensioning in service.

The presentation contains the following:

- An overview of typical MP-TP bolted flange arrangements and a description of why they have become widely used, as opposed to other MP-TP connection options, e.g. grouted connections.
- A description of the in-service issues that drive the requirement for re-tensioning in service and experience from other more established industries, e.g. bridges and antenna structures, to highlight best practice.
- A summary of products available that may enable more accurate measurement of bolt preload or reduce the maintenance overhead.

A key message is that the requirement for through-life inspection and re-tensioning of preloaded bolts is consistent with a range of other, more established industries. For these industries, there are examples of where the frequency and nature of the maintenance regime has evolved based on in-service experience.

G+ Safe by Design Workshop: Hydraulic Torqueing/Tensioning Systems
Typical Bolted Connections

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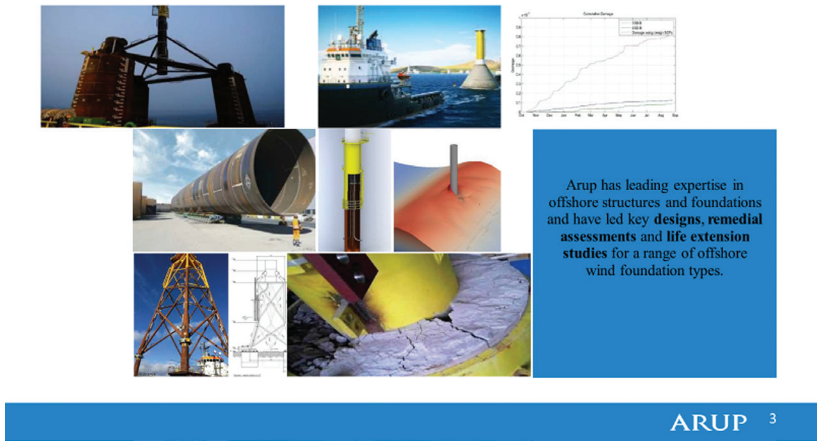
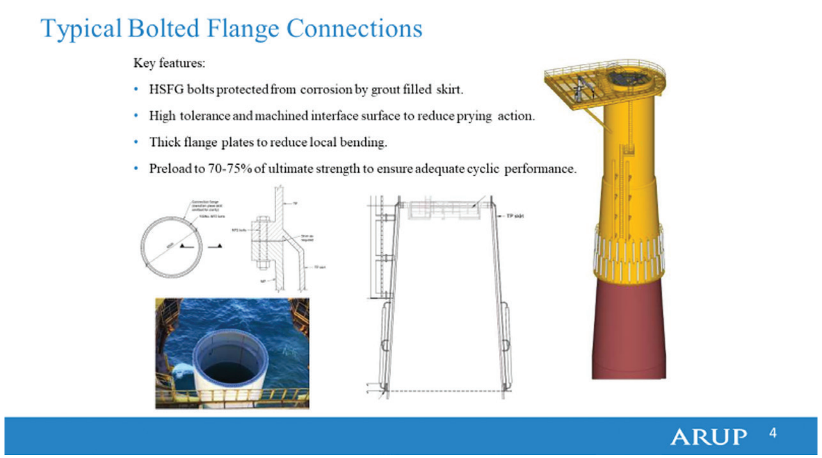
Aim and Agenda

Summary of the design drivers behind MP-TP bolted flange connections, and the need for re-tensioning.

1. Overview of MP-TP bolted flange connections
2. Why are bolted flange connections required?
3. What drives the requirement for re-tensioning?
4. Experience from other industries
5. Available technology



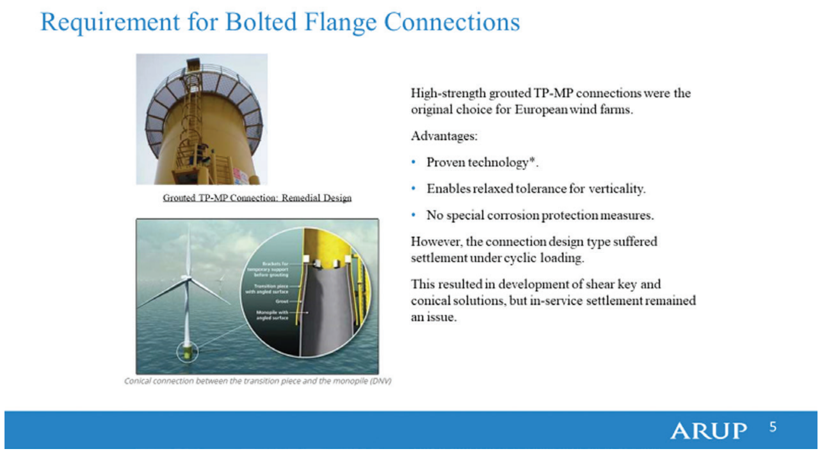
Arup has leading expertise in offshore structures and foundations and have led key **designs, remedial assessments** and **life extension studies** for a range of offshore wind foundation types.



Typical Bolted Flange Connections

Key features:

- HSFG bolts protected from corrosion by grout filled skirt.
- High tolerance and machined interface surface to reduce prying action.
- Thick flange plates to reduce local bending.
- Preload to 70-75% of ultimate strength to ensure adequate cyclic performance.



Requirement for Bolted Flange Connections

Grouted TP-MP Connection: Remedial Design

Conical connection between the transition piece and the monopile (DNV)

High-strength grouted TP-MP connections were the original choice for European wind farms.

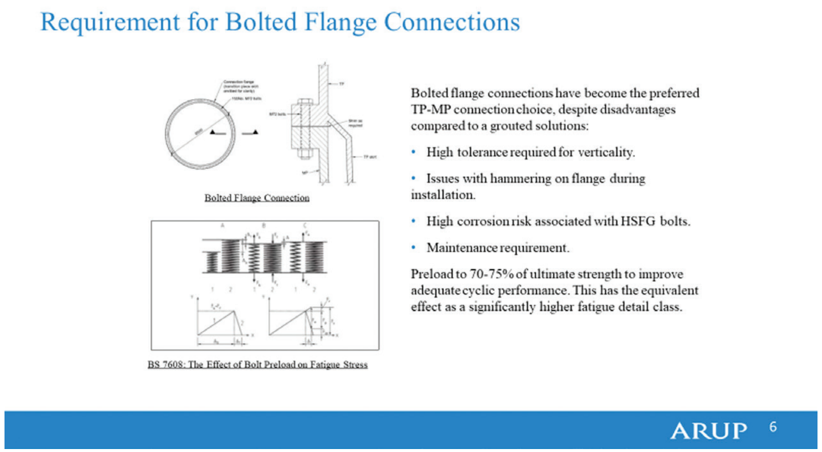
Advantages:

- Proven technology*.
- Enables relaxed tolerance for verticality.
- No special corrosion protection measures.

However, the connection design type suffered settlement under cyclic loading.

This resulted in development of shear key and conical solutions, but in-service settlement remained an issue.

ARUP 5



Requirement for Bolted Flange Connections

Bolted Flange Connection

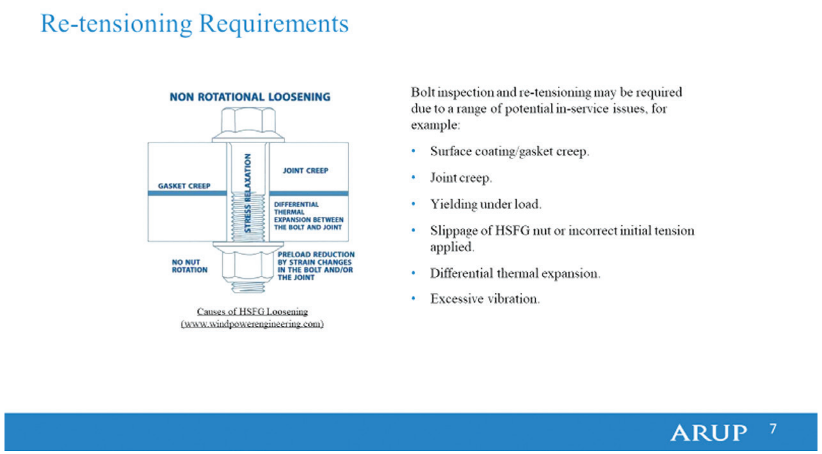
BS 7608: The Effect of Bolt Preload on Fatigue Stress

Bolted flange connections have become the preferred TP-MP connection choice, despite disadvantages compared to a grouted solutions:

- High tolerance required for verticality.
- Issues with hammering on flange during installation.
- High corrosion risk associated with HSFG bolts.
- Maintenance requirement.

Preload to 70-75% of ultimate strength to improve adequate cyclic performance. This has the equivalent effect as a significantly higher fatigue detail class.

ARUP 6



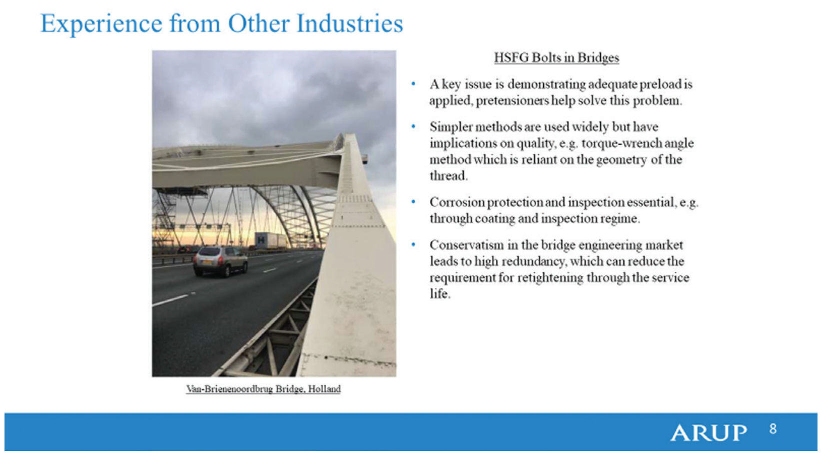
Re-tensioning Requirements

Causes of HSFG Loosening
(www.windpowerengineering.com)

Bolt inspection and re-tensioning may be required due to a range of potential in-service issues, for example:

- Surface coating/gasket creep.
- Joint creep.
- Yielding under load.
- Slippage of HSFG nut or incorrect initial tension applied.
- Differential thermal expansion.
- Excessive vibration.

ARUP 7



Experience from Other Industries

Van-Brienenoordbrug Bridge, Holland

HSFG Bolts in Bridges

- A key issue is demonstrating adequate preload is applied, pretensioners help solve this problem.
- Simpler methods are used widely but have implications on quality, e.g. torque-wrench angle method which is reliant on the geometry of the thread.
- Corrosion protection and inspection essential, e.g. through coating and inspection regime.
- Conservatism in the bridge engineering market leads to high redundancy, which can reduce the requirement for retightening through the service life.

ARUP 8

Experience from Other Industries

High Roller Wheel, Las Vegas

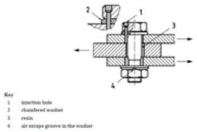
HSFG Bolts in Slender Structures

- Frequent inspection and maintenance requirements, particularly at early stages following construction.
- As more experience is gained in an industry the maintenance requirements can evolve.
- Where possible (e.g. radio mast trusses), alternatives to HSFG are often taken as the preferred choice.

ARUP 9

Available Technology

- Products are available to enable more accurate measurement of bolt preload and to improve resistance to slip.
- These products aim to reduce maintenance and inspection requirements.
- However, conservatism in the construction market leads to high redundancy and reluctance to adopt novel products for monitoring preload.



Resin Injection Bolts (Eurocode 1090-2 Annex J)

ARUP 10

Conclusions

- Bolted flange MP-TP connections are the preferred choice for offshore wind due to issues associated with grouted solutions.
- A range of mechanisms can cause loss of preload, which is essential for fatigue performance, leading to the maintenance requirement.
- This is consistent with experience in a range of other industries. Preloaded bolts have stringent inspection requirements, particularly to monitor corrosion.
- Products are available to more accurately measure bolt pre-load which may reduce inspection/maintenance overhead. In-service experience is more typically relied upon to inform an appropriate maintenance regime.

ARUP 11

Thank you. Questions?

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12

B.2 PRESENTATION 2 – E.ON CLIMATE & RENEWABLES GMBH – MP/TP BOLTING OPERATIONS

B.2.1 Executive summary

The presentation was provided to inform the audience of the two methods of bolt tightening and the risks associated with each. Its main aim was to facilitate the further discussions on the hazards and risks of bolting, especially on the MP-TP flange using M72 bolts. Therefore, it should be noted that the slides are filled with useful pictures of what not to do!

The presentation was focused on three main areas:

- A section of the presentation was dedicated to the logistical hazards and problems associated with offshore bolting works.
- The main body of the presentation explained the many hazards associated with the process.
- The final section looked at the different tool failures that have occurred during E.ON's many bolting activities.

Associated risks were also highlighted to allow the participants of the HAZID workshop exercises to form holistic judgements of the process and not simply focus on the risks at the point of work.

MP/TP Bolting Operations

Challenges related to torqueing and tensioning M72 bolts

e·on

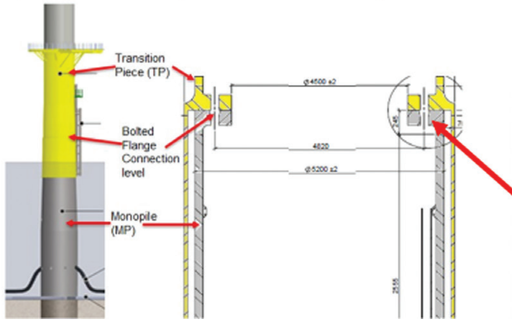
Content of my Presentation

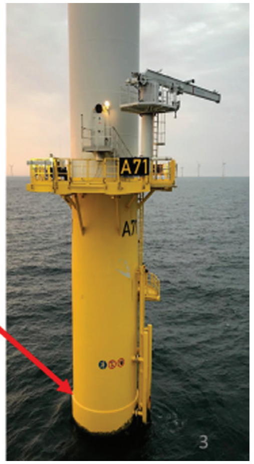
1. Brief overview of an MP-TP Connection and the Logistical problems
2. Torque vs Tension and the Risks with associated with both
3. Risks in detail
4. E.ON's tool failures experiences
5. Questions

e·on

Monopile – Transition Piece (MP-TP) Connection

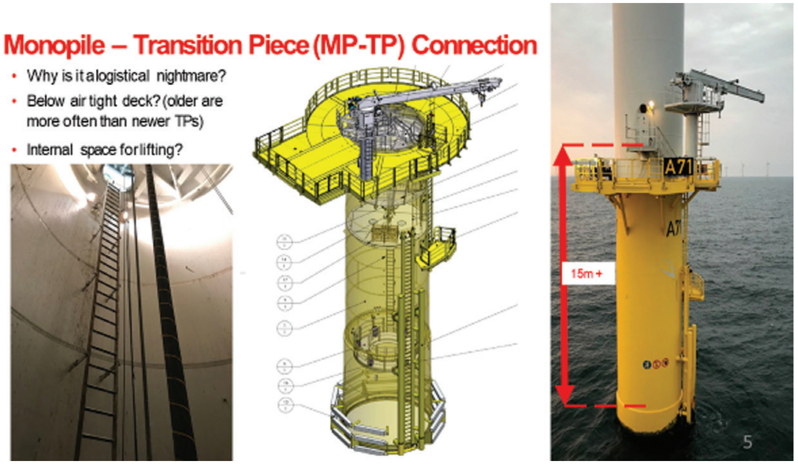
- Bolted Monopile to Transition Piece Connection, is the main structural load path
- 90-120No. M72 Bolts per Connection
- Bolt pre-tension is the critical parameter that dictates the fatigue life of the bolts





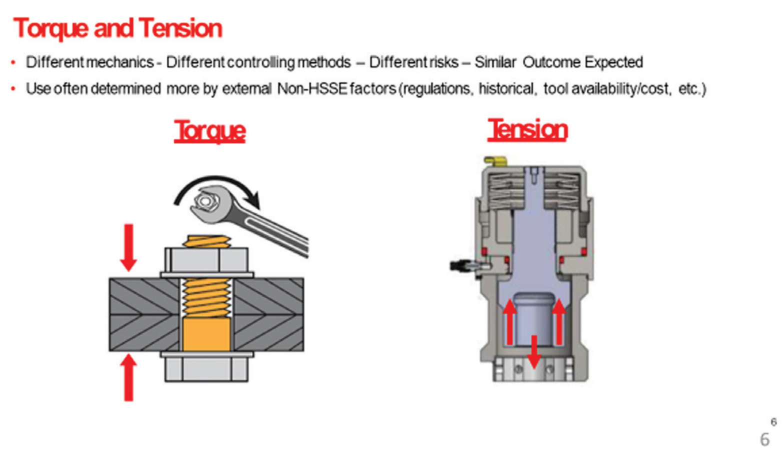
Monopile – Transition Piece (MP-TP) Connection

- Why is it a logistical nightmare?
- Getting there with all the equipment:
  - Installation
  - Inspections or re-works



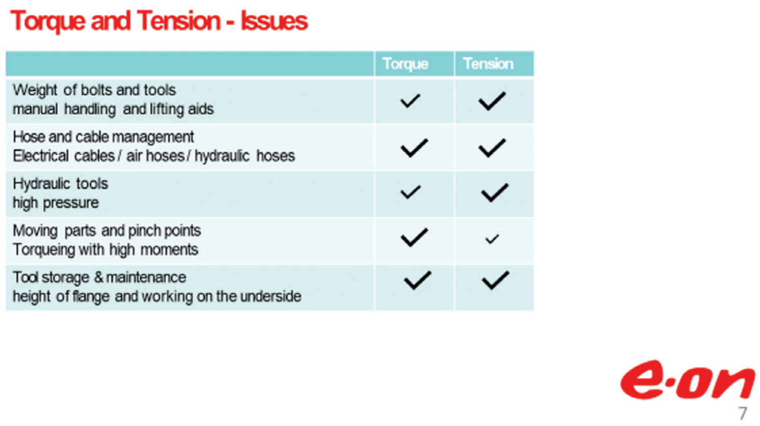
Monopile – Transition Piece (MP-TP) Connection

- Why is it a logistical nightmare?
- Below air tight deck? (older are more often than newer TPs)
- Internal space for lifting?



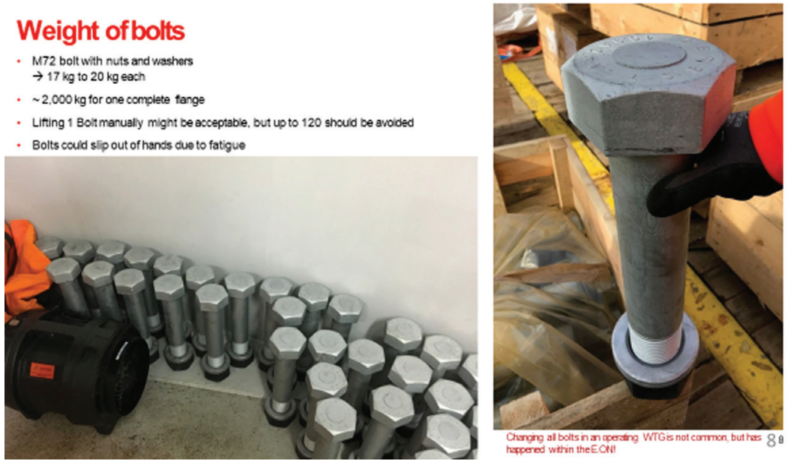
Torque and Tension

- Different mechanics - Different controlling methods – Different risks – Similar Outcome Expected
- Use often determined more by external Non-HSSE factors (regulations, historical, tool availability/cost, etc.)



Torque and Tension - Issues

	Torque	Tension
Weight of bolts and tools manual handling and lifting aids	✓	✓
Hose and cable management Electrical cables / air hoses / hydraulic hoses	✓	✓
Hydraulic tools high pressure	✓	✓
Moving parts and pinch points Torqueing with high moments	✓	✓
Tool storage & maintenance height of flange and working on the underside	✓	✓

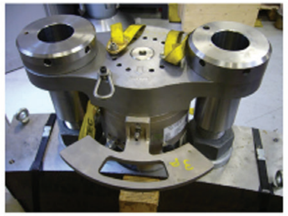


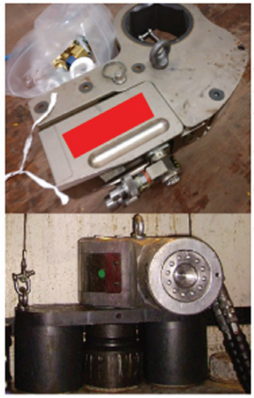
Weight of bolts

- M72 bolt with nuts and washers
  → 17 kg to 20 kg each
- ~ 2,000 kg for one complete flange
- Lifting 1 Bolt manually might be acceptable, but up to 120 should be avoided
- Bolts could slip out of hands due to fatigue

Changing all bolts in an operating WTG is not common, but has happened within the E.ON!

Weight of tools



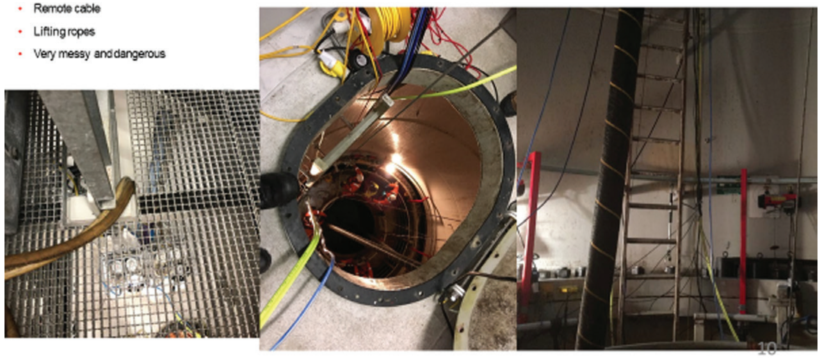


[redacted]

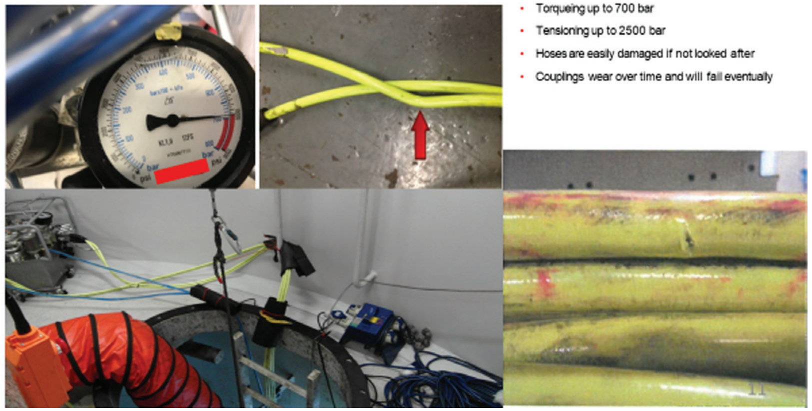
- Typical torque and tensioning tools
- Weight starts at 35 kg
- Torque gun setup at the bottom right weighs 75 kg
- Tools can be broken down into lighter components which is time consuming
- For tensioning 10 – 12 tools are used at the same time
- Having to move the tool manually many times should be avoided

Hose & cable management

- 110 V / 230 V electrical cables
- Hydraulic hoses
- Remote cable
- Lifting ropes
- Very messy and dangerous



High pressure hoses

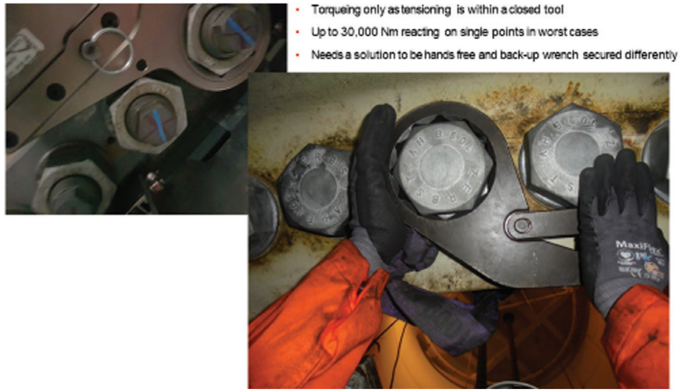


[redacted]

- Torqueing up to 700 bar
- Tensioning up to 2500 bar
- Hoses are easily damaged if not looked after
- Couplings wear over time and will fail eventually

Pinch points and moving parts

- Torqueing only as tensioning is within a closed tool
- Up to 30,000 Nm reacting on single points in worst cases
- Needs a solution to be hands free and back-up wrench secured differently



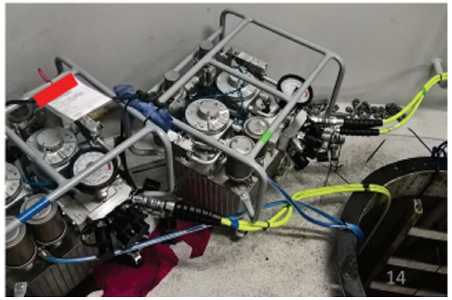
Storage & transportation

- Tools are transported in lifting bags
- All in one bag thrown together
- Heave tools resting on hoses
- Steel on steel resting against each other


[redacted]

Maintenance of tools

- Tools are working towards their limits as being used 24/7
- High pressure involved
- Frequent use of the couplings as handles, due to lack of other obvious easy lifting points
- Vague maintenance time interval specifications from the manufacturers
  - "Tools should be **regularly** maintained"(?!?)
  - Meaning Contractors define exact schedule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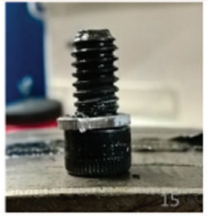
Torque Tool Failure

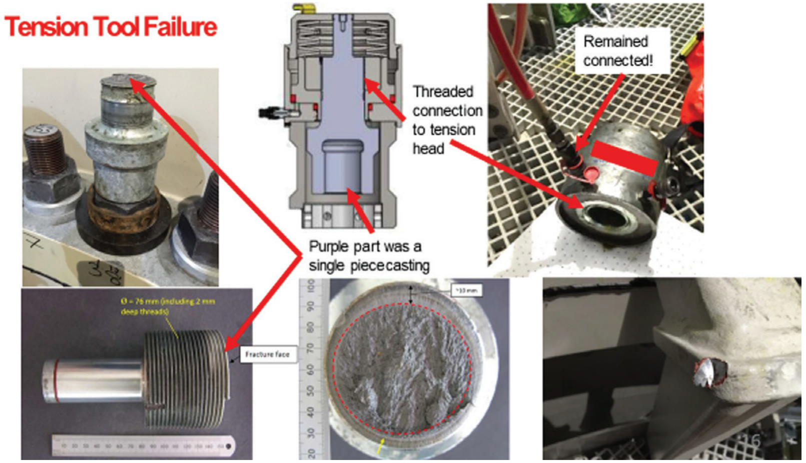
- Failure of the hydraulic hose coupling
- No one injured, hydraulic oil misted – but a very shaken operator
- Retaining plate sheared
- RCA found it was a manufacturing fault, exacerbated by poor handling and maintenance


[redacted]


[redacted]



Tension Tool Failure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Threaded connection to tension head

Remained connected!

Purple part was a single piece casting

Other risks and hazards

- Confined Spaces
- Working at heights
- Lifting and suspended loads
- Electrics (HV/LV)
- Housekeeping
- Offshore environment

Thank you

Any questions?

ANNEX C
ABBREVIATIONS AND ACRONYMS

EI	Energy Institute
G+	G+ Global Offshore Wind Health and Safety Organisation
HAZID	hazard identification study
H&S	health and safety
HSE	Health and Safety Executive
MP	monopile
NDT	non-destructive testing
OEM	original equipment manufacturer
O&M	operation and maintenance
PPE	personal protective equipment
QC	quality control
QR	quick response
RAMS	risk assessment & method statement
SbD	safe by design
TP	transition piece
WTG	wind turbine generator

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