PETROLEUMSTILSYNET

Investigation report

Report	
Report title Investigation of the reasons for the challenges faced in constructing hull and equipment for Johan Castberg	Activity number 001532039

Security grading		
☑ Public	☐ Restricted	☐ Strictly confidential
☐ Not publicly available	☐ Confidential	

Involved	
Team T-1	Approved by/date Kjell Marius Auflem/12 May 2021
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Contents

1 Summary

The Petroleum Safety Authority Norway (PSA) was informed in the first half of 2020 about quality defects in welds on the hull for the Johan Castberg FPSO, as well as errors in the analysis programme for fatigue calculations. A large number of welds need to be repaired, and the analysis errors will also require extensive reanalysis and subsequent repairs. Improvement work related to welding and fatigue analysis errors create uncertainty about the hull's integrity over the field's producing life, which must be handled with measures taken during commissioning, readying for operation and operation of the facility.

The PSA decided to investigate the causes of the welding and analysis errors. This investigation has sought to identify why the Johan Castberg project organisation for design and construction of the hull with integrated living quarters (LQ) failed to uncover the errors at an earlier stage. It has covered the project's follow-up strategy, reporting to licensees and government, and verification plans. The investigation will also contribute to learning for future field developments.

Equinor placed the contract for constructing the hull with integrated LQ to DNV GL class with SCM in Singapore during November 2017. The contract specified that fabrication and assembly of hull modules and the LQ would take place at the Tuas Boulevard Yard (TBY) over a 19-month period. During the first construction year, fabrication of the LQ and part of the hull modules was transferred to three other yards. Equinor has not previously used SCM for newbuilding offshore production facilities, and the yard's experience related primarily to ship repair. A desire to establish a lean project organisation underpinned Equinor's follow-up of the construction contract itself, even though it was aware of quality, capacity and expertise challenges at SCM.

SCM underestimated the scope of work related to further progress with front-end engineering design (Feed). This was reflected in the number of revised drawings issued as well as challenges with clashes as well as hull/bulkhead penetrations. SCM nevertheless reported that engineering-related milestones were reached in accordance with the contract, and Equinor was accommodating in accepting the milestones reached in order to encourage continued commitment by the yard.

Engineering lags at the start of the project led to an even tighter timetable for subsequent activities, since the planned milestones were retained. Against that background, Equinor's attention was primarily concentrated on progress.

Welding expertise and quality assurance/control (QA/QC) at SCM were inadequate. During its final inspection of the prefabrication stage, Equinor found quality nonconformities which should have been picked up by SCM's QC department and corrected. To remedy some of this, grinding stations were established to achieve

adequate surface quality for painting. This is not an appropriate response to poor welding. Status reports for class follow-up in the third quarter of 2018 clearly spelt out the quality challenges. Equinor failed to get to grips at a sufficiently early stage with the problems of inadequate expertise and poor welding quality.

Dimensioning of the follow-up was based on assumptions about fabrication at a single yard and the desire for a lean project organisation. Spreading fabrication between four yards put the project organisation under pressure. From the third quarter of 2019, the organisational strategy was changed by strengthening the project with resources. Equinor's aims and priorities have contributed to the failure to get adequately to grips with the weaknesses in execution quality, which have thereby persisted over time.

Identified risks remained unresolved over a long period, and the seriousness of some increased during the project period. Quality challenges related to welding and consequent delays were initially escalated out of the project and included in enterprise risk in connection with the Covid-19 pandemic.

Construction follow-up has been based on random sampling, which assumed that the yard's own QA/QC system was functioning. Classification societies will normally concentrate such sampling on critical areas. If quality is uneven – higher in critical areas than in less critical ones – this will give an inaccurate picture of quality.

The quality challenges have meant a significant expansion in inspection scope to include, for example, all hull welds exposed to the sea and all erection joints, and associated repair work has delayed completion.

Currently delayed by about a year, the project is now expected to come on stream in the fourth quarter of 2023 with a consequential reduction in present value for Equinor, the other licensees and the Norwegian government as a result of delayed earnings. Identified requirements for modifications and improvements as a consequence of errors in the Stofat analysis programme are not on the critical path for project execution, and will therefore not affect the project's completion date.

Nonconformities have been identified by the investigation in relation to risk reduction, management of project execution, qualification and follow-up of the contractor and application of experience in dimensioning own follow-up. Identified improvement points relate to information to the licensees and verification of fatigue analyses.

2 Abbreviations and terminology

Akso: Aker Solutions
Aris: Equinor's management system
AY1: Part of Admiralty Yard for fabrication of hull blocks
AY2: Part of Admiralty Yard for fabrication of the living quarters
CCE: Current cost estimate
DG: Decision gate
EPC: Engineering, procurement and construction
EPMA: Engineering, procurement and management assist
FCAW: Flux cored arc welding
Feed: Front-end engineering design
FPSO: Floating production, storage and offloading
FSU: Floating storage unit
HSE: Health, safety and the environment
IFC: Issued for construction
ISO: International Organisation for Standardisation
ITT: Invitation to tender
ITP: Inspection and test plan
KPI: Key performance indicator
NCR: Non-conformance report
NCS: Norwegian continental shelf
NDE: Non-destructive evaluation (normally applied to NDT activities)
NDT: Non-destructive testing
NTK: Norwegian total contract
Norsok: NCS competitive position (standards for offshore petroleum activities)
LQ: Living quarters
PDO: Plan for development and operation
PMF: Project manager field (head of DNV GL's on-site inspection team)
PSA: Petroleum Safety Authority Norway
SCM: Sembcorp Marine Rigs & Floaters Pte Ltd
Sesam: Software package for hydrodynamic and structural analysis
SSU: Safety and sustainability (specialist department in Equinor)
Stofat: Software utilised for stochastic fatigue analysis
Swot: Strengths, weaknesses, opportunities and threats
TBY: Tuas Boulevard Yard
TKY: Tanjong Kling Yard
TPD PRD: Technology, projects and drilling, project development (Equinor)
TQ: Technical query
UT: Ultrasonic testing
QA/QC: Quality assurance/control
QRM: Quality and risk management
QSP: Quality survey plan

Regulations
Framework regulations: Regulations relating to health, safety and the environment in the petroleum activities and at certain onshore facilities
Management regulations: Regulations relating to management and the duty to provide information in the petroleum activities and at certain onshore facilities
Facilities regulations: Regulations relating to design and outfitting of facilities, etc, in the petroleum activities

3 PSA investigation

The investigation team has comprised

- Roger L Leonhardsen – structural integrity discipline (investigation leader),
- Tom Haldorsen – HSE management discipline
- Knut Ivar Hjellestad – occupational health and safety discipline
- Lars G Bjørheim – structural integrity discipline
- Morten A Langøy – structural integrity discipline.

The investigation has been conducted through interviews with Equinor employees involved in the Johan Castberg project, including safety delegates, personnel in operations north, the managers for major projects and for project development in the technology, projects and drilling (TPD) unit as well as people in the risk and management system department. Interviews have also been conducted with personnel from licensees Vår Energi and Petoro. All interviews have been conducted as video meetings. Governing and project documentation has been obtained and used with the interviews as the basis for the team's assessments and observations. After completing its work, Equinor's internal investigation team presented its observations on the causes of welding errors and recommended measures for learning lessons. Its internal investigation report was sent to the PSA.

Infection conditions and quarantine rules mean no inspection or verification has been conducted at the construction site for the Johan Castberg FPSO.

The purpose of the investigation has been to identify the reasons why the Johan Castberg project organisation for design and construction of the hull with integrated LQ failed to detect the welding and analysis software errors earlier. Investigation work has covered the follow-up strategy for the project, reporting to licensees and government, and the project's verification plans. It is also intended to contribute to learning lessons for future field developments.

Investigation work has covered the period from the award of the contract for the hull with integrated LQ to SCM in November 2017 until the management committee meeting of 25 June 2020.

The investigation has aimed to address the following points.

a. Clarify the course of events (with the aid of a systematic review which typically describes time lines and incidents).
b. Assess the actual and potential consequences of welding and analysis programme errors for HSE.
c. Assess direct and underlying causes of the present position.
   The investigation will particularly address the project's follow-up strategy, reporting to licensees and the government, and its verification plan.
d. Identify nonconformities and improvement points related to the regulations (and internal requirements).
e. Discuss and describe possible uncertainties/unclear points.
f. Assess the player's own investigation report.
g. Prepare a report and a covering letter (possibly with proposals for the use of reactions) in accordance with the template.
h. Recommend – and normally contribute to – further follow-up.

The report utilises Equinor as the name of the company, even for the period before it changed its name from Statoil.

4 Background information

The Johan Castberg field lies in the Barents Sea, 240 kilometres north-west of Hammerfest, and is being developed with a floating production, storage and offloading (FPSO) facility and subsea templates tied back to this. The planned date for coming on stream in the original plan for development and operation (PDO) was the fourth quarter of 2022. Production is expected to continue for 30 years. Equinor ASA (50 per cent holding) is operator, with Vår Energi (30 per cent) and Petoro AS (20 per cent) as the other licensees.

The contract for fabricating the hull with integrated LQ was awarded to SCM in November 2017. The contract with Aker Solutions (Akso) for design and procurement management was entered into in December 2017.

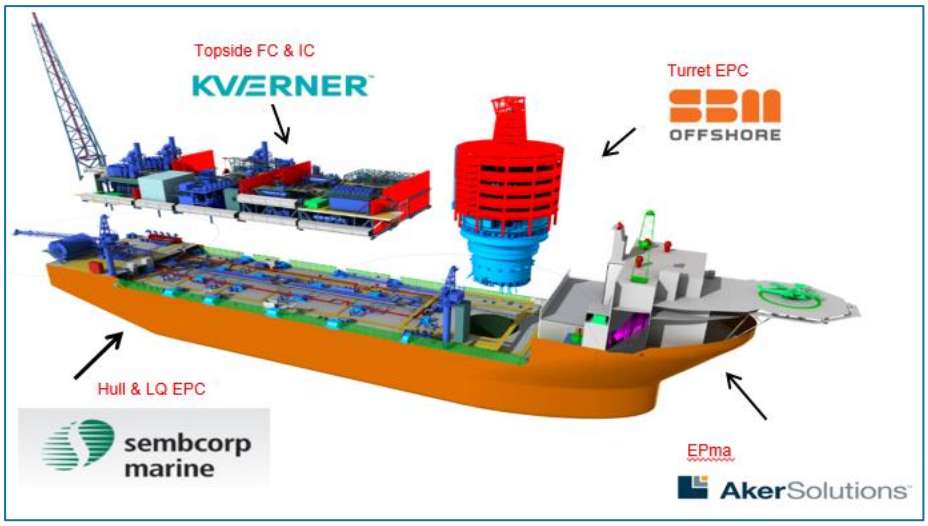

Figure 1: Contracts for constructing the John Castberg FPSO (source: Equinor).

Construction of hull blocks for the Johan Castberg FPSO began in June 2018 at SCM's Tuas Boulevard Yard (TBY).

The PSA was made aware at the management committee meeting of 1 April 2020 that major weld-quality challenges had been identified in the Johan Castberg FPSO hull.

On 25 June, the management committee meeting was informed that extensive weld repairs were required and that errors discovered in the Stofat analysis programme used for fatigue calculations would also call for extensive reanalysis and consequent repair work.

The extensive improvement work contributed to delaying the hull with integrated LQ by about a year. Such work related to welding and fatigue analysis errors also creates uncertainty about hull integrity over the field's producing life, which must be handled with measures taken during commissioning, readying for operation and operation of the facility.

Following the 25 June management committee meeting, the PSA held three follow-up meetings with Equinor. Those on 10 July and 11 August were with the Johan Castberg project organisation, and that on 26 August was with the TPD management and Equinor's TPD PRD (projects development) unit.

The PSA decided on 1 September to investigate the causes of the welding and analysis programme errors.

4.1 Description of the contract form

4.1.1 EPC contract with SCM for hull with integrated LQ

SCM has been awarded an EPC contract for design and construction of the hull, with welding in of the turret structure and LQ. In addition comes maritime, utility and process equipment installed in the hull. This lump sum contract specified that all construction would take place at TBY. A lump sum contract means that SCM bears the financial risk. The breakdown between lump sum and hourly-based compensation is 96 and four per cent respectively.

SCM had a strategy of taking an increased share of the FPSO market and becoming a preferred supplier to Equinor. The latter saw this as an opportunity to increase capacity in the market. A short execution time was planned at SCM, and the contract and its incentives were based on construction progress. A tight execution plan was also identified as a key threat to the project in Equinor's follow-up strategy.

Equinor opted for DNV GL class approval as part of the EPC contract in order to strengthen construction follow-up. SCM is responsible for delivering the FPSO and has a contract directly with DNV GL. The latter has also submitted copies of its monthly reports to Equinor.

In line with section 24 of the framework regulations on the use of recognised standards, DNV GL's classification requirements have been applied to systems which are maritime in character and the hull, as well as the support structures for the LQ and turret.

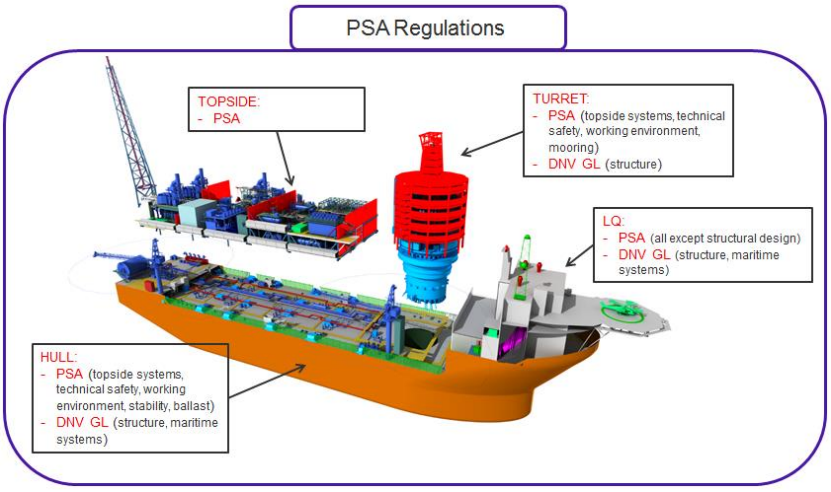

Figure 2: Application of regulations and class rules (source: Equinor).

SCM hired LMG Marine as additional capacity to reinforce its own organisation for construction analysis. Equinor's project organisation has helped to strengthen

SCM's engineering capacity and expertise by making resources available via Akso as EPMA contractor. Figure 3 shows the contractual and communication lines.

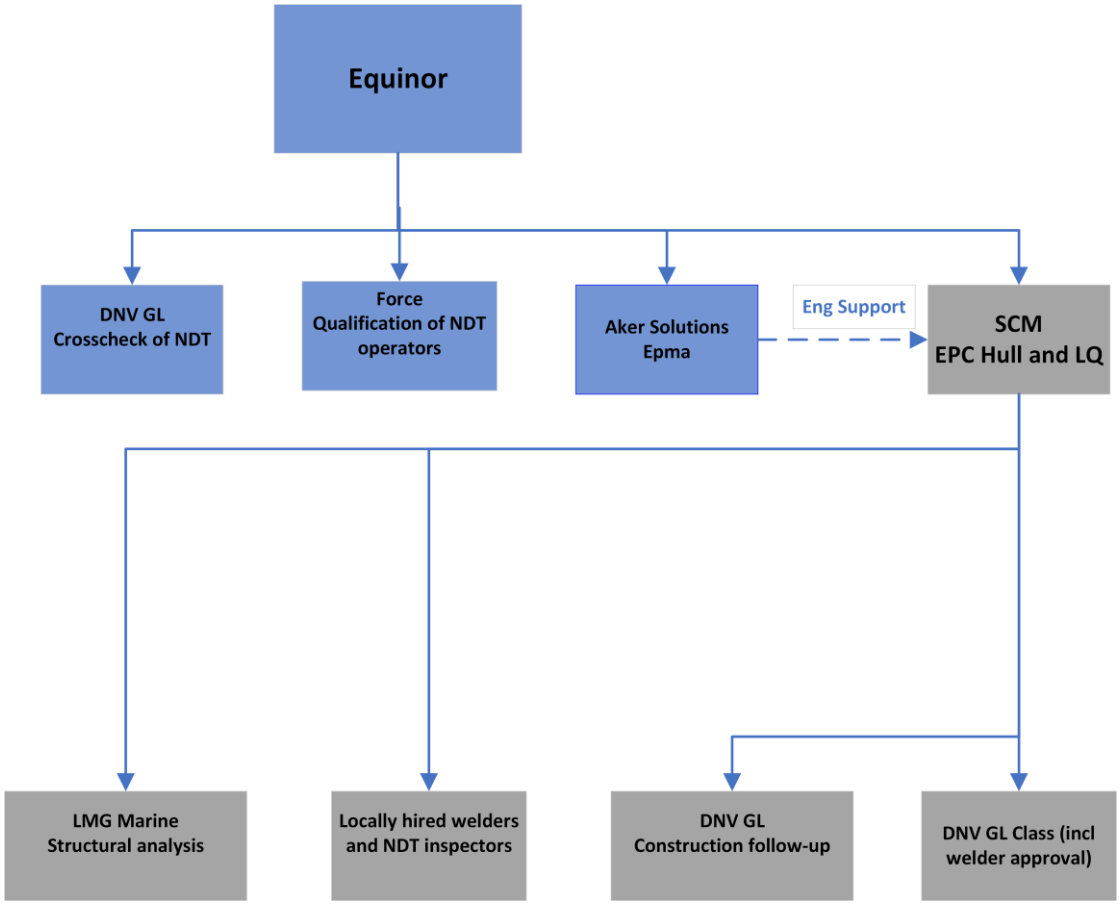

Figure 3: Diagrammatic presentation of relevant contracts for the Johan Castberg project.

4.1.2 Equinor's identified risks from choosing SCM as contractor and TBY as construction yard

In connection with awarding the contractor, the following were among the main risk components identified:

- human rights
- unknown supplier for Equinor
- limited experience with Norwegian engineering contractors
- lack of sufficient engineering manning at SCM
- limited track record with newbuild FPSOs.

These components were carried forward to the follow-up strategy in the project organisation.

4.1.3 Engineering scope for EPC contractor

The invitation to tender (ITT) for the EPC contract was issued when Feed was 60 per cent completed. Since potential bidders were unable (or not allowed) to

contact the Feed supplier, they lacked a full overview of the work being tendered for. An opportunity to adjust the tender was provided three months after the contract was entered into.

Feed maturity for the cargo area of the hull was regarded as good, but less advanced for the foreship and aftership areas where further design development was needed. An important job for the contractor was to complete necessary analyses and prepare construction drawings.

4.1.4 EPMA contract with Akso

Equinor awarded an engineering, procurement and management assist (EPMA) contract to Akso. This covered an overall responsibility for interfaces throughout the FPSO and a global system responsibility.

4.1.5 Contracts with Force Technology and DNV GL for verification and follow-up of construction

Equinor awarded a contract to Force Technology for qualification of NDT operators at the yards fabricating the hull with integrated LQ as well as the turret and topsides. The assignment also covers NDT crosschecking during fabrication, but that part of the contract has not been applied to hull construction. Qualification of operators must accord with the principles in ISO 9712 *Non-destructive testing – qualification and certification of NDT personnel*.

The contract for classification approval and construction follow-up is between SCM and DNV GL, and accords with the strategy specified in Equinor's ITT to SCM. The DNVGL-OS-C401 *Fabrication and testing of offshore structures* standard sets competence requirements for welders and NDT operators.

Via DNV GL, Equinor has engaged resources which conduct NDT cross-checking of weld execution on its behalf.

4.2 Equinor's project execution requirements

The following Equinor governing documents and process descriptions related to project execution are referenced in the investigation report.

- Aris – Equinor's management system
- *Function requirements 05* (FR05)
- Project execution and overall procurement strategy (Peops)
- Follow-up strategy.

4.2.1 Aris

The *Function requirements* (FR05) governing document establishes Equinor's basic project-execution requirements, while Aris describes them in detail.

Aris provides a process-based description of project development, where the investment project process describes the phases from DG0 to DG4. The initiate and plan execution phase process includes processes for establishing a project team (PDn02), accessing experience (PDn03), and quality plan (PDn17). The execute the investment project process includes processes for project follow-up (PDn51) and management of interfaces (PD460), risk (PDn65), and change (PDn59).

The construction process (PD431) describes the requirements for such aspects as project management and fabrication to completion. Requirements related to fabrication are described in the construction management process (R-103562).

4.2.2 Project execution and overall procurement strategy (Peops)

The applicable Peops for Johan Castberg (version 2) was issued on 31 October 2016. This describes the project's success criteria as follows:

- dedicated HSE commitment throughout the organisation
- commitment to cost consciousness
- team alignment and good working environment
- risk-based manning
- "no change" philosophy on frame conditions
- secure competitive contracts/purchase orders
- timely deliveries with quality in all deliverables
- effective utilisation of Equinor competence and operational experience
- proactive stakeholder management.

The project's risk profile is identified as:

- mega project (high capital exposure) also on sub-project level
- large and complex floater on critical path for first oil in Oct 2022.
- continuity in floater engineering is secured from concept through fabrication and completion
- limited pre-investment (engineering and critical material) before PDO approval will be required to achieve date for first oil.
- likely to have floater fabrication contract(s) in Far East, acknowledging previous project experience
- execution complexity above average, being Equinor's first Barents Sea greenfield development, with extensive drilling, subsea and logistics scope including seabed intervention
- the project has a moderate extent of new technology, mainly related to subsea standardisation (VXT) and harsh climate (ice management and winterisation)
- limited contractor market for turret.

Furthermore, key success factors for project success relate in part to close follow-up in the execution phase: "A key success for the project is to use competent and

experienced personnel and suppliers familiar with Norwegian regulations and Norsok requirements. Close cooperation between the supplier resources, Equinor technical resources and operational resources is a key success factor for the project. Thus a hands-on follow-up strategy will be the basis for company involvement during execution, keeping in mind the split of roles and responsibility between company and contractor."

4.2.3 Follow-up strategy for hull and LQ contract

A follow-up strategy describes how the contract with the contractor(s) is to be monitored to ensure that the project reaches its overall goals. The need for, goal of and development of a follow-up strategy is described in Aris process R-60329.

The first version of the follow-up strategy was issued in December 2017. Its Swot analysis of the contractor identified such weaknesses as unfamiliarity with Equinor, no experience of Equinor's requirements and work processes or of the NTK contract format, the quality of the fabrication method and skilled personnel, and limited FPSO newbuilding experience (only one FSU previously). Its identified strengths included flexible organisation and fabrication, fabrication capacity, manning and co-located fabrication.

Guidance was provided in the strategy for Equinor's follow-up through a hands-on approach, with a dedicated engineering and fabrication team at SCM. Important areas for fabrication follow-up included the quality of NDT operators and thereby of welds, as well as early identification of challenges and communication of these to the contractor to ensure improvements to fabrication execution.

The second version of the strategy was issued in June 2018. Its Swot analysis by and large identified the same weaknesses and strengths at the contractor as the first version. Where fabrication follow-up was concerned, construction at three sites was highlighted. The governing document for construction (PD431) specifies that the follow-up strategy must be reviewed and the need for updating assessed. The investigation team has been told that the project document describing the follow-up strategy has not been updated since June 2018.

4.3 Description of the project organisation

4.3.1 Technology, projects and drilling (TPD)

Project development is the responsibility of the TPD unit, which comprises various business units – including PRD. The Johan Castberg project is organised with several other projects in the major projects (MP) unit.

The Johan Castberg FPSO project is organised in three construction packages:

- topside and integration

- hull and LQ
- turret.

TPD is responsible for project execution with development and production Norway (DPN) as its internal end customer, which takes delivery of the Johan Castberg FPSO when it is completed, has been installed on the field and tested.

4.3.2 Development and production Norway (DPN)

DPN is responsible for safe and efficient operation on the NCS and comprises the operations north, west and south units as well as operations technology and support. Operations north will take over the Johan Castberg FPSO from TPD. It has its own personnel involved in the project, including people in Singapore. Operations personnel have supported the project organisation during the construction period in Singapore by meeting the need for operational preparations. The operations unit has also been represented in the project's management team through the project manager operations (PMO) role.

4.3.3 Project organisation

Figure 4 presents the organisational structure for the hull and LQ at 31 March 2018.

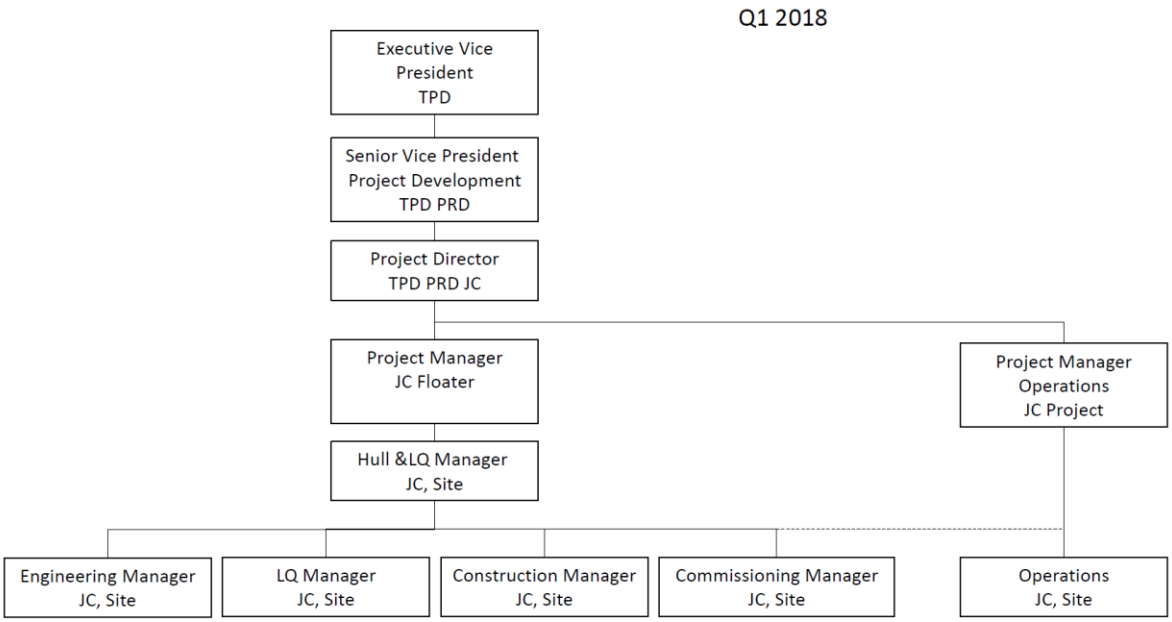

Figure 4: Organisational structure for Johan Castberg – hull and LQ at 31 March 2018 (source: Equinor).

The follow-up strategy referenced in section 4.2.3 was drawn up by the hull and LQ project on award of the contract to SCM. It describes how follow-up is to be conducted to ensure that Equinor's applicable internal requirements are met along with the contractual specifications for the hull and LQ project. That includes the

way the project organisation is to be structured and organised, priority areas for follow-up and various milestones defined for the execution phase.

It emerged from both interviews and documentation that Equinor wanted a lean project organisation, even though the Swot analysis from the follow-up strategy identified challenges related to capacity and expertise at SCM. The aim was an organisational model where disciplines had Equinor personnel as leaders and the associated inspection teams were made up of resources hired locally. Furthermore, efforts were made to utilise personnel across yard locations as well as between the engineering and fabrication departments. Pursuant to the follow-up strategy, manning was to be risk-based and upscaled as required.

Equinor personnel reported in interviews that Shell's Vito project[1] opted for a larger project team than Equinor chose for Johan Castberg, and that Shell's decision was based on its own experience with and awareness of SCM's weaknesses and limitations. Although this information was known to Equinor through experience acquisition, it nevertheless selected a lean project organisation and also faced challenges securing the personnel it wanted in strategically important positions.

The strategic choice of a lean, risk-based organisation was retained when revising the follow-up strategy in the second quarter of 2018.

According to project risk 1469 – "Lack of resources for hull project may lead to insufficient follow-up and lack of quality", the organisation strategy was changed in July 2019 from a lean risk-based structure to one with sufficient manning to improve SCM's progress.

4.3.4 Operating parameters for Equinor's organisation

The PSA team has been told that a general ceiling on using hired consultants at Equinor imposed restrictions on actions the hull and LQ organisation wanted to take. Challenges have also been faced over access to internal resources related to compensation for outstationing to Singapore. Personnel from the Johan Sverdrup project who were envisioned for roles on Johan Castberg were not transferred as planned because of Equinor's acquisition of a production licence with an ongoing development project in South Korea.

4.3.5 Project organisation changes in the construction phase

Fabrication at a single location was assumed in the contract, and was planned to be SCM's TBY facility. About two months after contract award, SCM proposed

[1] PSA comment: Equinor is a partner in the Vito licence in the Gulf of Mexico.

transferring LQ construction to its Admiralty yard (AY2) in Singapore. The latter had experience from constructing the LQs for Ivar Aasen and Ekofisk 2/4-L. Equinor approved this proposal in February/March 2018.

In late February/early March 2018, SCM also proposed using its Tanjong Kling Yard (TKY) in Singapore to build foreship blocks because of capacity problems at TBY. Equinor approved this proposal.

In October/November 2018, SCM proposed transferring some block fabrication to Indonesia's PT SMOE yard at Batam and fabrication of midships blocks to another part of the Admiralty yard (AY1) because fabrication of structural blocks had fallen behind schedule. Equinor approved the request in December 2018.

Figures 5 and 6 provide an overview of the expansion in the number of fabrication yards and their geographical location respectively.

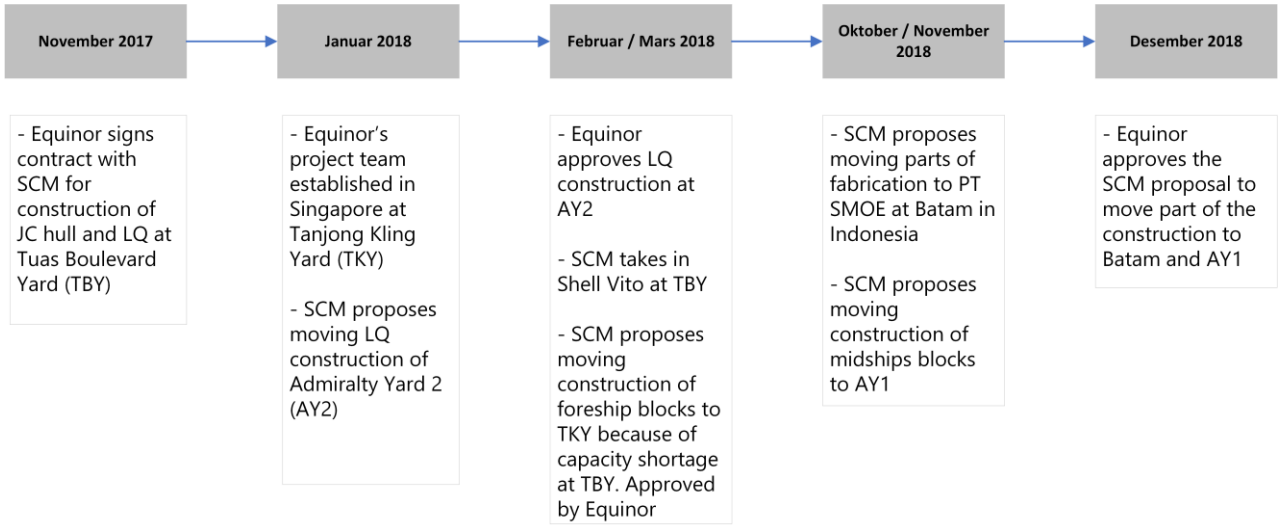

Figure 5: How Johan Castberg construction changed from one yard specified in the contract to four.

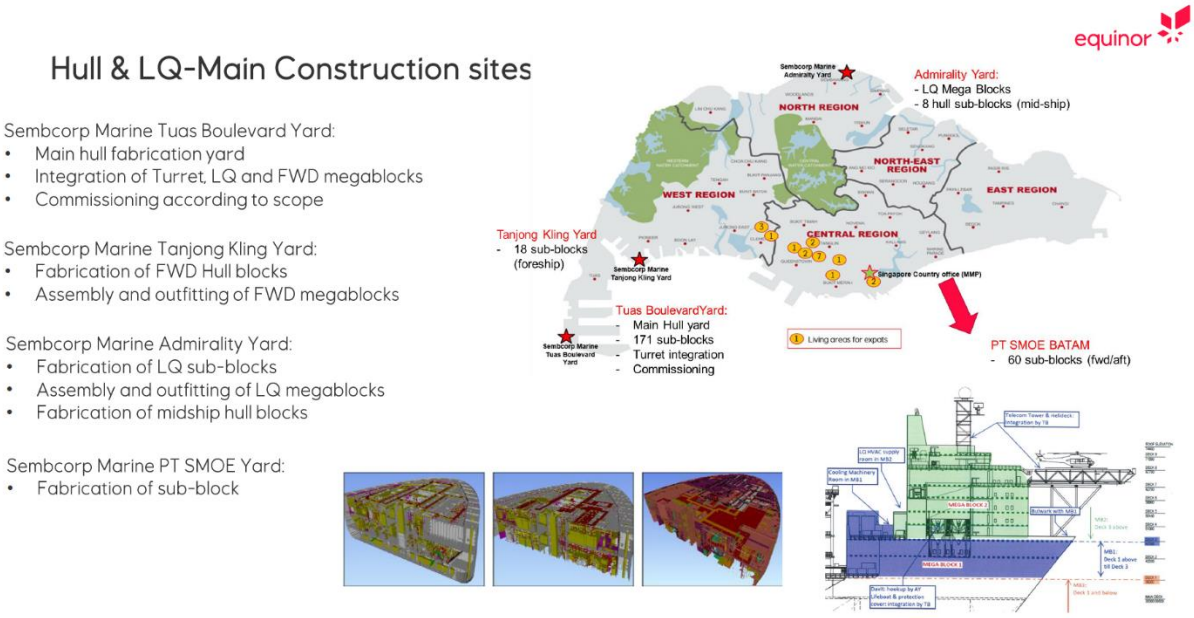

Figure 6: Construction sites for hull with integrated LQ, presented to the PSA in April 2019 (source: Equinor).

In connection with the expansion in the number of yards, the project organisation was also adjusted. The main change involved the construction department, where sub-organisations were established for each yard. Inspector teams were established in relevant disciplines at each yard, and the size of these teams has been gradually adjusted. Equinor has reported that much of the resources were directed at fabrication follow-up of the LQ at AY2, given its experience of quality challenges with building such structures in South Korea.

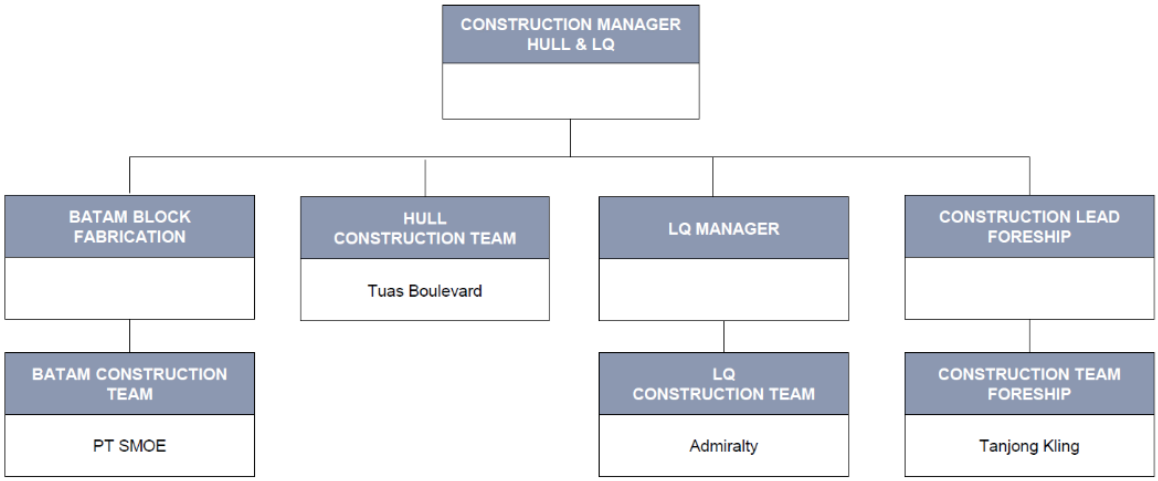

Figure 7: Organisation of the construction department after the increase in number of yards (source: Equinor).

4.4 Description of fabrication follow-up

Fabrication follow-up of the project is illustrated as barriers in figure 8, with specification of roles.

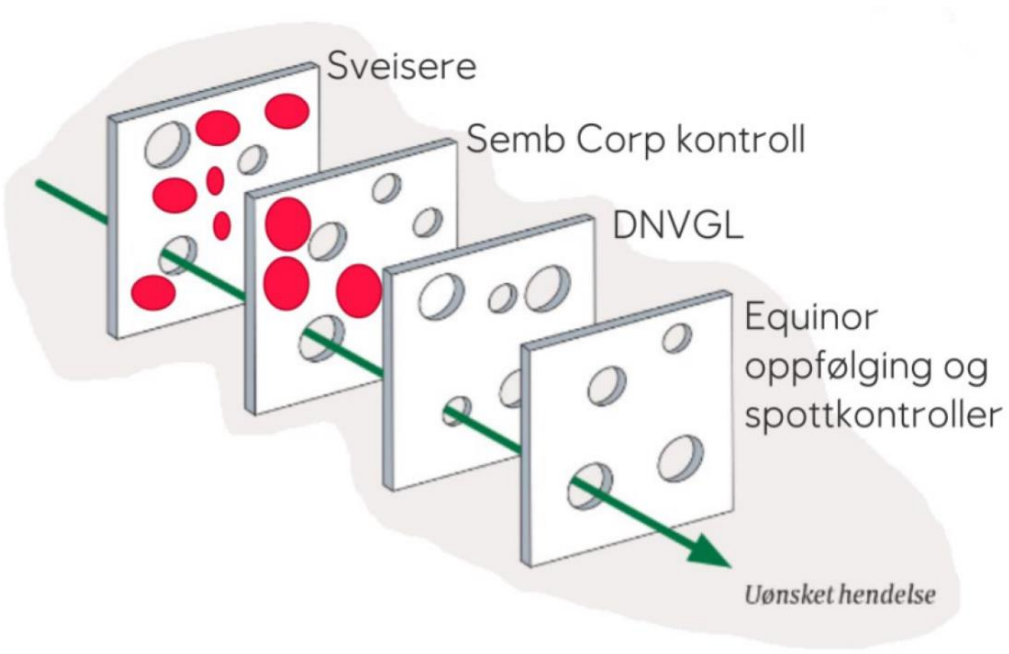

Figure 8: Quality follow-up during fabrication (source: Equinor).
Key: Welders; Semb Corp checks; DNV GL; Equinor follow-up and spot checks; *Undesirable incidents*.

Equinor initially adopted the barrier model illustrated above to ensure it met its see-to-it responsibility.

The first barrier was welder quality. Access to competent welding personnel was a known challenge in Singapore. Among other things, it emerged that the welders were not familiar with the prevailing procedure owing to language barriers. SCM has its own department for training and certifying welders, with a third party responsible for certification.

Challenges related to QC at SCM were known to Equinor through experience transfer from a construction project led by Heerema Marine Contractors. Force Technology was mobilised to qualify controllers, and this qualification confirmed that challenges existed in relation to their competence. Many controllers needed several attempts to qualify.

The third barrier was DNV GL, which was to give class approval for the facility. As a basis for such approval, the society conducts its own structural analyses as well as monitoring construction at the yard. Equinor views class approval as a verification. In accordance with normal practice in this area, the contract for class approval is between SCM and DNV GL.

DNV GL's local representation for construction follow-up has varied over time. The PSA team has been informed that the society's average presence has been in the order of three-five people. This has reportedly been somewhat larger for the Johan Castberg project than is normal for such contracts.

The final barrier was Equinor's follow-up and spot checks. Local inspectors have been hired by the company for its organisation at the yard, and these have reported in line to the construction manager. Equinor has explained that its site organisation initially numbered three inspectors at TBY, which was gradually expanded by four-five additional inspectors in the second quarter of 2018. One construction inspector was deployed at both AY and TKY. The number of hired inspectors has increased as the quality and QC weaknesses at SCM emerged.

The scope of QC for hull fabrication is formalised in the *Inspection and Test Plan Matrix (Structure)* document. It has emerged from the PSA's audit in April 2019 and through interviews that Equinor pursued more quality-related activities than are reflected in this plan.

In addition to the specified barriers for securing quality, Equinor has taken the following initiatives with SCM:

- incentive programme for progress
- quality programme.

Entitled *What does it take*, the incentive programme for progress was established in the third quarter of 2018. As a consequence, the project approved in December 2018 that blocks could be fabricated at PT SMOE and AY1.

The quality programme was initiated in September 2019, with its mandate and participants presented on 13 September. Members of the work group were drawn from Equinor and SCM. This programme was intended to improve quality in defined areas of the hull and LQ. A deadline of 1 October 2019 was set for completing the process of clarifying, identifying and implementing compensatory measures. The list of actions to be implemented was established at the end of November, and supplemented with further actions from March 2020.

4.5 Follow-up by the licensees

When the PDO was submitted, the licensees explained – in separate submissions – how they would follow up their see-to-it duty until to PDO approval and in the construction phase.

In its explanation, Vår Energi (ex Eni Norge) specified that the Johan Castberg project is categorised as "strategic". The company identified the EPC contract, fabrication and integration of topside modules, and the completion phase as the most critical aspects in terms of costs, schedule and HSE. Dedicated personnel had been allocated to the technical and management committees.

In connection with partner verification at the yard in August 2019, Vår Energi presented its experience from the Goliat development to the Johan Castberg project team. The latter also presented and discussed workmanship and quality,

with the emphasis on structural and welding quality, QC at SCM, painting quality, resources/capacity, experience of resources/welders/workers, insulation and EIT.

Vår Energi has reported that this was the first time the weld-quality challenges became known to the partners. After the partner verification, one comment made by the company in its internal summation was the poor weld quality compared with Korean yards (welding, inspection/NDT). Main challenges mentioned included quality with the comment that, since the yard is primarily concentrated on progress, Equinor was working hard to maintain quality and avoid repair work.

In its explanation, Petoro said that a risk-based follow-up was planned in the construction phase. The company would continuously monitor the development of the project's risk picture, with particular attention to HSE, cost trends, progress and the reserves basis. With regard to HSE, emphasis was given in part to involvement in selected HSE management inspections and reviews/verifications. Where quality, costs and planning were concerned, the company gave emphasis in part to seeing to it that the operator implemented the project in accordance with its established management principles, and to participation in selected/prioritised committees, verifications and reviews.

Petoro has reported that its follow-up of Johan Castberg definitely falls into the "active" category. Dedicated personnel are allocated to both technical and management committees. The company's internal quarterly assessment for November 2019 discussed weld quality in the turret area and capacity, and its assessment on the basis of several meetings with Equinor was that this was being well looked after. Petoro was informed of a large number of weld errors during the winter/spring of 2020, including in February and May, and grasped their scope and consequences at the management meeting in June.

The company was unable to participate in the partner verification at the yard in August 2019.

Partner follow-up of the hull with integrated LQ included the independent partner review i September 2017, the partner visit: experience transfer and site inspection in August 2019, and two partner reviews – the readiness review Singapore and the readiness review Stord, which were planned for March and June 2021 respectively.

4.6 Experience transfer

The first version of the follow-up strategy referred to projects it was based on. These included the Johan Sverdrup, Aasta Hansteen, Mariner FSU, Gina Krog production facility and FSU, Valemon and Gudrun developments. When updating the strategy to version 2, experience transfer from similar projects and SCM contracts in Singapore were described for improvement and to benefit

development and execution of the hull and LQ project. Johan Castberg will also contribute to other projects by sharing its experience. This is logged and documented in the lessons learned database.

In addition to Equinor's own project experience, this database includes similar SCM assignments involving construction of a semi-submersible production facility, a heavy-lift ship and an FSU. Equinor's own project experience is primarily related to building the LQ. The experience from SCM highlights such aspects as NDT cross-checking and QA/QC manning as well as experience of a technical and general character where Equinor's action is close follow-up to ensure HSE, progress and quality.

The PSA team has been told that Equinor initially concentrated its follow-up, with manning of the follow-up team, on building the LQ and midships blocks at AY. This was based on experience with quality from LQ projects in South Korea.

4.7 Stochastic fatigue analysis using Stofat

Personnel from Akso's Bergen office were asked to assess and QA the results from fatigue analyses related to repair work in the moonpool area. Their assessment was that Stofat underestimated the calculated fatigue damage, and reported this to Equinor in April 2020. Akso's analysis team in Bergen had notified DNV GL in 2018 of its suspicion that Stofat underestimated calculated fatigue damage.

In April 2020, DNV GL confirmed the suspicion that Stofat underestimated calculated fatigue capacity for given assumptions which were present for Johan Castberg.

Underestimating fatigue damage can yield a significant change in calculated service life for a number of hull areas and details. However, errors in the software have only had design consequences for those details which changed status from adequate to inadequate fatigue capacity. The design of many areas and details will be governed by loads other than fatigue, and consequently have a fatigue capacity above the minimum requirement. Recalculating such details could still lead to the conclusion that fatigue capacity is adequate.

An express assumption for class approval by DNV GL is that details which fail to meet the required fatigue capacity will be modified or improved through grinding.

The identified need for modifications and improvements resulting from the Stofat error is reportedly not on the critical path for project execution, and will accordingly have no effect on the completion date.

Verifiers have used the same software as the designers for fatigue analysis. This weakens the barrier verification is meant to provide. Availability of software and expertise in its use are factors which could favour conducting design and verification with the same software. Norsok N-001 provides some recommendations on compensatory measures in such cases, including simplified calculations.

Equinor compared results from simplified and stochastic fatigue analysis during the Feed study in May 2017. It found an unexpectedly large variation between the two analyses from Akso, which had design responsibility during Feed. Akso carried out a quality check of its analyses without finding any errors. However, it was noted that the assumptions chosen for the analysis could account for part of the difference in the analysis results.

Observed variations were not followed up further. When SCM won the contract, it continued its design development with the same software used in Feed.

4.8 Risk management

This section will present risk management in Equinor relevant for this investigation, as well as negative risk and an assessment of risk-handling in the construction project.

The goal of risk management is to identify, eliminate/reduce and/or mitigate conditions which could have a negative effect on goal attainment. Its position in the overall corporate management system is presented in figure 9. At the top level, enterprise risk management utilises the RM100 process. At lower levels, however, such as a development project, the PDn65 process is used for task risk management as shown in figure 10. Where a project is concerned, one or more risks can in total represent an “enterprise risk”. Attention in this investigation has therefore been concentrated on the PDn65 process, which deals with project risk.

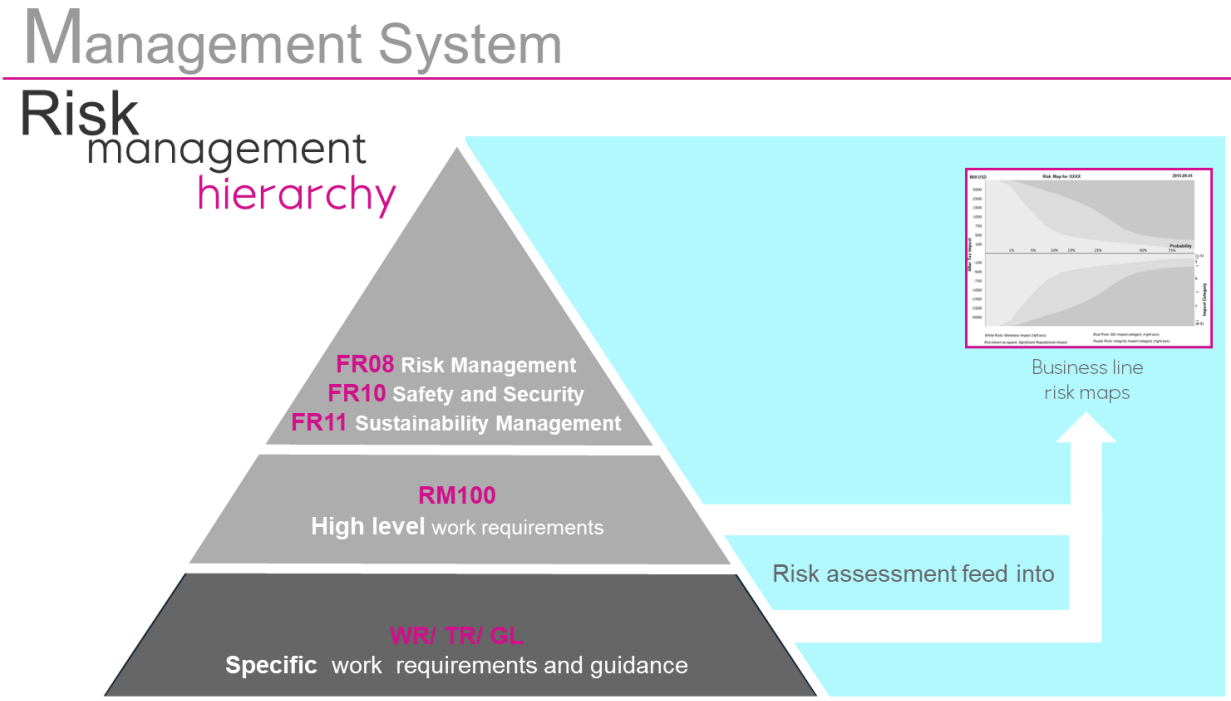

Figure 9: Hierarchical structure of risk management in Equinor, from MIS risk course for the PSA, 2020 (source: Equinor).

Management System – Risk Management – Overview

Where	Scope	Applicability
Equinor Book	Fundamentals	Corporate
FR08	*Enterprise Risk Management* Function Requirements	Corporate
RM100	*Enterprise Risk Management* **Main work process for Risk management across business areas**	Corporate
OMC05	*Enterprise Risk Management* Risk Management at project portfolio level and above	Technology, Projects and Drilling (TPD) business area
FR05	Function Requirements	Corporate - Investment projects
PDn65	*Task Risk Management* **Main work process for Risk management in investment projects** (includes relevant elements from RM100)	Investment projects in Project Development (PRD)
GL0659 – App.C	*Task Risk Management* Supporting PDn65	Investment projects in PRD
Training Material	*Task Risk Management* Supporting PDn65	Investment projects in PRD
PMS (030)	*Task Risk Management* **Main project document for risk management**. (includes/supplements relevant elements from PDn65)	Single project
Contract	*Task Risk Management*	Single project
++		

Increasing detail

Figure 10: Processes and governing documents for risk management by area of use, from input to meeting with the PSA on 10 December 2020 on risk management in project development (source: Equinor).

The work flow in the PDn65 process is presented in figure 11, where the horizontal axis is a timeline and the vertical axis specifies the person with task responsibility/ contributor on four levels – from top: SSU, responsible person for risk process, contributor – stakeholders/project members, and accountable – risk owner.

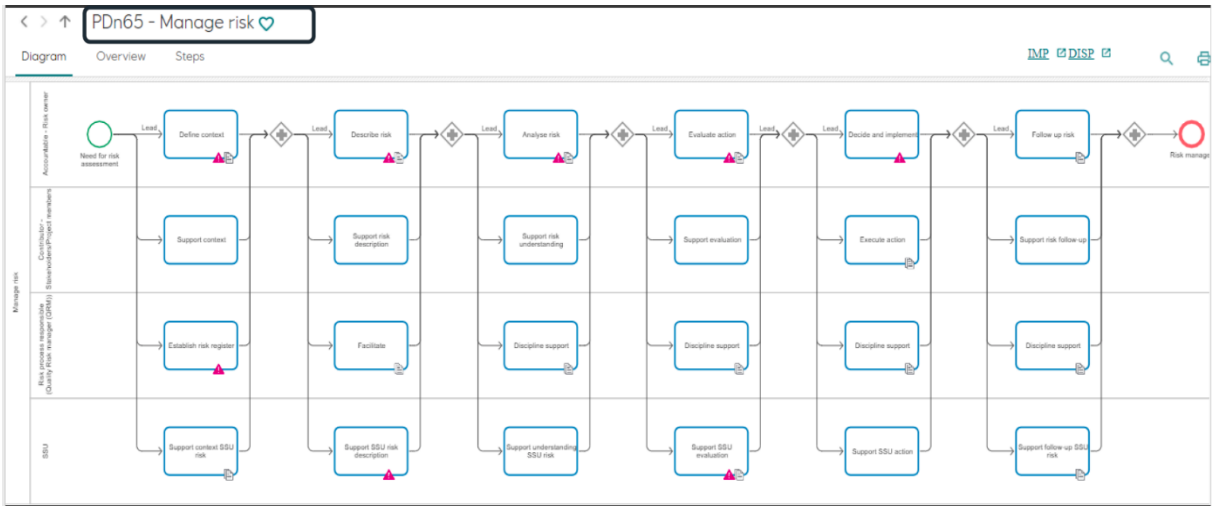

Figure 11: Process flow for risk management in PDn65, from input to meeting with the PSA, 10 December 2020, on risk management in project development (source: Equinor).

Each risk is assigned a unique ID number, and the person establishing the risk must fill out several fields with such information as risk name, description, category and date. Probability and impact must also be entered. This will produce a score in a risk matrix as shown in figure 12. The matrix presented is for enterprise risk, but also illustrates the methodology for project task risk. Pursuant to RM100, the 8x9 matrix shown here for use with R-12325 "SSU – Identify/establish risk tolerance criteria" can be replaced in R-105890 "SSU – risk matrix format – for asset/unit level" with a 5x5 matrix.

	PROBABILTY	Unknown in the industry	Very rare but known in the industry (1)	Has rarely occurred (1-3) in the industry	Has occurred several times (4- 20) in the industry	Has occurred in the region/ company	Has occurred more than once in the company	Has occurred locally/in facility	Occurs frequently
		< 0,001%	0,001 - 0,01%	0.01 - 0,1%	0,1 - 1%	1 - 5%	5 - 25%	25 - 50%	> 50%
IMPACT	1-3/ Minor								
	4/ Moderate								
	5/ Serious								
	6/ Severe								
	7/ Major								
	8/ Catastrophic								
	9/ Extreme								

Figure 12: Risk matrix. R-12325 Identify/establish risk tolerance criteria, from MIS risk course for the PSA, 2020 (source: Equinor).

Management rules specified for the colour codes in the risk matrix are presented in figure 13. As well as placing the risks in the matrix, a severity index is calculated. The more severe an identified risk, the more attention must be paid to it at senior management levels. Depending on the degree of severity, possibly for the sum/ aggregate of several risks in a project, the risk must be shared with and notified up the organisation – if severe enough, right to the CEO.

RISK LEVEL	MITIGATION and SHARING of RISK
RED	Single red risk is generally intolerable and far beyond the Group's risk tolerance criteria. Mitigating actions must be implemented as soon as possible. The Business Area SSU shall without delay share single red risk with Corporate Safety and Security, unless immediate risk reduction is implemented. Both the risk and its further handling shall be described The CEO needs to be informed. The Corporate Executive Committee will be informed if the risk has relevance for other Business Areas or Corporate Staff functions.
ORANGE	Single orange risk is generally intolerable, and mitigating actions must be implemented. Single orange risk in impact categories 5 through 9 shall be shared with the organizational levels above to ensure that the risk information is available at all levels at all times.
YELLOW	Mitigating actions shall be identified based on the ALARP (As Low As Reasonably Practicable)/ BAT (Best Available Technology) principle or other applicable principles subject to relevant jurisdiction (s). Sharing is not required.
GREEN	Risks in the green zone are generally tolerable and actions are normally not required. Sharing is not required.

Figure 13: Rules for dealing with risk in accordance with colour coding, from MIS risk course for the Ptil, 2020 (source: Equinor).

Requirements for project execution and overall procurement strategy (Peops) are described in section 4.2.2, while the follow-up strategy is described in section 4.2.3. An extract from the follow-up strategy (June 2018 version) relevant for risk has been examined in more detail in the investigation. Emphasis has been given to management involvement and traceability of decisions. This extract is taken from the heading "Engineering follow-up (Risk & Lean based)", numbered by the PSA team to simplify the discussion and utilised in tabel 1.

1) <u>Focus areas:</u>
   a) Short and intensive detail engineering to meet milestones per contract
   b) Scope understanding and engineering capacity/progress
   c) Maturity and quality in 3D model – 60 per cent and 90 per cent review with formal comments close out

Extract from the section headed "Construction follow-up (Risk & Lean based)":

2) <u>Focus areas:</u>
   a) Close communication with contractor personnel to ensure good cooperation and early involvement when challenges occur
   b) Close communication with DNVGL as body of site surveillance for the construction of the hull to class/flag level to ensure alignment both with respect to inspection activities and alignment of standards.

3) <u>Coordination of three building sites:</u>

a) Dedicated teams on each site, but with flexibility to move between sites when needed

4) Follow-up actions:
   a) Quality of NDT operators and hence quality of welding – company testing of NDT operators
   b) Early detection of issues and communication of these issues to contractor to allow early correction during construction – minimize punch items
   c) Quality in welding of aluminum[2] helideck – close follow-up of welding performed on site, ensure welding is performed in controlled climate, ensure training and qualification of all welders

A development project is associated with many challenges, most of which are dealt with in day-to-day operation. But others are of such a character that they are handled as an identified risk. It is uncertain whether the identified challenges cited above can be regarded as manageable in everyday work, and what level qualifies for inclusion in the risk register. Several of these challenges were identified early in the register. Uncertainty also prevails about the way information from Equinor, other players and partners in earlier development projects was transferred and translated into action.

The history of severity, see figure 14, traceability and the involvement of relevant disciplines/stakeholders has been investigated for the following risks by Risk ID.

0325 - Intense workload may lead to health problems for project personnel.
1341 - Completion of "must-do" scope in Singapore (formerly: Capacity issues at Tuas yard may lead to delay of sail away).
1469 - Lack of resources for hull project may lead to insufficient follow-up and lack of quality.
1610 – Engineering deliverables from SCM with low maturity or errors give schedule consequence.
1646 – Quality issues related to SCM Construction may lead to rework or delay.

The PSA team considers that all these risks contain elements identified as challenges in Peops and the follow-up strategy, and its assessment is presented in table 1. These risk conditions have thereby been known to Equinor from start-up when establishing the project organisation in Singapore.

[2] PSA comment: It is known in the industry that achieving acceptable quality with structures in aluminium is more difficult than in steel. This has been quoted here to illustrate the welding challenges in general.

Table 1: Challenges identified by Equinor at an early stage and their relevance for given risks.

	Challenge								
Risk	1a	1b	1c	2a	2b	3a	4a	4b	4c
0325	X					X			X
1341		X	X				X	X	
1469	X	X	X			X	X		
1610	X	X	X					X	
1646		X		X	X				X

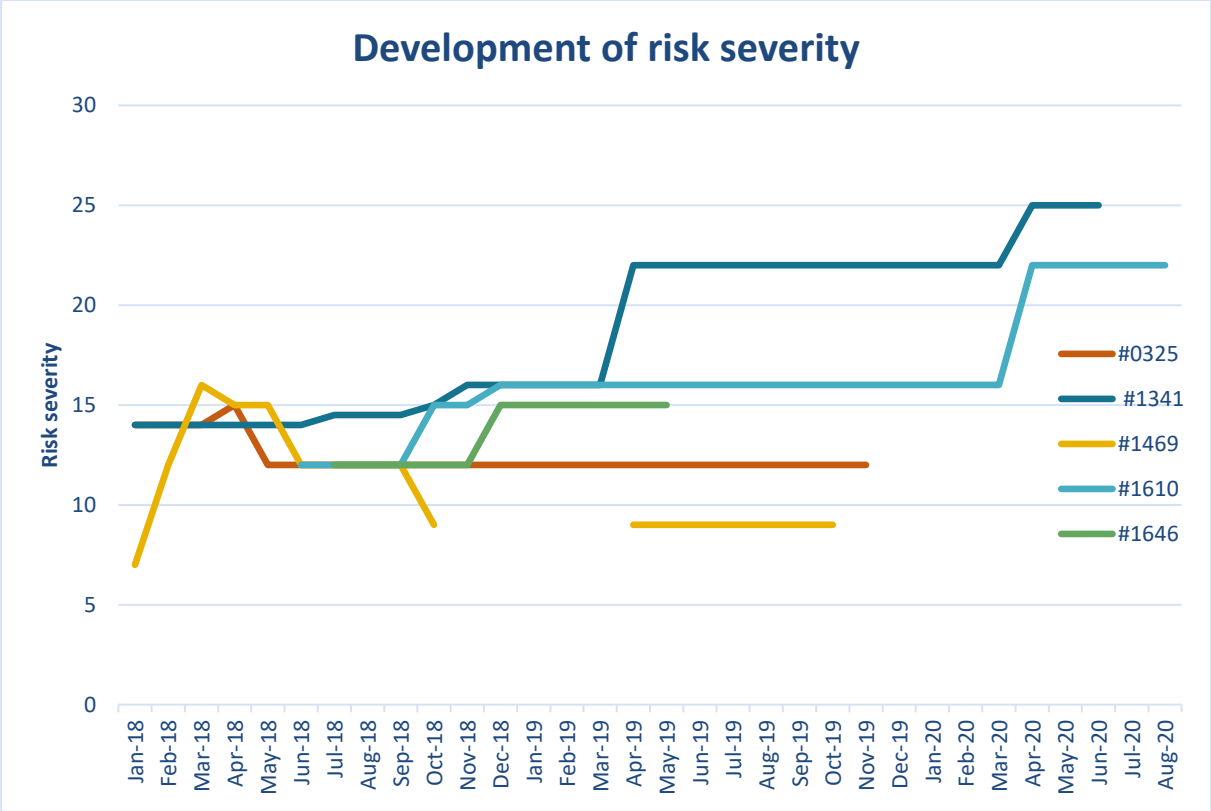

Figure 14: Development in severity for selected risks over time.

The figure above shows that the most significant risk challenges remained unresolved for a long time, and the severity of some increased during the project.

Challenges with poor quality were sharpened in September 2019 when project risk 1952: "Risk that rework due to poor piping quality may lead to schedule delay and increased carryover" was established for pipework. A project risk which included structural welding was also established as 1953: "Risk for poor piping and structural quality, leading to rework due to poor welding and QC follow up at SCM construction site". This was later incorporated in 1952, which then covered poor quality for both hull and piping welds. In the PSA team's view, the root cause was the same as for project risk 1646: "Quality issues related to SCM Construction may lead to rework or delay", which had already been identified.

It emerges from the document review that welding-related quality challenges and consequent delays were first escalated out of the project together with the Covid-19 position, and then included in an enterprise risk established in April 2020.

Risks have been identified which the project organisation for the hull and LQ could not handle alone. An example is manning, where TPD[3] PRD sets the terms for the project organisation and associated development of the risk picture. It was not the project team which wanted a lean organisation. Furthermore, it emerges from project risk 1469 that the project first became adequately manned from the third quarter of 2019.

The involvement of more senior management levels is not explicitly traceable in the risk history of the risks reviewed, since responsibility for the actions rests with the project organisation.

5 Timeline

The timeline has been developed from contract award in November 2017 until the management committee meeting of 25 June 2020. Figures 15 and 16 provide an overview of important incidents in this period.

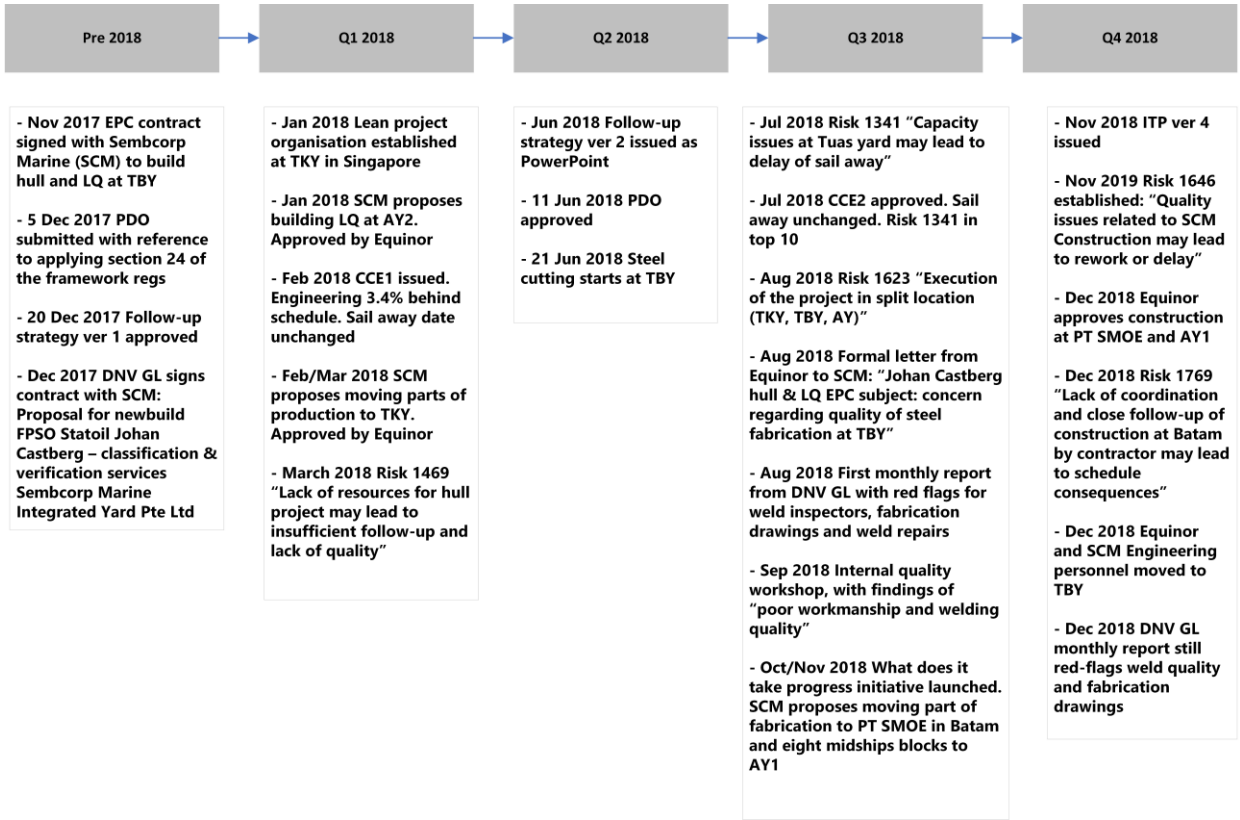

Figure 15: Overview of important incidents in 2017-18.

[3] TPD – management of the technology, projects and drilling business area.

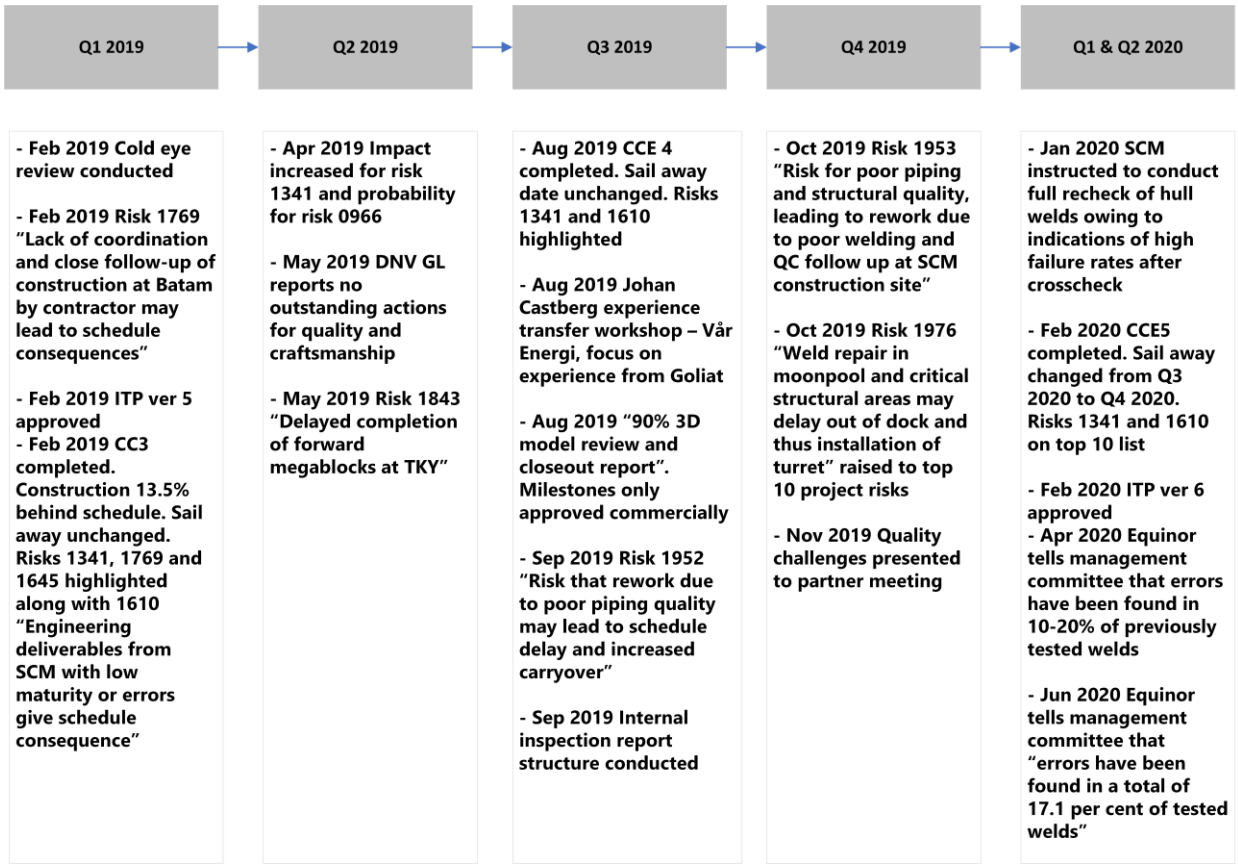

Figure 16: Overview of important incidents in 2019-20.

2017

Equinor signed the contract with SCM on 15 November 2017 for construction of the hull with integrated LQ for the FPSO in the Johan Castberg development. This EPC contract covered engineering services, procurement, construction and completion. It assumes construction of the hull with integrated LQ at the TBY), with an execution time of 29 months including 19 months for construction.

The licensees submitted the PDO for Johan Castberg on 5 December. On the same day, Equinor signed an EPMA contract with Akso AS.

On 7 December, Equinor awarded SBM Offshore a contract to deliver the turret with mooring system.

The project conducted start-up verification of SCM's execution model for the detailed engineering on 12-14 December.

Version 1 of the follow-up strategy for the hull and LQ contract was approved on 20 December.

2018

Equinor mobilised a lean project organisation to TKY in Singapore, where SCM Engineering was also located. SCM initiated a process with Equinor on constructing

the LQ at AY2. This yard had previously delivered LQs to Ekofisk 2/4-L and Ivar Aasen.

The project carried out verification of SCM's engineering process review – structural on 1 February.

CCE1 with cut-off at 31 January was issued in February. The critical tasks for reaching the steel-cutting milestone were identified and rested with engineering in the form of ensuring procurement and producing construction drawings. A financial incentive programme was introduced to ensure progress with engineering and procurement activities – supporting mitigating actions financially to deliver on a challenging schedule and to secure readiness for construction.

At 31 January, engineering work was 3.4 per cent behind schedule.

The contract for fabricating and assembling the topsides was awarded to Kværner on 13 February.

In February/March, the project approved the proposal to build the LQ at AY2.

SCM initiated a process with Equinor on building 18 foreship blocks at TKY. Transferring part of the construction assignment was justified by capacity shortages/challenges at TBY. The project approved the proposal to build at TKY.

Lessons learnt from Shell's Vito project dated 28 March were described as "issues with NDT discovered". The measures described covered preform crosschecking of NDT by use of Force agreement. Equinor's comments on the challenge were: "DNV GL is performing crosschecking. Results not as expected. Close follow up by DNV GL ongoing. Own NDT cross checkers mobilised." General lessons learned from the Vito project were also described, where the measure involved "[…] close follow-up is needed to secure HSE, progress and quality".

DNV GL issued the first version of the quality survey plan on 6 April, where special areas were identified as "witness for fit-up" and final inspection. Primary areas were identified as "monitoring/witness".

Version 2 of the follow-up strategy was issued on 1 June. An overview of the contractor's weaknesses and possible threats to project execution was also reproduced here: Threats to project execution were now more specific:

- capacity in construction and priority to Equinor
- availability of skilled construction resources
- delays caused by quality in engineering deliverables

- lack of communication between engineering, procurement, construction, commissioning.

As the strategy highlighted, these points were important for good execution.

Identified project risks included 1341 "Capacity issues at Tuas yard may lead to delay of sail away", 1469 "Lack of resources for hull project may lead to insufficient follow-up and lack of quality" and 1241 "Hull contractor engineering capability may affect project milestones".

The project conducted verification on 1 June of the contractor's construction readiness – TBY. This concluded that the yard was well on target with the fabrication preparations. Some observations were noted.

A hull workshop took place on 6 June.

On 8 June, a meeting ahead of fabrication start-up was held at TBY.

The Storting approved the PDO on 11 June.

Lessons learnt from the Maersk Culzean project dated 14 June were described as "Technical spec for eq packages, packages follow up, standard of sub contractors on yard, preservation on board, pre-fabrications sites, use of DNV Singapore". Measures described covered: "Confirming that close follow up is needed to secure quality".

Equinor's comment on the challenge was: "This is implemented in our daily work and contractor follow up".

Steel cutting began at TBY on 21 June for constructing 170 blocks (turret area, midships and aftership).

The project conducted verification on 28 June of the contractor's construction readiness at AY. This concluded that good understanding prevailed about the preparations required before fabrication started, and noted some observations.

Construction of the LQ at AY2 began in July.

DNV GL's team for fabrication follow-up, with the PMF and three inspectors, was established at TBY from 1 August. Three conditions were red-flagged in the monthly report for August.

1. SCM had not addressed critical structural details which required extra attention in assembly and welding.
2. After DNV GL had approved the construction drawings, SCM continued updating these without approval from DNV GL or Equinor.
3. SCM's QC department lacked sufficient experience or knowledge to conduct the planned inspections.

The report recommended that the yard implements training and improves the expertise of its welding inspectors.

CCE2 was issued in August. Important goal attainments noted were the following.

- All P&IDs had IFC status. Closure of hold points was ongoing.
- Work was under way to check all the findings of the 90-per-cent design review in order to avoid these affecting construction drawings. Engineering was reported to be behind schedule and had, with few exceptions, been in this position since project start-up.

In the risk picture, the probability of project risk 1341 "Capacity issues at Tuas yard may lead to delay of sail away" was raised to 25-50 per cent. Area design freeze was set to 1 August 2018, but was not achieved and was about a month behind schedule at the report cut-off. No change was made to main milestones.

A formal letter from Equinor to SCM on 23 August pointed to challenges with weld quality and quality follow-up at TBY. The weld-quality challenges are said to relate to welding expertise and welder supervision, while insufficient manning for quality follow-up in the fabrication shop was noted.

Project risk 1646 "Quality issues related to SCM Construction may lead to rework or delay" was established in late August. The risk is described as: "SCM has experienced problems to achieve the quality standard that is specified in the contract. This results in an increase in required manhours to complete the fabrication and hence delays. Closing comment: Actions ongoing, more risk details for construction."

Experience transfer from Heerema's *Sleipnir* project on 28 August was described as "QA/QC is seriously understaffed and consequently affects production quality". Measures described covered: "Ensure proper manning in QA/QC and closely monitor performance". Equinor's comment on the challenge was: "Continued push to increase manning".

The project conducted verification of contractor's construction readiness at TKY on 31 August. No nonconformities were identified, but six observations were made.

The activity concluded that the contractor was well prepared and responded well to questions raised.

SCM responded to Equinor on 13 September with proposed measures for meeting the challenges with weld quality and quality follow-up.

The project conducted verification of third-party/DNV GL construction follow-up on 17-18 September. A high failure rate for welds after NDT was cited as an observation. This was closed after agreement that verification of welder certification and execution quality was part of classification follow-up.

DNV GL's monthly report for September noted the start-up of NDT crosschecking at TBY. A red-flag observation repeated that the yard's QC department lacked sufficient knowledge of inspection categorisation and its effect on inspection and welds. The recommendation that the yard should train and improve the expertise of its weld inspectors was also repeated. DNV GL questioned the knowledge of the weld inspectors because of the failure to detect poor or erroneous welding. A single inspector monitored fabrication at AY2 on a weekly basis.

A quality workshop was implemented on 26 September.

Steel cutting at TKY began in October.

Fabrication of blocks was behind schedule in October/November. The project launched the *What does it take* initiative to improve fabrication progress. SCM proposed to Equinor that fabrication of 60 foreship and aftership blocks be transferred to PT SMOE in Batam, Indonesia, with eight midships blocks transferred to AY1.

DNV GL's monthly report for October contained a red-flag observation about weaknesses with welding and quality monitoring by TBY. It commented on a noticeable commitment by the yard's QC/QA department to improve quality by taking on more inspectors with production experience and by training welders and inspectors.

SCM conducted an audit of fabrication execution where Equinor and DNV GL took part. The report, with generally positive observations, was issued on 11 October.

Revision 4 of the ITP with the IFC status was issued by SCM on 9 November. This was the first IFC version for the project, issued four months after construction started. No hold points were noted in the ITP for Equinor before crosschecking of NDT related to welds or building activities.

DNV GL's monthly report for November contained a red-flag observation about weaknesses with welding and quality monitoring at both TBY and TKY. Weld quality at AY2 was reported to have improved.

In December, the project approved construction at PT SMOE and AY1. Steel-cutting started.

The construction readiness start-up meeting took place on 10 December at PT SMOE with participation by Equinor, SCM and DNV GL.

A welding supervisor workshop was held on 13 December on the basis of experience from fabrication and constant quality challenges.

A separate station named the Tiger Team was established after pre-fabrication, where quality deficiencies such as uneven and rough weld surfaces were corrected to permit surface treatment. The station at TBY was established in December.

2019

DNV GL's monthly report for January contained red-flag observations of weld quality, completion of blocks after final inspection, and welding of outfitting steel. It commented on a noticeable improvement at TKY and AY1 related to their own inspection and preparation for inspection.

CCE3 was issued in February 2019. The probability of the following top 10 risks had been increased to 50-100 per cent.

- Project risk 1341 Capacity issues at Tuas yard may lead to delay of sail away
- Project risk 1610 Engineering deliverables from SCM with low maturity or error give schedule consequence
- Project risk 1645 Lack of coordination between SCM engineering, procurement and construction disciplines/areas may lead to late engineering, bulk and BFE deliveries.

Project risk 1769 "Lack of coordination and close follow-up of construction at Batam by contractor may lead to schedule consequences" was a new member of the top 10 with a probability of 25-50 per cent and a severity of "serious".

At that time, engineering was one per cent, equipment deliveries 6.6 per cent and fabrication 13.5 per cent behind schedule since CCE2. No change in the main milestones.

SCM issued revision 5 of the ITP on 19 February. No hold points were noted for Equinor before crosschecking NDT related to welding or building activities.

DNV GL issued a revised QSP on 21 February, where witness for primary areas fit-up and primary joint fit-up were introduced.

A cold eye review of follow-up in Singapore was implemented in late February. The mandate for this verification was to investigate the project organisation, particularly with regard to adequate and correct manning, the right expertise and the handling of four construction sites. Furthermore, the mandate covered investigating the reasons for construction delays, the SCM engineering progress, and the interface with the EPMA and other contractors, and assessing use of best practice for costs, planning and baseline processes. The review identified major challenges rooted in:

- a scope of work more in line with a topsides built to an offshore standard rather than a traditional ship's hull
- Feed less mature than thought
- substantial deficiencies in the EPC contractor's experience and expertise
- tight execution schedule
- strategy of a lean Equinor project organisation.

DNV GL's monthly report for February contained red-flag observations about weld quality, completion of blocks after final inspection and welding of outfitting steel. It commented that the yard did not appear to be in control of the fabrication process. A large number of penetrations not reflected in the construction drawings were also reported. DNV GL reported a marked improvement at TKY and AY1 related to own inspections and preparation for inspection.

The project conducted a verification of SCM's dock phase preparations and readiness on 1 March. This concluded: "No findings prevent the start of the dock period according to current schedule, but work shall be given priority to not hamper coming phases". Some observations were noted.

TBY laid the keel on 7 March.

DNV GL's monthly report for March contained red-flag observations on the transfer of outstanding work to the assembly phase, welding of outfitting steel and non-approved penetrations. At the same time, it observed that no further quality conditions related to execution were outstanding at the yards and that the level of quality had stabilised.

Equinor's monthly report for April increased the probability of project risk 0966 "Schedule and cost impact if scope transfer and/or COW to the integration site, from hull and/or turret" to 5-25 per cent with the impact "Severe". The impact of project risk 1341 "Capacity issues at SCM yards may lead to delay of sail away" had been changed to "Severe", with 50-100 per cent probability. Both risks were

classified as "red". The change was related in the report to updating the impact matrix in order to adapt to the project phase and other projects. Project risk was unchanged, but more risks were classified as red.

DNV GL's monthly report for April contained red-flag observations on NDT and completion when inspecting blocks at PT SMOE.

Equinor's monthly report for May renamed project risk 1341 to "Risk of hull scope not completed according to contract, due to capacity and quality issues at SCM yard, may lead to delayed sail away or extensive transfer of scope from Singapore to Stord".

In June, surface cracking was discovered in special parts of the moonpool area. A UT inspection by SCM found that 20 per cent of welds gave indications of errors.

DNV GL's monthly report for June contained red-flag observations of weld quality in the turret area related to preheating, speed and expertise in using FCAW for rootstock welding.

Via DNV GL, Equinor hired a dedicated UT inspector from 24 July for a crosscheck in the moonpool area.

CCE4 was issued in August 2019. Most of the KPIs directly related to progress here were negative compared with CCE3. In relation to CCE3, the risk picture was:

- project risk 1341 Capacity issues at Tuas yard may lead to delay of sail away – severity increased to "Severe"
- project risk 1610 Engineering deliverables from SCM with low maturity or error give schedule consequence – unchanged
- project risk 1645 Lack of coordination between SCM engineering, procurement and construction disciplines/areas may lead to late engineering, bulk and BFE deliveries – unchanged
- project risk 1769 Lack of coordination and close follow-up of construction at Batam by contractor may lead to schedule consequences – no longer in top 10.

The progress curve showed that each CCE had assumed planned progress which was higher than that actually achieved. Several activities for improving project progress to meet the unchanged contractual sail-away date were noted.

A visit by the licensees for experience transfer and yard inspection took place on 30 August.

The UT crosscheck commissioned by Equinor in September revealed that up to 40 per cent of the hull breakline in the moonpool area had indications of welding errors.

Equinor's monthly report for September outlined welding challenges: "Welding quality is improving, but is still a concern as it is causing significant rework which in turn pushes the schedule. Focus is to train and qualify more welders, and to remove subcontractors that are not delivering acceptable quality."

Equinor and SCM initiated a quality programme related to improving weld quality. A team with participation from both organisations was set up on 13 September and an action plan established in a working meeting on 27 November.

As part of familiarising itself with the project, Equinor's asset integrity department conducted an internal inspection of the structure in late September/early October. This included a check of the hull to see the access and entry arrangement, an external pre-launch hull check and introducing operational experience from Norne and Åsgard A on inspection, welding and repair. The report pointed to extensive deficiencies at SCM in the quality of hull fabrication, where the use of inexperienced sheet metal workers and welders had meant a high failure rate and challenges for the project in correcting the necessary scope of checks. SCM's QA/QC department was not adequately manned and had insufficient expertise to ensure a strong and operative function.

Project risk 1952: "Risk that rework due to poor piping quality may lead to schedule delay and increased carryover" was established in response to poor weld quality. Actions included: challenge SCM on strength of own QA/QC organisation, consider all possible measures to perform full welder training and lift welder competency, and challenge SCM on lack of quality in sub-contractors' work. Project risk 1952 covers poor weld quality for both hull and pipework.

Equinor's monthly report for October provided supplementary information on weld-quality challenges: "Welding defects in the turret moonpool area of the hull will require weld repair and this will postpone the launching from dry-dock." And, furthermore: "Welding quality is still a concern, critical defects have been discovered in the turret moonpool area, which is likely to push launching from dry dock and subsequently turret installation dates." Project risk 1976 "Weld repair in moonpool and critical structural areas may delay out of dock and thus installation of turret", with the impact "Severe" and probability 50-100 per cent, was included as a top 10 risk. The description of the risk includes the following: "Due to repeated observations on poor welding, lack of supervision and shortage of SCM QA/QC resources and presence, Equinor decided to initiate a cross checking programme for structural steel. During NDT cross checking in turret moonpool area elevation

3550, several weld defects were discovered (39.6 of tested length). There is a risk that weld repair rate will increase as NDT re-examination is being performed."

Equinor instructed SCM on 1 October to conduct a full ultrasonic re-examination in the turret area.

At the end of October, Equinor established a structure and welding work group in Singapore in order to "ensure shared understanding and achieve good quality in structure and welding on Johan Castberg". The group was led by the head of the asset integrity department.

SCM's monthly report for October observed: "During NDT UT cross checking of welds in the lower moonpool area, there were indications of defects at several locations. There is an understanding of urgency to repair and re-inspect the affected weld seams, as it will not be feasible to repair after undocking." Where piping was concerned, it stated: "There is quite a significant quantity of piping field welds that require repairs. Further, additional control measures are being enforced, these include performing rootcause analysis to identify defects and developing detailed plan for repair of affected pipes. Boroscopic check implemented with daily inspection regime set at site for welded field joints."

Based on inspection findings, DNV GL requested on 5 November that five per cent additional UT be conducted, with 2.5 per cent covering untested welds and 2.5 per cent previously tested ones.

Equinor began random sampling of bottom-plate welds on 8 November. Based on the inspection findings, it was decided to conduct UT with all erection joints.

In the minutes of the 28 November meeting of the quality programme work group, Equinor noted that SCM had worked to improve quality in certain areas while many activities had still not been initiated. SCM was asked to speed up implementation of actions in the quality programme.

Equinor's monthly report for November observed that the hull and LQ were behind schedule as a result of repair welding. Improvement work in the moonpool was making better progress than expected and was estimated to be completed by 31 December.

SCM's monthly report for November observed: "Contractor is performing reworks on the welding at the turret moonpool area which was previously accepted according to ITP." And furthermore: "Extend of external side shell NDT was concluded on 27 Nov 2019. Joint efforts by Equinor & SCM to perform NDT check according to priority."

Where piping was concerned, the report stated: "Additional boroscope inspection was requested, all exotic piping fabricated outside Admiralty Yard are requested to be re-inspected using boroscope. Discussion is ongoing between company and contractor on the scope of re-inspection required."

DNV GL's monthly report for November contained red-flag observations related to welding in the moonpool area, a large number of weld errors in the turret bottom plate, the execution quality of blocks from PT SMOE, and crosschecking with findings of welding errors in approved welds.

At the management committee meeting of 17 December, Equinor reported that: "Repairs to the turret have gone better than expected. Welding has gone well."

Equinor's monthly report for December stated that repairs in the moonpool area were completed on 23 December. Project risk 1976 had been renamed "X-checking/repairs of critical structural areas may delay out of dock and remaining scope". Impact remained at "Severe", with probability of 50-100 per cent.

SCM's monthly report for December stated: "Additional piping re-inspection using boroscope are being carried out, contractor monitor the works closely and daily report are being submitted to company."

2020

Equinor instructed SCM on 13 January to carry out full NDT with hull erection welds following indications of an overall 17 per cent error rate after crosschecking.

SCM's monthly report for January stated: "Shipside shell cross-check and welding repair works according to direction given by company's site team." And furthermore: "Boroscope re-inspection are ongoing according to late instruction given by company's site team."

DNV GL's monthly report for January contained a red-flag observation about additional inspection of prefabrication welds and erection joints based on failure rates of 12 per cent for previously tested welds and 16 per cent for welds not previously tested.

CCE5 was issued in February 2020. All KPIs for progress were negative compared with CCE4, and weld challenges were one of the priority areas. The sail away date was changed from 30 April to 16 September 2020.

Equinor commissioned DNV GL on 7 February to conduct verification of fabrication follow-up for the Johan Castberg hull with integrated LQ.

On 13 February, SCM began full UT crosschecking of the external hull.

SCM issued revision 6 of the ITP on 21 February. The company strengthened quality follow-up of welds. No new hold points for Equinor were noted.

Equinor's monthly report for March stated that "Extensive ultrasonic testing of structural welds has revealed a substantial scope of repairs which will affect painting and the sail away date."

Supplementary activities were added to the quality programme during March.

At the management committee meeting on 1 April, Equinor reported that "errors have been found in 10-12 per cent of tested welds (five kilometres)".

DNV GL's monthly report for March contained a red-flag observation about expanding the scope of crosschecking fabrication welds.

On 4 April, DNV GL issued the report on the verification of its own follow-up. This stated: "The intention was to properly review the work done through interviews, record reviews and onsite visits to significantly increase Equinor' s confidence level that the end product will have the required standard." The report summarised DNV GL's own fabrication follow-up as well as Equinor's proposals and activities. It concluded that class approval can be given on the basis of specified assumptions.

DNV GL's monthly report for April contained a red-flag observation on the results of crosschecking, with a failure rate of about 13.5 per cent for previously approved NDT and roughly 19 per cent for welds not previously tested.

Fabrication work at TBY ceased on 17 April as a result of Covid-19. Equinor's construction project team continued NDT crosschecking.

On 26 May, DNV GL informed the PSA in an e-mail that an error had been detected in Sesam's Stofat module. It reported that registered users of the software had been informed of the position.

DNV GL's monthly report for May contained a red-flag observation which identified substantial quality challenges with welds in the foreship area.

At the management committee meeting on 25 June, Equinor reported that "errors have been found in a total of 17.1 per cent of tested welds".

6 Assessment of consequences

6.1 Actual consequences

The quality challenges have meant a significant expansion in inspection scope to include, for example, all hull welds exposed to the sea and all erection joints. With the project about a year behind schedule, the field is now expected to come on stream in the fourth quarter of 2023 with a consequential reduction in present value for Equinor, the other licensees and the Norwegian government as a result of delayed earnings.

6.2 Potential consequences

Residual risk – weld quality
Inspection and repair cannot compensate for inadequate welding expertise. Full inspection of all welds is impractical, nor is it technically feasible for inspection to identify reliably all defects which might be present. Inspection quality is quantified as probability of detection (POD). This parameter is normally a function of the size of the defect, and subject to statistical spread as a consequence of operator competence, equipment, access and so forth.

Where details and areas are accessible for inspection and repair, some increase will be experienced in the expected need for maintenance and repair. Inaccessible details and areas will have a lower structural reliability than would have been the case if the welding had been done by competent personnel.

7 Direct and underlying causes

7.1 Direct causes

Through interviews with Equinor and the necessity of providing SCM's engineering department with additional resources, it emerged that SCM had underestimated the scope of work related to further progress with Feed. This was reflected in the number of revised drawings issued as well as challenges with clashes and hull/ bulkhead penetrations. SCM nevertheless reported that engineering-related milestones were reached in accordance with the contract, and Equinor was accommodating in accepting the milestones reached in order to encourage a continued commitment by the yard.

It emerged from interviews and documentation that welding expertise and QA/QC at SCM were inadequate. Equinor had control mechanisms in place, which led to a number of welders being required to undergo new training and re-testing against the background of a high error rate. Welders were also replaced because of inadequate quality. Site testing of NDT inspectors revealed that some had insufficient expertise. During its final inspection of the prefabrication stage,

Equinor found quality nonconformities which should have been picked up by SCM's QC department and corrected. To remedy some of this, grinding stations (Tiger Teams) were established to achieve adequate surface quality for painting. According to DNV GL, this approach is not an appropriate response to poor welding. Equinor failed to get to grips with the problems of inadequate expertise and poor welding quality at a sufficiently early stage. It did not establish its own NDT crosschecking and a quality programme in collaboration with SCM until the third quarter of 2019.

Dimensioning of the follow-up was based on fabrication at a single yard and the desire for a lean project organisation. Spreading fabrication between four yards put the project organisation under pressure. From the third quarter of 2019, the organisational strategy was changed by strengthening the project with resources. Equinor's goals and priorities have contributed to the failure to get adequately to grips with the weaknesses in execution quality, and these have thereby persisted over time.

DNV GL was outspoken about the quality challenges in its status reports for class follow-up during the third quarter of 2018. This was toned down somewhat in subsequent reports, and the one for March 2019 stated that the quality level had stabilised and that welding quality no longer posed any major challenges.

At Equinor's request, DNV GL verified its own construction follow-up. This review concluded that follow-up was strengthened pursuant to the contract and normal practice with similar projects. DNV GL's concerns about welding and quality follow-up were communicated and documented in joint quality meetings. Construction follow-up is based on random sampling and assumes that the yard's own QA/QC system functions. Classification societies will normally concentrate their sampling on critical areas. If quality is uneven, because critical areas maintain a higher level than less critical ones, such random samples will give an inaccurate picture. This could explain why DNV GL's monthly report for March 2019 stated that the level of quality had stabilised and welding quality no longer posed any major challenges.

Engineering lags at the start of the project led to an even tighter timetable for subsequent activities, since the planned milestones were retained. Against that background, Equinor's attention was primarily concentrated on progress.

7.2 Underlying causes

When contracts were awarded and the project started up, oil prices were low and margins in the industry moderate. That prompted a focus on costs as well as on lean project organisations and site teams. This was also desired for the Johan Castberg hull and LQ project. Equinor was also short of engineering personnel because of a cap on the number of contract engineers hired in at any one time.

SCM was a new supplier for Equinor, and the contract was originally to be performed by TBY – which had experience with ship repairs and limited involvement with offshore newbuilding for the NCS. The fabricator had a strategy of taking an increased share of the FPSO market and becoming a preferred supplier for Equinor, which saw this as an opportunity to increase capacity in the market. A tight timetable for project execution was adopted. Experience was available from earlier projects with SCM which had revealed challenges both with quality and related to execution and completion on schedule, but this does not appear to have been taken into account in Equinor's dimensioning of the project organisation and site team. Based on its own experience in South Korea, Equinor chose to concentrate on construction of the LQ.

Identified risks remained unresolved over a long period, and the seriousness of some increased during the project period. Quality challenges related to welding and consequent delays were initially escalated out of the project, and included in enterprise risk, in connection with the Covid-19 pandemic.

8 Observations

The PSA's observations fall generally into two categories.

- Nonconformities: this category embraces observations where the PSA has identified breaches of the regulations.
- Improvement points: these relate to observations where deficiencies are seen, but insufficient information is available to establish a breach of the regulations.

8.1 Nonconformities

8.1.1 Risk reduction

Nonconformity
Risk management during fabrication had deficiencies.

Grounds
Equinor has not chosen the organisational solutions which, based on an individual and overall assessment of the damage potential and future use, give the best technical and operational results and thereby reduce the probability of errors, hazards and accidents. Challenges with project execution were identified at an early stage and risk assessed. The investigation has found that these challenges were not overcome and that their severity increased over the project period. It emerges that quality challenges related to welding and consequent delays were first escalated out of the project along with the Covid-19 position, and then included in the enterprise risk established in April 2020.

Risks have been identified which the project organisation for hull and LQ was unable to handle alone. An example is manning, where TPD PRD sets the terms for the project organisation and associated development of the risk picture. It was not the project team which wanted a lean organisation. Furthermore, it emerges from project risk 1469 that the project first became adequately manned from the third quarter of 2019.

Requirement
Section 4 of the management regulations on risk reduction

8.1.2 Management of project execution

Nonconformity
Adequate resources for executing planned activities have not been made available for the Johan Castberg hull and LQ project. Furthermore, follow-up to ensure the elements in the company's own management system have been established and are functioning as intended has been inadequate.

Grounds
It emerged from the investigation that the project was strongly driven by progress. The project management emphasised reaching the planned milestones, which the cold eye review in February-March 2019 regarded as unrealistic.

The quality challenges did not receive sufficient attention until into the second half of 2019. It has emerged that important project management documents, such as the follow-up strategy, were not updated and that the inspection and test plan did not reflect Equinor's own follow-up.

The follow-up strategy describes quality targets related to control of repair work resulting from insufficiently mature engineering. That requires a project organisation capable of both monitoring and supporting the contractor. Several weaknesses at the contractor identified in the strategy call for a robust team mobilised to Singapore. Choosing a lean project organisation as well as challenges in recruiting the site team have not contributed to reaching the quality goals.

Governing documents for quality follow-up drawn up by the project have not been complied with. Earlier audits of the Johan Castberg hull and LQ project observed that the inspection and test plan did not reflect Equinor's own quality follow-up.

Requirements
Section 12, paragraphs 1 and 2 of the management regulations on planning
Section 21 of the management regulations on follow-up

8.1.3 Qualification and follow-up of the contractor

Nonconformity
Equinor has failed to ensure that the contractor has the expertise to carry out the work it has contracted to perform in a prudent manner. Nor has Equinor initiated measures sufficiently early to correct the contractor's deficiencies.

Grounds
Welding errors in the fabrication phase may have negative HSE effects when operating the facility. Indications from the tendering phase and symptoms during fabrication revealed that achieving the necessary quality would be affected by deficiencies in expertise and capacity at the yard. Equinor initiated certain activities, but these failed to have sufficient effect – partly because they came too late.

DNV GL reported deficiencies with welding and quality follow-up at the yard as early as the start to fabrication. To some extent, efforts were made to correct this, without having the necessary effect. Welders with a high error rate were taken out of fabrication for training and qualification. Welders who failed to qualify were reportedly taken off the project, but this was not systematically applied until the third quarter of 2019. Inadequate knowledge of procedures was also identified, which partly reflected language barriers. Completion inspections by Equinor found quality deficiencies even though the yard's QC department had approved the work. One solution was the introduction a separate fabrication stage for grinding weld surfaces in order to achieve acceptable quality for surface treatment. NDT crosschecking identified errors in welds which had previously been approved by the yard.

Requirements
Section 12, paragraph 2 of the framework regulations on organisation and competence
Section 18 of the framework regulations on qualification and follow-up of other participants

8.1.4 Application of experience in dimensioning own follow-up

Nonconformity
Equinor has made little use of experience gained from its own activities and those of others in ensuring adequate manning and overall expertise for its own follow-up of the contractor.

Grounds
It emerged from the investigation that SCM is a new contractor for Equinor, and that experience at the original construction yard derived primarily from ship repair. Experience from earlier and ongoing projects underlined the need to devote extra

Equinor resources for construction follow-up in order to compensate for QC deficiencies at the yard. See also section 4.6 for further information.

Requirements
Section 23, third paragraph of the management regulations on continuous improvement, see section 14, paragraphs 1 and 2, litera b) of the management regulations on manning and competence

8.2 Improvement points

8.2.1 Information to the licensees

Improvement point
Equinor has failed to inform the other licensees early enough for them to meet their obligations.

Grounds
Information on quality challenges with welds was first provided in Equinor's report to the partnership in September 2019. During the partner visit to the yard in August 2019, quality challenges in the moonpool were presented and discussed. The quality challenges were known internally in the project as early as the third quarter of 2018, but not fully acknowledged before the quality programme and the report from Equinor's own inspection (internal inspection structure) in September-October 2019. The scope of the quality challenges identified by this internal inspection was under-communicated until April 2020. The project's internal cold eye review in February-March 2019 identified serious challenges in implementing the hull and LQ project in line with the applicable schedule. This report was not shared with the partnership until the autumn of 2020.

Requirement
Section 7, paragraph 3 of the framework regulations with guidelines on responsibilities pursuant to these regulations

8.2.2 Verification of fatigue analyses

Improvement point
Equinor's observation from the Feed phase, with an unexpectedly large deviation between results from the simplified fatigue calculation and the stochastic fatigue analysis, was not followed up in the verification of detail design of the Johan Castberg hull.

Grounds
Equinor regards DNV GL's class approval as a verification of the Johan Castberg hull. DNV GL has used the same software as SCM for fatigue analysis. This weakens the barrier verification is meant to provide. Availability of software and

competence in using it are factors which could justify using the same programme for design and verification. Norsok N-001 provides some recommendations on compensatory measures in such cases, including the implementation of simplified calculations. Norsok N-001 is not one of the base standards for verification, but the reference in the guidelines specifies the expected scope of verification.

Equinor compared results from simplified and stochastic fatigue calculations as part of the Feed study, and noted that the deviation between them was unexpectedly large. Observed deviations were not followed up with SCM in its design development and documentation for the Johan Castberg facility.

Requirement
Section 56, paragraph 4 of the facilities regulations with guidelines on load-bearing structures and maritime systems

9 Discussion of uncertainties

This investigation has primarily acquired information from a single party – Equinor. Interviews have been conducted at all levels in the project organisation. Reports from individual interviewees have been in agreement for the most significant areas and have not provided directly contradictory information on the course of events. Considerable information has also been acquired from governing and project documentation.

The mandate for the investigation has been limited to a specific period. Decisions of significance for executing the project may have been taken outside this time frame, bit the PSA team has not been able to investigate their effect.

10 Assessment of the player's investigation report

Equinor has conducted an internal investigation at group level L1. Commissioned by the executive vice president for TPD, this covers the period from January 2017 October 2019. The description of decisions taken and activities conducted accords with the information obtained by the PSA team.

The main impression is that Equinor's investigation report largely accords with the one compiled by the PSA team concerning observations on the causes of the challenges with weld quality. As part of its mandate, the Equinor investigation has also assessed the tendering phase and contract award. Recommendations for learning lessons and making improvements are related to more detailed evaluations of the bidders, contract follow-up and project management, recruitment/resources/team organisation, and risk management. These recommendations appear to address the report's observation, but no timetable is given for their implementation, follow-up and closure.

The following quotation appears in section 6.3.3 of Equinor's investigation report on reporting internally in Equinor and to the licence: "The welding quality issues have never been identified in the risk register nor lifted to the top 10 risks before October 2019". This deviates from the PSA team's assessment, since risk 1646 – "Quality issues related to SCM Construction may lead to rework or delay" deals with the challenges posed by poor weld quality. This was established on 1 November 2018 at the latest, when status was reported to be "ongoing".

Differences over weld error rates are observable between the Equinor and PSA investigation reports. The specific weld error rates reported by Equinor are lower than in the PSA report. Equinor's report specifies the following weld error rates.

- Section 2.2: "Equinor site team confirmed 7.8 per cent weld defect rate in the turret area and sent a letter instructing SCM to re-examine the welds in this area."
- Section. 6.3: "During the CER in February/March 2019, it was commented that the NDT rejection rate of 3.5 per cent was high compared to other Equinor projects."

The following weld error rates are specified under the timeline for 2020 in chapter 5 of the PSA report .

- "Equinor instructed SCM on 13 January to carry out full NDT with hull erection welds on the basis of indications of an overall 17 per cent error rate after crosschecking."
- "DNV GL's monthly report for January contained a red-flag observation about additional inspection of prefabrication welds and erection joints based on a 12 per cent failure rate for previously tested welds and 16 per cent for welds not previously tested."
- "At the management committee meeting on 1 April, Equinor reported that 'errors have been found in 10-12 per cent of tested welds (five kilometres)'."
- "DNV GL's monthly report for April contained a red-flag observation on the results of crosschecking, with a failure rate of about 13.5 per cent for previously approved NDT and roughly 19 per cent for welds not previously tested."
- "At the management committee meeting on 25 June, Equinor reported that 'errors have been found in a total of 17.1 per cent of tested welds'."

The differences observed in reported error rates could be explained in part by the time frame for reporting. Equinor's investigation covers the period up to October 2019, while the PSA investigation covers the period up to June 2020.

It emerges from the list of interviewees in the Equinor report that neither the safety delegate service nor employee representatives have been interviewed in the investigation.

The investigation report reveals that information on weld-quality deficiencies was not provided to the PSA, since plans called for this to be improved before delivery of the hull. In addition, the primary focus of attention in the spring of 2020 was the Covid-19 position, and the scope of defects had not been adequately clarified.

Meetings in the management committee during the first half of 2020 and subsequent meetings with the project at the initiative of the PSA provided the authority with information on the scope and severity of the quality challenges. Equinor should inform the PSA on its own initiative of conditions which are significant for HSE. See chapter 6 on residual risk – weld quality.

11 Appendices

A: Overview of personnel interviewed
B: Documents utilised in the investigation