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Ormen Lange Subsea Production System

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Abstract

This paper presents the concept and the technical solutions developed and applied to the Ormen Lange subsea production system. First, the key technical challenges related to the subsea system are presented. Thereafter the paper describes the extensive design, fabrication and testing processes undertaken in order to verify correct functionality and gain confidence in the applied solutions. Finally the paper summarizes achievements and key success factors for the project.

Introduction

The Ormen Lange field is located in the Norwegian Sea, approximately 100 km off the northwest coast of Norway. The field is located within a prehistoric slide area, the Storegga Slide, with water depths reaching 850 meters in the main production area.

The selected development concept for Ormen Lange comprises a subsea tieback to an onshore processing plant at Nyhamna as shown in Fig. 1.

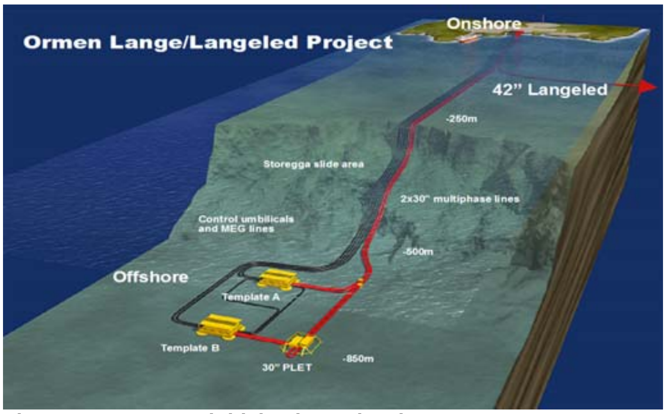

Fig. 1 Ormen Lange initial subsea development

The gas will be produced from up to 24 subsea wells. The well fluid will be transported to the Nyhamna plant via two 30" multiphase lines. After processing, the dry export gas is transported from the onshore plant through a new 42" pipeline via the Sleipner riser platform and further through a new 44" pipeline to the gas-receiving terminal in Easington, England.

Overall project schedule. The conceptual engineering of the subsea production system was initiated in 2002. The main contracts for subsea equipment supply, umbilical fabrication and template installation were awarded between the autumn of 2003 and the summer of 2004.

The main part of fabrication and testing took place during 2004/2005 with the subsea templates installed offshore in the late summer of 2005. Umbilical A and remaining subsea equipment were installed during the summer of 2006 and the first Xmas tree was installed on Template A in December 2006.

Completion of the first subsea well on Template A is scheduled for spring 2007 and subsea production start-up scheduled for autumn of 2007.

Subsea system configuration. Due to the large geographical extension of the Ormen Lange reservoir and the risk of reservoir segmentation, the subsea system design has a high degree of flexibility with four planned template locations. For this reason, a phased development scheme has been chosen. The phasing and location of the subsea wells will be timed to maintain plateau production as the field depletes.

Initial development. The initial subsea development consists of two 8-slot production templates (A & B), located approximately 4 km apart in the main production area. Each template is tied back into the two 30" multiphase pipelines to shore. The two 30" lines are interconnected via a pipeline end termination system (PLET) as shown in Fig. 2.

Two main control umbilicals link the onshore plant to the subsea production system; one is connected to template A, and the other to template B. A crossover control umbilical interconnects the two production templates, providing redundant hydraulic supply to all the subsea wells.

For prevention of hydrate formation, all wells are continuously injected with monoethylene glycol (MEG) via two 6" pipelines from the onshore plant. One line is connected to template A, and the other to template B. A 6" crossover MEG line interconnects the two production templates for added flexibility.

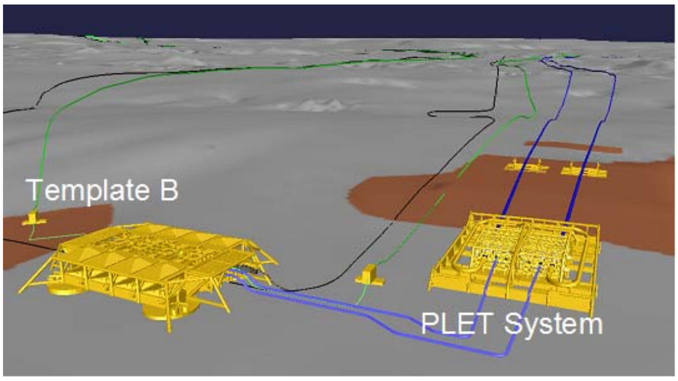

Fig. 2 PLET system

Future development. To maintain plateau production, further development of the Ormen Lange field will take place in the future. The future extension of the field may comprise two additional production templates (C & D). Each template will produce gas through dual infield flowlines tied back to the 30" multiphase pipelines to shore. A new infield 6" MEG line will be connected to each of the two future templates as extensions from templates A & B. Similarly, a new infield control umbilical will be connected to each of the two new templates as extensions from templates A & B.

The design has provisions for tie-in to a future pre-compression platform or a subsea compression unit.

Key technical challenges. The Ormen Lange subsea development has faced the following key technical challenges:

- Seabed and environmental conditions.
- Hydrate prevention.
- Long offset control.
- High well flow rates.

Seabed and environmental conditions. The seabed in the development area is highly irregular with soil conditions varying from very stiff clay with boulders to soft clay. Also the environmental conditions are extremely challenging and the installation season very short.

Currently there is no fishing activity in the area where the subsea templates are installed. In the future, however, trawling activity may commence and hence the large subsea installations are equipped with overtrawlable protection structures.

Hydrate prevention. Hydrate prevention has been one of the main technical challenges for the Ormen Lange subsea system. Due to the low seabed temperature (-1ºC) both hydrates and ice may form, unless the well fluid is sufficiently inhibited.

The overall hydrate prevention strategy is to minimize the risk of operation within the hydrate region. This will be achieved through continuous MEG injection at the individual wellheads. For accurate injection control each well is equipped with a MEG flowmeter and dosage valve.

The MEG distribution system is designed with a capacity to inhibit the maximum expected condensed water plus a set amount of formation water production from individual wells. MEG delivery requirements for each well are individually determined based on water production measurements and calculations.

Long offset control. The control of the subsea production system from the onshore terminal at Nyhamna over a distance of 120 km is a major challenge. The availability of the subsea control system on Ormen Lange is strongly emphasized, as the production rate from each well is very high, and interventions will be both costly and challenging due to water depth and weather conditions.

A fibre optical-/electro-hydraulic multiplexed control system has been designed, built and tested. Technology development has been required for the following components:

- High voltage power transformers.
- Low pressure, hydraulic power over long distances.
- Backup communication on high voltage power.

High well flow rates. The initial development includes eight off 9 5/8" hybrid well completions with dual 7" downhole safety valves (deep set) and horizontal Xmas trees. The remaining well completions for template A & B are planned to be 7" completions using identical Xmas trees.

The average flow rate from each individual well may be as high as 10 MSm3/day. A major challenge for the project has been to ensure that all equipment is designed to accommodate this very high flow rate. Erosion and vibration have been two important areas of focus in this respect.

Main contractors. The Ormen Lange subsea production system has been developed through a close and successful co-operation between Hydro as development operator and the supplier industry. The main contractors for the Ormen Lange subsea production system design and installation are:

- FMC Kongsberg Subsea – EPC contract for the subsea production system.
- Nexans Norway – EPC contract for umbilical fabrication.
- Heerema Marine Contractors – Heavy Lift contract for the templates and the PLET bottom structure offshore installation.
- Saipem/Sonsub – Installation of PLET modules, Spools, Pig loop and In-line tee valve modules. Field tie-ins and connections.

Template system. A template system solution has been developmed for the Ormen Lange subsea development.

The design allows for simultaneous production and drilling/completions/workover operations to be performed. During deployment of heavy equipment in open water from the drilling/completion rig, the rig is positioned at a safe horizontal distance from any subsea installation, even though dropped object protection is part of the template design.

The template system comprises a foundation bottom structure (FBS) with skirt foundations and a manifold module as shown in Fig. 3 and Fig. 4.

Fig. 3 Foundation Bottom Structure (FBS)

Fig. 4 Manifold Module

The two units were designed and fabricated to allow for either separate or combined subsea installation to facilitate early drilling. As a risk reducing measure, it was decided to perform the template installation as a single lift with the manifold pre-installed in the FBS.

The production manifolds have dual production headers. For each well, there are two hydraulically operated valves to allow direction of the gas flow to either of the manifold headers.

Umbilicals and pipelines/spools have been tied in by the use of horizontal connection systems developed by FMC Kongsberg Subsea.

The dropped object protection covers and hatches on top of the manifold module are mechanically locked in both the closed and open position to prevent movement during installation, due to snagging or high currents. The covers, approximately 100 square meters in area, are operated by wire from a surface vessel or by using a subsea winch.

Foundation bottom structure (FBS). The FBS contains an integrated overtrawlable protection structure. Furthermore, it includes protective bumpers and guide arrangements for safe installation and retrieval of drilling and production equipment. A cutting- and cement return system is included for each well. The FBS allows the conductors to be vertically landed and locked in the guide sleeves.

The suction anchored based leveling system was designed to achieve an inclination of less than 1.0 degree relative to the true horizontal plan and a conductor inclination of less than 1.0 degree relative to true vertical.

The as-built weight of the FBS is 675 metric tonnes.

Manifold module. The manifold module commingles the gas production from the Xmas trees. Furthermore it distributes MEG, hydraulic supply, electrical power and optical communication.

The manifold gas production piping has isolation valves inboard all flow line-/header- and wing-hubs.

The production pipe work is designed with minimum 3D bends to minimize pressure drop and erosion. Operation of all large bore valves is by vertical tooling access. Operation of the valves can either be by hydraulics and/or ROV tooling. Small-bore valves are mounted in vertical panels on top of the manifold module to allow horizontal access by ROV.

The as-built weight of the manifold module is 430 metric tonnes. After completed fabrication, the manifold module was lifted onto the foundation bottom structure to form a complete template system.

Fig. 5 Lifting of manifold module onto the FBS

Fabrication and testing. Grenland Offshore in Tønsberg, Norway fabricated the two complete templates under a contract with FMC Kongsberg Subsea. Following mechanical completion of the template system, an extensive integration test was performed in Tønsberg over a period of several months. During this testing, the Xmas tree system and the tie-in system was installed and operated on the template to ensure the correct functionality. The test program proved to be very useful and identified several areas of improvement, which were implemented prior to offshore installation.

Offshore installation. Heerema Marine Contractors were responsible for the offshore installation of the two templates using the SSCV Thialf.

After the test programme was completed in June 2005, the templates were moved from the Tønsberg fabrication facility and loaded onto two transportation barges.

Fig. 6 Loadout of Template A and B

Thialf was mobilized offshore in August 2005 and the two barges towed from Tønsberg around the southern coast of Norway to the Ormen Lange offshore location.

The installation was performed as a dual crane lift from Thialf. The barges were brought in position at the stern of the crane vessel and the templates lifted from the barge directly into the sea. The lifting weight for each of the template system including lift rigging was 1150 (430 + 675 = 1105) metric tonnes.

Fig. 7 Installation of template from Thialf

The achieved position accuracy was less than 1.0 meter and the inclination was less than one degree. This was well within the specified tolerances.

Fig. 8 Installation of Template A

Xmas Tree system. The Xmas tree system comprises a 7" horizontal production tree equipped with annulus bore. The Xmas tree is configured with separately retrievable subsea control module (SCM) and choke module, the latter containing instrumentation, flow control and measurement equipment. The production flow loop, MEG, annulus test and control lines on the Xmas tree are connected to the choke module through a multibore horizontal hub. An ROV panel is attached to the Xmas tree frame structure. All valves to be operated by ROV are located on this panel.

Fig. 9 Xmas tree system

Xmas tree installation is based on guideline-less techniques. The guidance system used is designed to prevent accidental damage to critical components during landing and recovery the Xmas tree and choke module. Furthermore it provides a wide capture range to minimize need for precise target control before landing and orientation of the tree into the template slot to permit connection to the manifold.

The Xmas tree is configured with hydraulics to enable a safe operation and testing of Xmas tree/running tool system via the workover system.

Choke module (CM). The main function of the CM is to serve as a flow loop with instrumentation and valves that can be easily retrieved and maintained. The CM is separately retrievable and replaceable and is equipped with bumper frames and local guidance system for safe handling. The CM contain the following system components.

- Production choke valve.
- MEG dosing valve (MDV).
- Instrumentation (including Roxar wet gas meter).
- MEG injection point upstream PCV.
- Scale injection point (future use).

Protection roof configured for ROV access to valves, jumpers and hydraulic stab.

The production flow loop, MEG, annulus test and control lines on the choke module are connected to the manifold through a multibore vertical hub.

Fig. 10 Choke Module (CM)

Production choke. The production choke is designed and delivered by Cameron Willis as a subcontractor to FMC Kongsberg Subsea. This is a newly developed Bi-Linear Cv 720 plug and cage choke. The initial travel allows for a very precise linear adjustment from fully closed to approximately 60% open while the remaining 40% in a steep linear travel from Cv 120 to fully open Cv 720. Hence, the choke design with these particular flow characteristics can be used throughout the field's lifetime.

The choke is operated by a hydraulic stepping actuator and is equipped with a secondary mechanical ROV override. A position sensor (linear variable differential transformer) is provided on the choke to provide feedback to the subsea control module. A position indicator readable by ROV is also provided.

MEG distribution system. The MEG distribution system is designed to minimize the risk of hydrate formation. Each well is equipped with a distribution system ensuring that sufficient MEG is injected into each individual well.

The Xmas tree system is equipped with two MEG injection points:

- During normal production, MEG is injected between the production wing valve and the production choke to ensure good mixing.
- During well start-up and for barrier testing, MEG is injected between the production master valve and the production wing valve.

MEG Dosage Valve (MDV). Each Choke Module on the Xmas tree has a MEG dosing valve that allows continuous MEG injection into either the 8" choke module or Xmas tree flowloop. The MEG valve is designed and delivered by Weir Valves & Controls. It is a new design consisting of six orifices installed into a rotating gate valve. The ID of the orifices varies from 3 mm up to 10 mm with a length of approximately 80 mm. While the gate rotates from one orifice to another the design ensures an overlap between an orifice and the main valve conduit to ensure an uninterrupted MEG flow.

Mitigation against hydrate formation if failure to inject MEG should occur for one or more wells, is handled by a combination of shut down of affected well(s), continuous overdosing and automatically compensated for by overdosing on the remaining wells to ensure sufficient inhibition of the multiphase pipelines to shore.

A computerized flow assurance system (FAS) is used to monitor the integrity and performance of the subsea MEG distribution system.

Wet Gas Meter. For control and montoring of the water in gas, a wet gas meter (WGM) is required on each well.

A dedicated technology development program for this meter was initiated early in the project, more than a year before awarding the contract for the subsea equipment. The early start was necessary to generate confidence in the selected solutions.

The Roxar WGM will be installed on each subsea well to measure the water content, condensate and gas flow rates. The meter is mounted on the choke module.

The following main production fluid properties are measured.

- Water mass flow rate.
- Water volume fraction.
- Hydrocarbon mass flow rate (gas and condensate).
- Formation water / salt detection.

The qualification of the Roxar WGM is in its final stage. Mechanical and software qualification have been completed. A performance test was conducted at K-lab in August 2005 with good results. At present it is assumed that the Roxar WGM in general will be qualified according to project requirements. A new K-lab test is scheduled for the winter of 2007 to address test rig problems and meter improvement opportunities from the previous K-lab test.

Completion and workover system. The subsea workover and completion system to be used includes the following main equipment:

- Dual bore workover riser.
- Lower Riser Package (LRP) and Emergency Disconnect Package (EDP) including retainer valve.
- Surface test tree and workover control system (WOCS).
- Test, transport and handling equipment.

The completion and workover system comprise all equipment and associated control systems required to install, retrieve and commission a horizontal tubing hanger system and to perform well intervention and workover during the operational phase over the life of field. The WOCS provides the necessary functionality to control all functions on the completion/workover equipment and Xmas tree system. It includes facilities to perform normal and emergency shutdown and disconnection of specified functions in automatic sequences upon activation from the surface unit.

The system has been designed to interface with the drill ship West Navigator which is used to drill and complete the subsea wells.

Fig. 11 LRP and EDP stacked on top of the Xmas tree system

Production control system. The production control system is an optical/electro-hydraulic multiplexed system. Primary communication is a redundant fibre optic communication bi-directional point-to-point communication link between land and each subsea control module (SCM). The communication protocol is TCP/IP. The control system has fully redundant hydraulic, electric and communication systems and is as far as possible based on proven subsea control system components. The subsea control unit installed at the onshore plant at Nyhamna and is a node on the main control system network. The subsea and onshore control systems are therefore fully integrated with no requirement for a subsea master control station.

Subsea control module. A retrievable control module (SCM) is located on each Xmas tree and on each manifold (MCM). Each subsea well is controlled by a dedicated SCM. The SCM controls all the Xmas tree sensors, hydraulic functions and interfaces with downhole functions. The MCM controls all sensors and MEG valve hydraulic functions on the subsea manifold.

Fig. 12 Subsea control modules (SCM)

Backup Communication. Primary backup communication is provided via a Local Area Network interconnecting all SCMs locally on a template. This enables all SCMs to communicate via high-speed fibre-optic communication, even if seven out of eight fibre channels are down.

Secondary backup communication is provided with a dedicated redundant communication signal superimposed on the high voltage power.

Power. High voltage power cables within the subsea umbilicals provide power for template A, B and have capacity also for the future template C and D. The subsea main umbilical termination unit contains step-down transformers from 3kV to 500V enabling the use of field proven low voltage electrical connectors, thus avoiding the need for qualification of new high voltage electrical connectors.

Hydraulic system. The Ormen Lange development has a zero-discharge philosophy. The hydraulic system is a closed loop system with return lines to shore, avoiding hydraulic fluid consumption and minimizing discharge to the sea. The hydraulic fluid is Castrol Brayco Micronic SV/A. The chosen hydraulic fluid is a synthetic, non-water based fluid. All SCMs have hydraulic, electrically continuously held, insulation valves for LP and HP supply in order to maintain umbilical pressure in case hydraulic bleed-down of the Xmas trees is required. These valves will lose electrical power in case of an ESD, thus enabling a safe bleed-down of the Xmas trees, without depressurising the umbilical. All onshore and subsea hydraulic distribution is hard piping.

Subsea instrumentation. Provisions for flow measurement and control of production from individual wells is implemented. Remote update of software and parameters for sensors is possible without affecting production of the well. All normal operation modes (start-up, continuous operation, start/stop of equipment) are performed from the central control room and with a very high degree of automation.

The electrical interface to downhole located equipment is an IWIS (intelligent well interface standardization) interface. IWIS is a standard interface that is agreed upon between oil companies, major subsea vendors and downhole equipment vendors. IWIS is included in last revision of ISO 13628-6 Subsea Production Control System.

Flexibility is maintained to run fibre optics downhole for future gauge applications. As all Xmas trees are identical, even the first Xmas tree includes preparations for single fibre optical connector and penetrator for downhole use.

Corrosion and scale inhibition. The subsea control system does not provide for the separate injection of corrosion inhibitors. The corrosion and scale inhibitor is mixed with the MEG onshore, and is thus injected into the production stream together with the MEG at the Xmas tree system.

For potential future use, a scale inhibitor line is included in the umbilical, and provision for injection points included in Xmas tree system design.

Sand control. The Ormen Lange wells will produce at very high rates; hence downhole sand control is installed as part of the well completion to minimize the risk of sand production under operating conditions. The erosion rate and accidental sand production is continuously monitored by means of a permanently installed erosion probe and an acoustic sand detector on each choke module.

Safety and shutdown. The production control system is fail safe on loss of electrical power and hydraulic supply pressure, and has been designed with safety integrity level 2 for emergency shutdown (ESD) according to IEC61508.

The shutdowns may be performed on individual wells, or for all wells simultaneously.

Subsea umbilicals. The Ormen Lange field is controlled via two 120 km long optical-/electro hydraulic umbilicals from Nyhamna. A crossover control umbilical interconnects the two production templates.Each main umbilical contains power cables, fibre optic lines, hydraulic supply and return lines, scale inhibitor and annulus test lines.

Fabrication and testing. The umbilicals have been fabricated by Nexans in Halden, Norway while the umbilical termination heads have been fabricated by FMC Kongsberg Subsea.

The cross section of the main umbilical has the following functions and design:

- 5 power cables for power/backup control of the wells, of which one cable is spare.
- 2 off 32 fibre optic lines for main communication/control of the wells.
- 2 off 21mm ID super duplex steel tubes for LP hydraulic supply and return.
- 2 off 19mm ID super duplex steel tubes for HP hydraulic supply and hydraulic spare.
- 1 off 21mm ID super duplex steel tube for scale inhibitor (future use).
- 1 off 21mm ID super duplex steel annulus test line. Umbilical outer diameter is 120mm.

The in-field umbilical contains one additional 21mm ID super duplex steel tube in order to provide 2 off HP, 2 off LP, 1 off hydraulic return, 1 off annulus test and 1 off scale inhibitor lines.

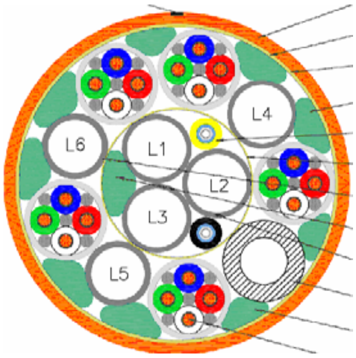

Fig. 13 Umbilical cross section

Due to their length, the main umbilicals required special considerations during the fabrication and installation process. Each main umbilical was fabricated in one continuous length.

Fig. 14 Umbilical A at Nexans in Halden

Umbilical termination head (UTH). The UTHs have three water barriers, or more precisely, the outer barrier (of two) is not directly exposed to seawater. The electrical cables are terminated in several pressure compensated chambers within the UTH. The design tolerates gas intrusion between the conductor cores. The conductor cores are at any stage protected from seawater ingress by two pressure compensated and separately testable barriers. This is a proven design principle specified for Hydro UTHs since 1992.

The UTHs also include transformers, and both electrical and optical connectors.

Fig. 15 Umbilical termination head

In-line tees. At template A, the 16" spools are connected to in-line tees on the 30" multiphase pipelines. The pipe joint containing the tee piece and hub blinded with ROV removable HP cap were welded into the 30" lines onboard the installation vessel and lowered to the seafloor during the laying operation. After completed pipeline installation, the tee valve modules were installed and connected subsea.

The in-line tee modules provide for tie-in of 16" rigid spools (20" connections) from templates A. They include ROV operated full bore isolation valves and are designed with dropped object protection. The connection system was designed such that the tee valve module installation could accommodate up to +/- 15 degree of rotation of the tee on the 30" pipeline.

An extensive test program was performed in Tønsberg prior to offshore installation. The test program included both dry and wet testing.

Fig. 16 In-line tee during testing

Pipeline end termination system (PLET). The 30" pipeline end termination (PLET) system is installed close to template B.

The PLET system design comprises a PLET bottom structure which was installed prior to pipeline lay down. The protection structure protects equipment from dropped objects and fishing activities. The PLET bottom structure was designed to function as a landing base for the pipeline terminations, the PLET Modules and the pig loop. The PLET bottom structure was fabricated by Grenland Offshore as a subcontractor to FMC Kongsberg Subsea.

The PLET system allows for 30" pipeline thermal expansion. It provides for tie-in of 16" rigid spools from template B and 12" rigid spools from template C (future).

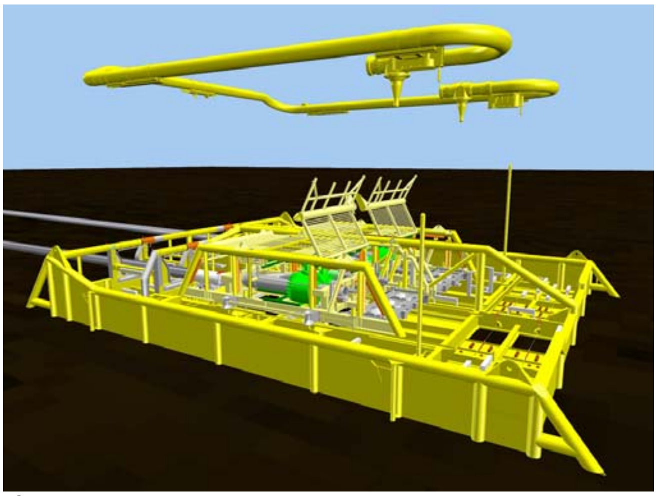

Fig. 17 PLET system

Pig loop. The pig loop is a 30" rigid pipe spool interconnecting the two multiphase pipelines. The pig loop allows round trip pigging of the multiphase pipelines to and from Nyhamna without subsea intervention other than ROV operation of valves. The pig loop reduces cost and time in connection with pigging during the operation phase. Benefits are also identified in connection with the ready for operation (RFO) and gas-up operations.

The pig loop was installed and tied-in after lay-down of the pipeline and installation of the PLET modules. The pig loop has 3D bends and accommodates expected maximum pipeline end expansion of 1.0 m.

Installation and tie-in. Heerema Marine Contractors were responsible for the offshore installation of PLET bottom structure using the vessel Thialf. Saipem/Sonsub were responsible for installation of the PLET valve modules (2 off 130 metric tonnes), 16" rigid spools, 30" pig-loop, in-line tee valve modules as well as all tie-in and connections using the construction vessel Normand Cutter. The 16" rigid spools and the pig loop were wet-stored by the heavy lift/pipe-laying vessel S7000.

Installation. Heerema Marine Contractors were responsible for the offshore installation of PLET bottom structure using the vessel Thialf.

After fabrication and mechanical completion of the structure in June 2005, the PLET bottom structure was loaded onto a transportation barge in Tønsberg together with Template B.

Upon arrival at the offshore location, the barge was brought in position at the stern of the crane vessel and the structure was lifted from the barge directly into the sea. The structure was rotated and lowered vertically through the splash zone and down towards the seabed. Uprighting of the structure was done 15 meters above the seabed prior to final placement on the bottom.

The lifting weight of the PLET bottom structure was 350 metric tonnes.

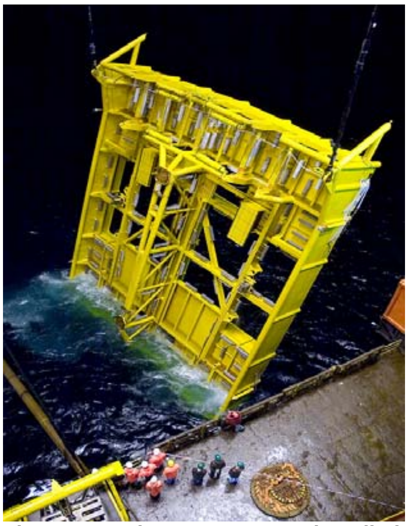

Fig. 18 PLET bottom structure installation

The achieved position accuracy for the PLET bottom structure was within 1.0 meter and the achieved heading was less than one degree from the specified. The heading tolerance was crucial to ensure tie-in to the pipeline ends successfully, and positioning bridles were connected to two preinstalled 35 metric tonnes gravity anchors to ensure heading control.

In the summer of 2006, adjustable pipe supports (APS) were installed approximately 60 meters in front of the PLET bottom structure to ensure proper alignment of the 30" pipelines for tie-in and connection to the PLET modules. During the following autumn the installation of PLET modules, spools, in-line tees and pig loop was successfully performed with the construction vessel in parts simultaneously with wet storing activities using the heavy lift vessel.

Dummy PLET. A complete replica of the PLET bottom structure was fabricated by Grenland Offshore. The purpose of this structure was to perform a complete and as realistic as possible integration testing of the PLET system, as the PLET bottom structure was installed before final fabrication of the PLET system components. An extensive test program was undertaken in Tønsberg during the winter and spring of 2006 to ensure the functionality of the PLET and tie-in system. The test program included laydown of 30" pipe and round trip pigging test with intelligent pig.

Fig. 19 Testing of PLET modules and pig loop on dummy PLET bottom structure

Tie-in systems and intervention tools. The tie-in philosophy for the Ormen Lange field development was to standardize tie-in tools for all flowline, umbilical and pipeline connections in the field.

The MEG lines and umbilicals are connected to the production manifolds by means of field proven and remotely operated tie-in tools. A collet type connector is used for these small-bore 12" connections.

The 20"/30" pipeline tie-in system is a new built system by FMC Kongsberg Subsea and has required technology qualification. A clamp type connector is used for these large bore connections.

Fig. 20 30" Clamp Connector

Testing. The Ormen Lange subsea production system has been subject to extensive testing prior to offshore installation. The testing activities comprised the following types of tests:

- Qualification and verification tests of all new components.
- Factory acceptance test (FAT) to prove that the components of the subsea production system satisfy all specific requirements to strength and functional performance.
- Extended factory acceptance test (EFAT), to prove that a sub-system performs satisfactorily in service and meet all specified system and detail requirements
- System test, to verify and demonstrate the capability of all the sub-systems to function and be operated as an integrated subsea production system.
- Integration test, to verify all external interfaces between the Ormen Lange subsea production system provided by contractors and systems/units supplied by other contracts.

Technology qualification program. To a large extent, the subsea system utilizes existing and proven technology with references from other worldwide applications. However, some elements have required specific qualification for Ormen Lange's conditions.

The primary objective of the Ormen Lange technology qualification process has been to ensure that all technology items are subject to the same management and follow up activities regarding quality assurance, planning, verifications, risk assessment and documentation.

The technology development programme includes the following items related to the subsea production system:

- Wet gas meter (WGM).
- Large Bore Tie-in System.
- MEG dosage valve (MDV).
- Subsea Step Down Transformer.
- Leak detector.
- 7” x 2” Completion/Workover Riser System.

Achievements

As of February 2007, the design, fabrication, testing and installation of the Ormen Lange subsea production system are nearly completed. Both template A and B, the in-line tees, the PLET system and spools have been successfully installed subsea and all tie-ins have been completed.

The work has been performed to the satisfaction of all the Ormen Lange stakeholders and no major unforeseen events have been experienced.

Key success factors

The success of the Ormen Lange subsea production system is a result of the following factors:

- The level of detail and the quality of the conceptual engineering performed prior to contract award provided a very good basis for project execution in terms of planning cost estimates, specification of installation vessels etc.
- Active risk management has been performed throughout the project, whereby key risks have been systematically and pro-actively identified evaluated and followed up in order to minimize negative impact and maximize benefit.
- The project team has executed effective change management, whereby all change proposals have been carefully reviewed and evaluated prior to implementation or rejection.
- The project team has performed close and active monitoring of interface work between contractors.
- Qualification and verification tests of all new components and thorough testing onshore has contributed to smooth and effective offshore operations.