Submarine link

Submarine HVAC cable to the floating oil and gas platform at Gjøa

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Title picture
The submarine cable on the drum of the cable-laying vessel.

1 Helicopter landing on the cable-laying vessel

The Gjøa platform is located west of the Sognefjord in Norway, about 100 km north-west of Mongstad. The platform was developed and built by Statoil and is currently operated by GDF SUEZ E&P Norge AS. Gas and oil produced by this floating platform are transported by pipelines to Mongstad and also to St. Fergus in Scotland.

It was initially intended to meet Gjøa's power needs with a gas turbine power plant. In order to reduce greenhouse gas emission, it was instead decided to import electric power from a shore connection at Mongstad (the Norwegian energy mix has a high proportion of hydropower). The platform's electrical consumption is estimated at 40 MW peak and 25 to 30 MW average.

Characteristics of the Gjøa cable link

The link consists of a 98.5 km static cable on the sea bed and a 1.5 km dynamic cable rising upwards to the floating platform ➔ 2. The dynamic cable must allow for the platform's horizontal and vertical movement, including a lateral radius of 75 m. To accommodate the additional length the cable requires for this, its lower part is lifted using 73 equidistant buoyancy units ➔ 7 in what is called a lazy wave configuration ➔ 2.

Design of the cable

An important part of the design process of the dynamic cable involved determining its fatigue life. This process had three main components ➔ 3.
- Global analysis
- Local analysis
- Fatigue testing

Global analysis

The mechanical load on the dynamic cable depends on several parameters, including the motion of the platform, water currents, marine growth and the cable's configuration ➔ 2.

The cable's response to translation, force, curvature etc. is analyzed by modeling it as a one-dimensional string using global properties such as weight, diameter, axial, bending and torsional stiffness. The configuration is optimized in an iterative procedure, selecting, for example, the position, size and number of buoyancy units.

The axial force and curvature of the cable were analyzed under extreme environmental conditions. An example of a typical extreme condition is a 100-year wave combined with a 10-year water current. The curvature and axial forces must remain within the design limits even under such conditions.

This analysis was accompanied by an interference analysis evaluating the possibility of collisions with neighboring risers and subsea infrastructure. Such occurrences are not permissible under any conditions.

Local analysis and lifetime estimation

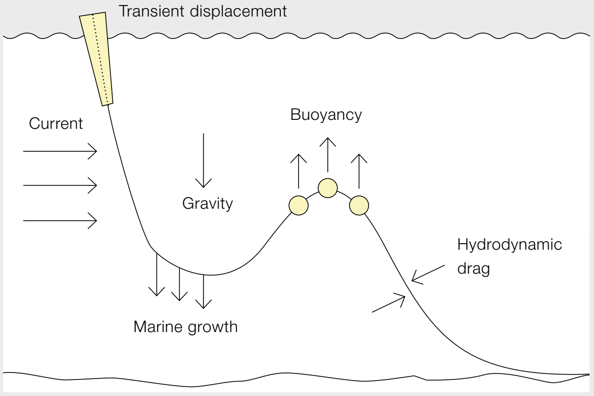
A dynamic cable is a complex structure. It contains different components and diverse materials. In general there are several ways of modeling the cable on a local level. Common methods include finite element modeling and analytical models. In the case of Gjøa, a conservative analytical model was used.

> The project brought together knowledge and skills from two industries that are normally largely separate: the oil and gas industry and the high voltage cable industry.

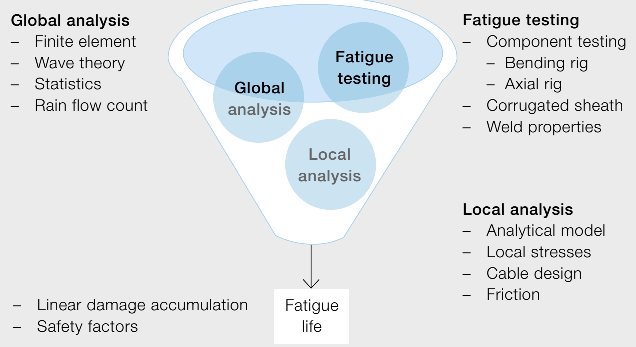
The strain in fatigue-critical components was calculated to be able to determine the lifetime of the cable, and is dependent on several factors, including curvature and friction between helical components.

Based on this analysis, the lifetime was calculated using the method of linear damage accumulation in the identified fatigue-critical components. The calcu-

2 Factors affecting the mechanical load on the dynamic cable



3 Conceptual layout of foundation in order to determine fatigue life



4 The cable submerged

5 Structure of the dynamic cable

lated lifetime of the cable exceeded 35 years with a safety factor of six.

Fatigue testing

The objective of the fatigue testing is to establish a Wöhler diagram (or S-N curve – a curve plotting cyclic stress against failure) of the identified fatigue-critical component. Emphasis was placed on the radial water barrier (the cable's welded copper sheath).

Components of the cable system

Bending stiffener

The severest loads to which the cable is subjected in terms of axial force and curvature occur at its upper end. An 8 m long stiffener was mounted here ➔ 10.

Static cable

The static cable is a three-phase, 115 kV cable using 240 mm^2 solid copper conductors. The conductors are enclosed in a lead sheath preventing water ingress. Lead was chosen (rather than copper as in the dynamic cable) as the sheath does not have to withstand recurrent mechanical forces. A bedding of semi-conducting tape is located underneath the sheath to prevent longitudinal water ingress (it is semi-conducting to even out charging currents in the lead). A polyethylene sheath covers the metallic sheath to protect it mechanically. A fiber-optical cable with 48 fibers is placed in the interstice of the three core conductors. The armor consists of two layers of galvanized-steel wires. The layers are wrapped in opposing directions to achieve a torsion-free yet strong structure, and are separated by bedding tape. The wires are covered with a bitumen compound to protect them against corrosion. The outer cover consists of two layers of polypropylene yarn, the inner one is impregnated with bitumen compound.

> A flex test simulates the fatigue the cable will be subjected to during its lifetime by applying increased bending stresses over a shorter time.

Dynamic cable

The dynamic cable ➔ 5 is a three-phase, 115 kV cable with 300 mm^2 conductors. The sheath is of corrugated copper, TIG [1] welded, and double armored to prevent water ingress and withstand mechanical fatigue during its design life time of 35 years plus with a safety factor of six. The sheath is also capable of handling phase to earth fault currents. The conductors are stranded and compacted in accordance with IEC 60228. The conductor section of the dynamic cable is larger compared to that of the static cable as the dynamic cable is thermally limited inside the stiffener at its upper end. The conductors are longitudinally water-sealed using a polymer compound. An optical-fiber cable with 46 single-mode fibers and two multi-mode fibers is located in one of the interstices. The multi-mode fibers can be used to monitor the temperature of the dynamic cable. To increase the weight/diameter ratio,

6 The cable tensioner (on board the laying vessel)

7 One of the buoyancy units used in the lazy wave configuration → 2

two lead rods are also placed in two of the interstices of the dynamic cable. A polyethylene sheath covers the galvanized wires and protects them from abrasion.

Repair joint

Should the dynamic section be damaged, it is most likely to be replaced in its entirety. For the longer static section, a repair joint was included in the cable's scope of delivery. The electrical part of the repair joint consists of three premolded rubber bodies, one for each phase, each covered by hermetically sealed casings. There is also one fiber optical cable joint and an outer common rigid casing for mechanical protection and to transmit the mechanical loads.

Flexible joint

The flexible joint connects the dynamic and static cables. It consists of:
- Three flexible molded core joints, one for each phase, each covered by a lead sheath soldered to the original metallic sheath of the cables
- One fiber-optical cable joint
- Armoring

Qualification

Various tests were performed as part of the qualification process. These include Electra 171 and IEC 60840. As this type of test is well known, this article will look at the less common flex test.

A flex test simulates the fatigue the cable will be subjected to during its lifetime by applying increased bending stresses over a shorter time. Two million cycles were applied on the full-scale dynamic submarine cable under constant axial load. The loads applied were calculated on the basis of the global analysis discussed above. The loads occurring at the top end of the cable are more severe than at the lower end.

A test rig was used to test a length of cable. The bending stiffener and hang-off were attached to the test section for the purpose of this test. The sample was installed horizontally in a rig, with the end that would normally be at the top being attached to a rocking head that flexed the cable. The other end was connected to the 500 kN servo-hydraulic tension actuator. Before and after the flex test the cable cores were measured electrically (partial discharge and conductor resistance) revealing that no degradation had taken place. The cable cores were also inspected visually and application of a penetration fluid confirmed there were no cracks in the copper sheath.

Sea trials

As the cable was to be installed with a new cable laying vessel and laying system, a sea trial was performed before the actual cable laying. The trial included the following:
- Verification of methods for installation of vortex-induced vibration (VIV) suppressors, buoyancy units and handling of the stiff cable end (a stiff tube on the cable simulated the bending stiffener and hang-off).
- Verification of cable-laying in deep water under relevant conditions (for North Sea in early spring).

The trials went well, with only slight modifications on some mechanical parts of the laying system being needed. The sea trial was also a valuable training opportunity for the cable-laying crew.

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Footnote

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[1] TIG: tungsten inert gas

8 The cable-laying vessel in Mongstad, where the cable connects to the shore

9 The Gloa platform with the cable being pulled aboard.

The Gjøa project combined innovative development with rigorous engineering in an environment that leaves no space for error or mistakes.

Cable laying vessel

The cable was transported and installed using the cable-laying vessel North Ocean 102 (the ship has a loading capacity of 5,800 tonnes). The entire cable (including static and dynamic sections) was laid in one length.

The cable was loaded onto a rotating drum → 8. To be able to lay the cable at a significant wave height of 4 m, a heave compensated chute (HCC) was developed for the project. The HCC reduces the dynamic tension during laying. The vessel was also equipped with two 120 ton tensioners → 6. The bending stiffener and the pre-installed hang-off body which were mounted on the cable before loading were stored on top of the carousel.

During loading, temporary terminations were mounted on the dynamic cable end on board the vessel. To test the complete cable after laying, each phase of the cable was terminated into a gas insulated (GIS) chamber.

Cable laying

The total route length of the cable was 98 km from Mongstad beach → 8 to the Gjøa platform → 9. The cable-laying work presented a number of challenge, including:

- The shore landing of the cable at Mongstad.
- Laying the cable down the steep underwater cliff at Mongstad including VIV suppression strakes.
- Routing of cable through an exposed area of sea.
- Laying cable at a water depth up to 540 m.
- Continuous touchdown monitoring during cable laying using underwater ROV (remotely operated vehicle).
- Safe handling and unloading of bending stiffener, pre-installed pull-in and hang-off body.
- Installation of 73 permanent buoyancy modules for the “lazy wave”.
- Storage of dynamic cable end including buoyancy modules, bending stiffener, pre-installed pull-in head and hang-off body on the seabed.

An underwater cliff, about 0.3 km from Mongstad, was so steep that the cable had to be suspended with considerable free spans. To reduce the risk of vortex induced vibration VIV, suppression strakes [2] were mounted on it. Free spans were also eliminated by rock dumping.

After laying the dynamic cable end (including the buoyancy modules), the bending stiffener and the pull-in head and hang-off body were temporarily placed on the sea bed for approximately three months before the pull-in operation.

10 The bending stiffener being lowered from the ship

11 Preparing the cable

Tests during and after laying

All optical fibers at the end of the cable were fusion-spliced to form separate loops. This permitted continuous OTDR[3] measurement during cable-laying. The OTDR measurement was performed from the Mongstad substation.

An electrical test was performed immediately after the positioning of the flexible transition joint on the seabed and installation of the buoyancy modules.

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Pull-in operation and top side joints

Before the pull-in operation, the stored cable was raised from the seabed and the pull-in head was secured to the platform pull-in winch wire. The pre-installed hang-off body was then raised to the hang-off table on the platform and the cable secured → 9.

Following the pull-in operation, the armored wires on the dynamic cable were removed and the phase cables and optical cables connected. The screens of the phases and the sheath of the optical cable were connected to an earthing bar.

A successful delivery

The Gjøa project combined innovative development with rigorous engineering in an environment that leaves no space for error or mistakes. It represents the first ever connection of a power cable to a floating platform. The project brought together knowledge and skills from two industries that are normally largely separate: the oil and gas industry and the high voltage cable industry. The resulting product is an energy supply reducing overall carbon dioxide emissions.

This article is a shortened version of a paper presented at JICABLE11 in Paris in June 2011 Paris by the same authors under the title "HVAC Power Transmission to the Gjøa Platform". A similar paper was published at CIGRE 2010.

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Footnotes

[2] A strake is an aerodynamic (or in this case hydrodynamic) surface that improves airflow.

[3] OTDR: optical time-domain reflectometer