A Testing Platform for Subsea Power Cable Deployment

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Abstract

The failure of subsea cables has been predominantly attributed to third party activities and cable field joints. Field joints may be unavoidable due to joining of insufficient factory-made cable lengths, cable repair, or when the cable installation process has to be abandoned due to rough weather or other unplanned events. Failures within the jointing location reveal that current quality testing of these joints may be inadequate. The failure mode in these joints is mainly a result of seawater ingress at the field joint. Current design practices for subsea cable field joints recommend offshore simulations/trials to demonstrate the long term performance of the joint under the expected mechanical loads during cable installation to demonstrate whether the planned field joining practice is satisfactory. Nevertheless, offshore simulations are costly, and therefore a set of standardized onshore testing schemes would be advantageous alternative. This paper presents an onshore testing scheme for subsea power cable deployment. The proposed testing arrangement can be employed to verify the design of the offshore field joint and to prove the functionality of the field joint under the installation loads.

Keyword: Subsea Cable; Deployment; Radial Water Penetration; Offshore Field Joint.

1.0 Introduction

Pervious work published in the literatures [1-4], has highlighted that jointing operations are complex and involve valuable vessel time. The jointing operations to be undertaken offshore require good planning, highly qualified personnel and an installation vessel equipped with proper equipment for handling and deployment. Jointing operations typically last for several days. This is depending on the subsea joint design as well as the type of the joint. Cable repair may not be possible during rough seas or windy conditions. It is well recognized in the offshore industry that it may be difficult to find favorable weather conditions of sufficient duration. It is necessary to carry out the joining operation in good weather conditions to guarantee the integrity of the joint and to prevent fatigue failure of the hanging cable sections. Ref. [5] proposes that cable joints as well as terminations should be subjected to a testing scheme as per industry standards.

The main contribution of this paper is the introduction of an onshore testing platform for Omega deployment which can be used to test the joint under the expected installation loads. The onshore simulation can be used to mimic the corresponding mechanical forces and handling of the lifting equipment for the “Omega-laying” procedures.

The proposed testing arrangement can be used to replace the sea simulations/trails to determine if the proposed field joining procedure is acceptable. The test could be implemented in conjunction with the typical mechanical tests listed in [6].

Ref.[1] presented a testing platform for the in-line offshore field joint (In-line joint is illustrated by Figure 1 and Figure 2) which can replace the sea trials undertaken offshore, whereas this paper proposes a testing scheme applicable only for the Omega offshore field joints. The Omega offshore field joint refers to a joint that will be deployed on the seabed in a “U” configuration, in an over length loop (Omega joint is illustrated by Figure 3 and Figure 4) . It is also defined as an Omega joint because the joint mimics the symbol Omega from the Greek alphabet “Ω”

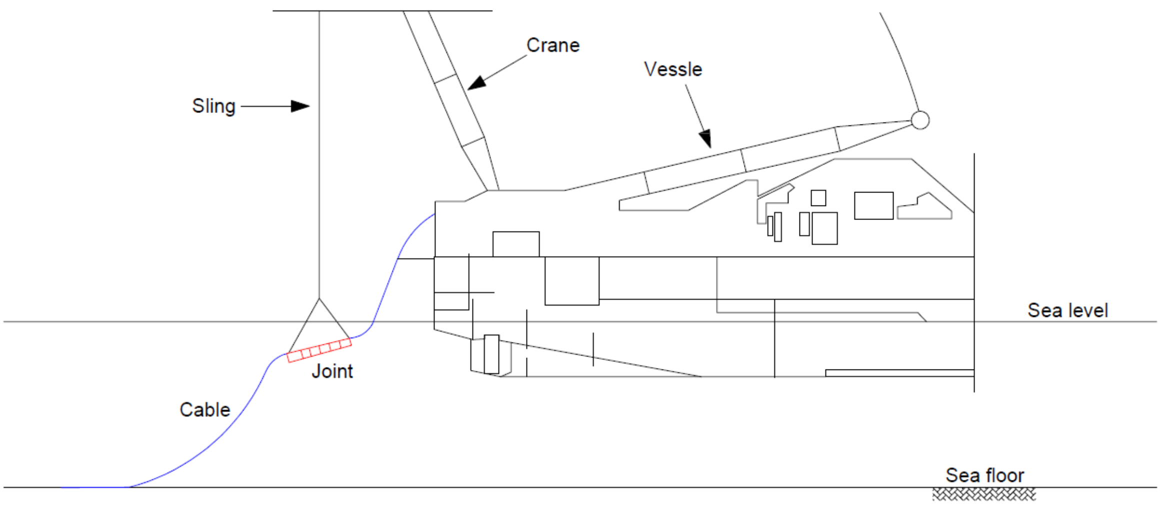

Figure 1: In-line offshore field joint deployment

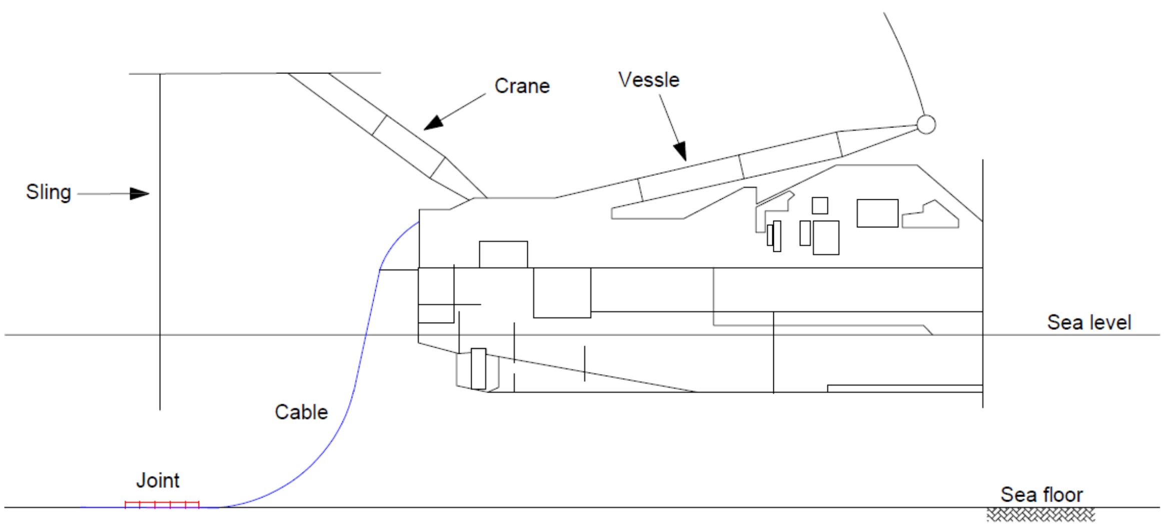

Figure 2: In-line offshore field joint-final position

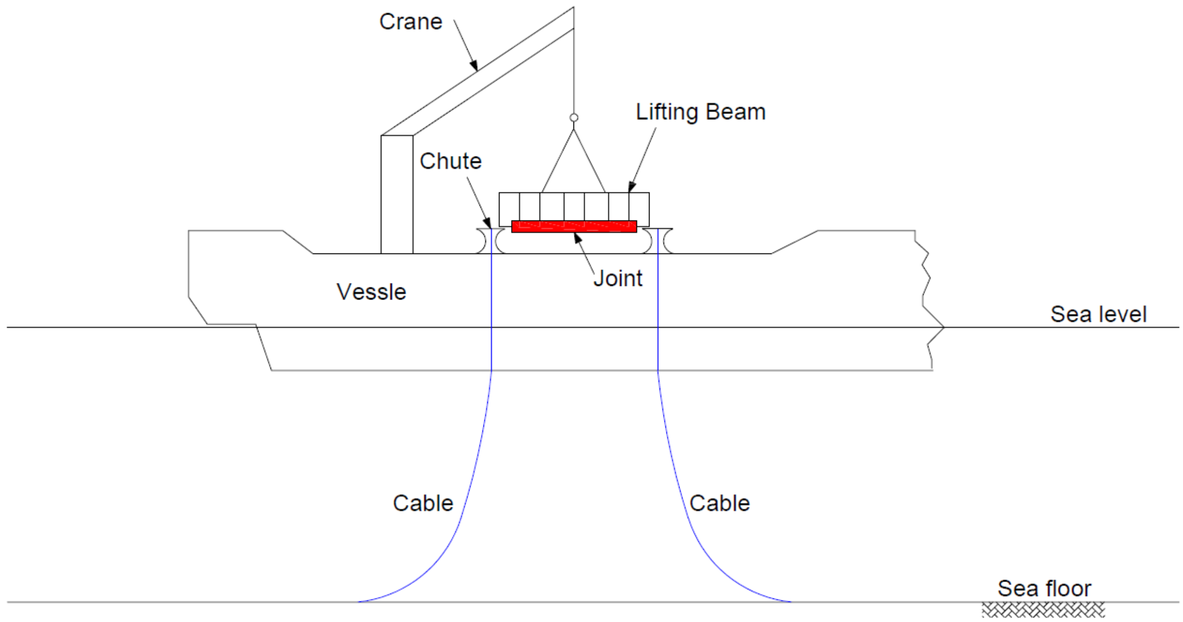

Figure 3: Omega offshore field joint deployment

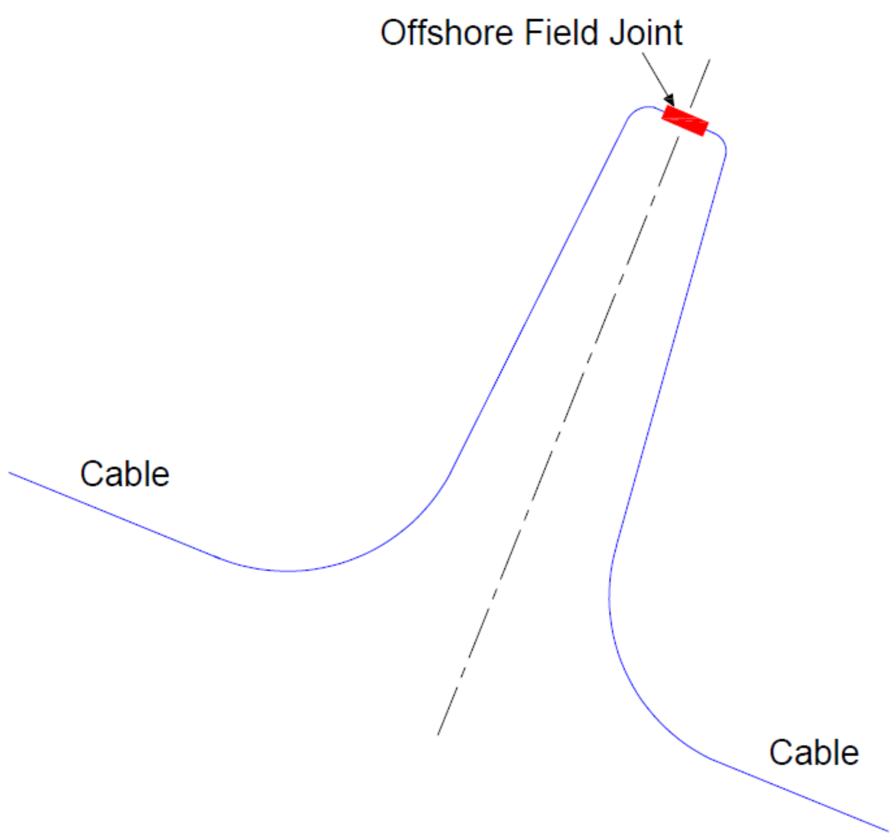

Figure 4: Omega offshore field joint-final position

The testing scheme presented in this paper should be undertaken to verify the design of the offshore field joint. Moreover, the proposed testing scheme increases the level of confidence in the design of the offshore field joint and proves the functionality of the field joint under the anticipated installation loads.

The proposed testing arrangement, combined with the outcome from the numerical simulations using finite element analysis, can be utilized in order to obviate the need for full scale offshore testing. It should be highlighted that the cost of offshore simulations/trials to demonstrate the long-term integrity of the joints under the loads associated with the installation, is quite high compared to the proposed testing arrangement. The proposed onshore testing scheme can be easily repeated where a wide range of variable conditions are to be considered. Furthermore, this proposed test minimizes the safety risks associated with the offshore operations.

2.0 Subsea Joint Failure

General statistics on land cables show a high fault rate caused by joints. This figure is mostly driven by poor workmanship rather than design defects. Based on a statistical survey conducted in 1986 on submarine power cables, failures due to human and natural hazards represented 82% while the remaining 18% of cable failures resulted due to joint failure [7]. The majority of the joint failures reported in this survey were attributed to poor engineering, installation or maintenance. Ref. [8] revealed that out of 49 failure incidents that took place in a 7000 km subsea cable, only four were due to joint failures. The ratio of joint failures has changed, during the period 1986 to 2009, from 0.22 to 0.095 failures/year/100 km as reported in [1]. The reduction in the failure rate was attributed to the continuous improvement in the design of submarine cables that makes cable joints more reliable.
Ref. [9] indicated that 10.4 % of the failures within the medium voltage subsea power cable system in Greece is related to the joints as highlighted in Figure 5.
Ref. [10] indicated that although the failure rate in subsea power cables has recently improved, joint failures are still taking place. It was reported that for a single core cable, the failure rate is 0.024 failures/100km/year in which joint failure rate is 0.01 per 100 components per year [11].

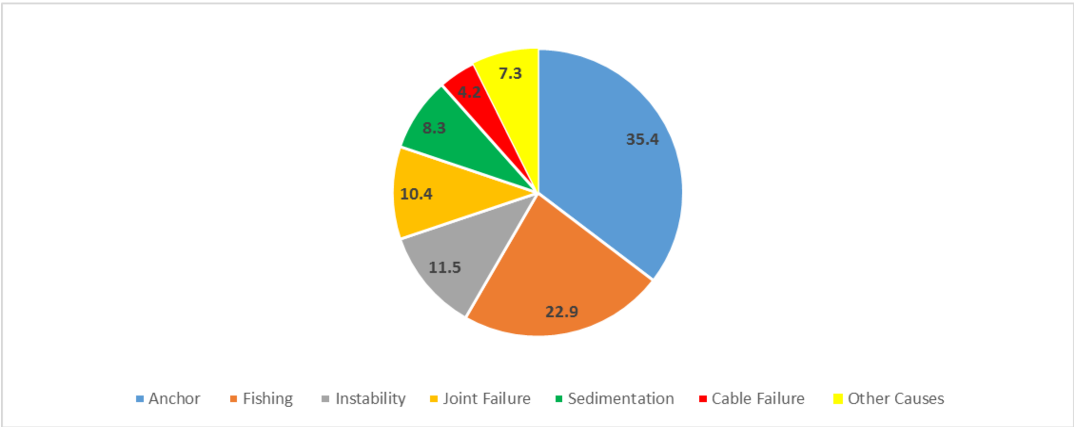

Figure 5: Proportion of cable faults

3.0 Subsea Joints

Ref. [1] indicated that offshore rigid joints require complicated rigging arrangements for offshore deployment. Offshore rigid field joints should be designed and installed using the appropriate methods. If not, the joint will represent a weak point in the power cable that may lead to seawater ingress and subsequent electrical failures. As such, where possible, offshore field joints should be avoided however, this may be almost impossible in real field applications especially in long subsea power cables and for damaged cables that require repair. As per [12], during the manufacturing process of XLPE (Cross-Linked Polyethylene), the production has to stop after a certain number of days (typically 10 days). The stop in production is required to clean down the extruder. As such, it can be seen that the larger the cable, the shorter the extrusion run. Hence, more field joints would be required. This will increase the probability of the cable having one or more faults during the cable operational design life.

The success of jointing operations as well as the long term integrity of the field joint is controlled by: 1) the workmanship and quality control during manufacturing. 2) Cable/ joint design. 3) Welding of the copper sheath to the lead sheath as illustrated in Figure 6.

Figure 6: Soldering between copper sheath and lead sheath

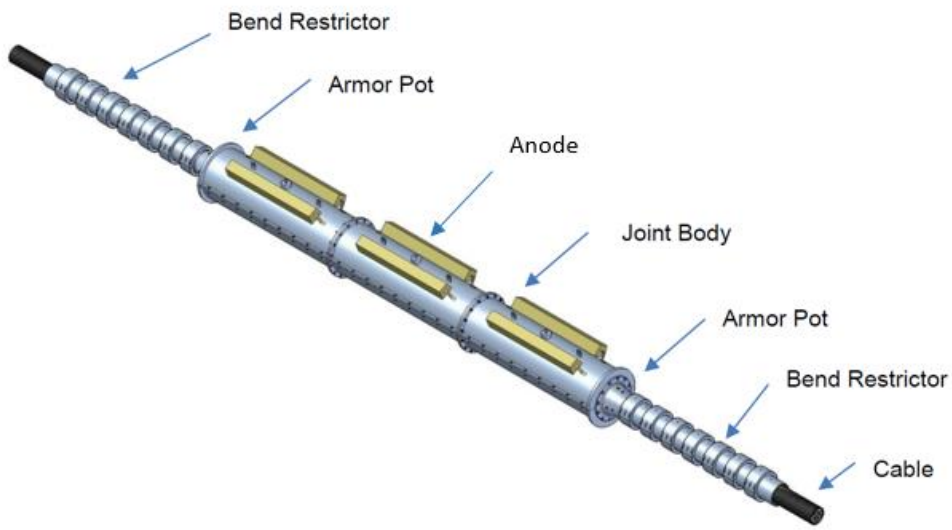

Figure 7: Offshore Field Joint (OFJ)

As per [6], the definitions of the Field Joint and Repair Joint are as follows:

1. ***Field Joint:***

A field joint is a joint made on board a cable laying vessel or barge, or in the beach area, between cable lengths which have been armoured. They are generally used to connect two delivery lengths offshore. The design principles of field joints are generally the same as for repair joints and are treated as such.

2. ***Repair Joint:***

A repair joint is a joint between cable lengths that have been armoured. They are generally used in repairing a damaged submarine cable or joining two delivery lengths offshore or in factory.

Based on these definitions, it can be seen that there is no practical distinction between the field joint and the repair joint. A schematic for the offshore field joint (OFJ) is shown in Figure 7.

4.0 Mechanical tests

Ref.[6] introduced the following recommendations and modifications to the mechanical tests reported in [13]:

- A radial water penetration test of rigid repair joints. This test is required to ensure the ability of the joint to withstand water penetration up to the maximum water depth of the subsea cable. This test is an essential characteristic for a subsea cable.

- A scheme for mechanical tests for different types of repair joints.

Ref. [6] emphasized that special attention is also to be given to mechanical tests for repaired joints under different installation conditions. The mechanical tests listed in Table 1 are typically conducted on rigid joints. According to [6], these tests are representative of the mechanical stresses to which the joints are subjected during installation and repair operations.

Table 1: Mechanical Test for Rigid joint

	Tensile Bending Test	**Tensile Test**	**Sea Trial Test**
Reference [14]????	**Electra 171, section 2.2**	**Electra 171, section 2.3**	**Electra 171, section 3**
There is no need for this column and reference; right?	Not Mandatory Bending test only with Radius R without load, if applicable.	Mandatory Straight tensile at T on the same joint assembly subjected to bend test at radius R without load.	Advisable

5.0 Case Study

Recently, type tests were conducted on an offshore field joint and was observed to fail three times. While the OFJ successfully met all the mechanical and electrical criteria in the first two type tests, it did not satisfy the criteria defined in [6] for the radial water penetration (RWP) test as illustrated in Figure 8, given the fact that the joint was tested in a well–controlled environment. Whereas, the joint will be performing offshore on a vessel (less controlled environment). Hence, it was decided to perform a trial of a deployment/installation test with an OFJ in conjunction with the third water penetration test as per the requirement of a part of the type test. The outcome of the investigations can be found in [1].

Figure 8: Offshore field joint after radial water penetration test during the examination (water spouted-out of the test object)

The repeated failure in the type test proved that inadequate joint design and poor joint assembly work could lead to joint failure. Bearing in mind that the joint was made in a well-controlled environment and would be undertaken offshore on the vessel in less ideal conditions. It is important to ensure that quality control procedures for the jointing procedure be well established to cover the offshore field jointing process. Therefore, it was agreed to substitute the sea trials requirements with simulated onshore testing.

6.0 Offshore Field Joint Deployment Procedure

This section summaries the sequence that should be employed to deploy an Omega joint on the seabed. Figure 9 and Figure 10 illustrate snapshots for the actual deployment of the offshore field joint. The loads experienced by the Omega field joint can be described in the following two stages:

- Stage-1: Lifting operation.
- Stage-2: Lowering operation.

Step-1 (Figure 11): Setup the vessel at the given cable end position. Then recover the cable ends to the vessel deck and secure the cable as required to facilitate the jointing operations.

Step-2 (Figures 12 and 13): After the completion of the jointing operation, lift up the lifting beam and commence the lifting of the cable joint.

Figure 9: Omega Joint rigging arrangement during the offshore simulation

Figure 10: Omega Joint rigging leaving the vessel during the offshore simulation

Step-3 (Figure 14): Lower the crane block by a certain distance and step back the vessel. Repeat this operation until the crane block is at certain level above the mudline. Then stop the vessel movement and lower the crane until it reaches the required elevation.

Step-4 (Figure 15): Gradually lower down the crane block until the cable is deployed on the seabed.

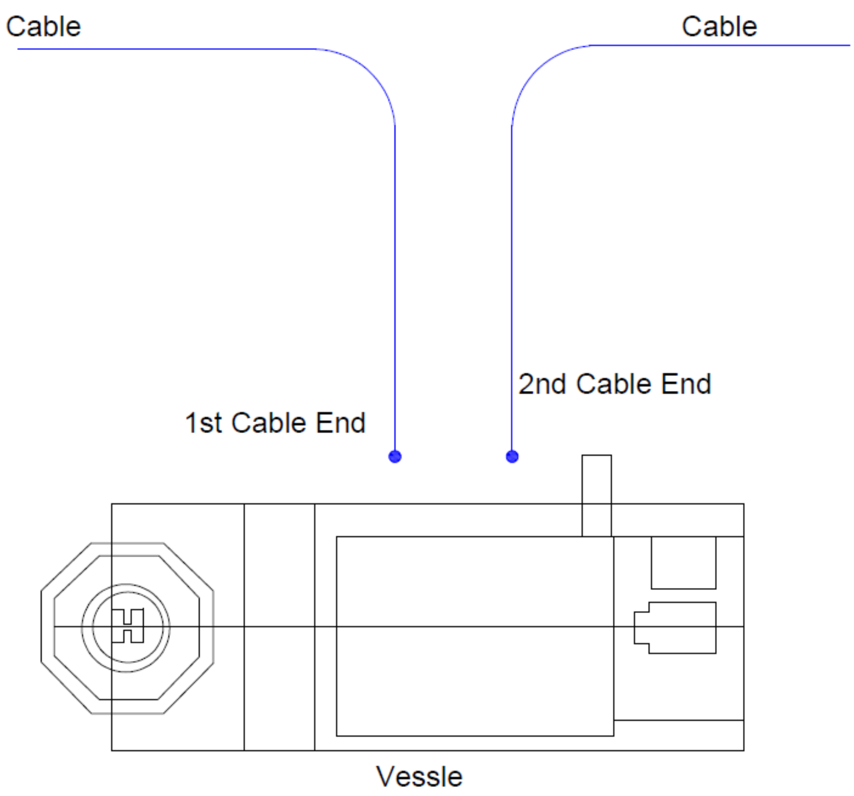

Figure 11: Schematic illustration of Step-1

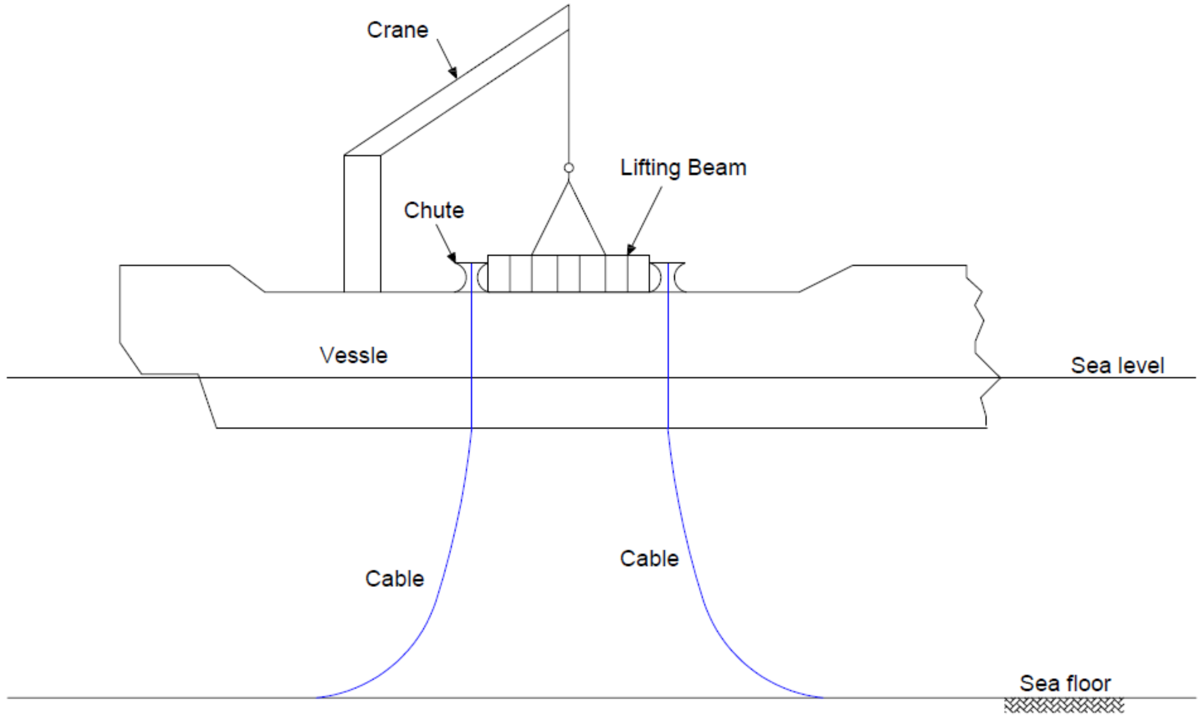

Figure 12: Schematic illustration of Step-2-a

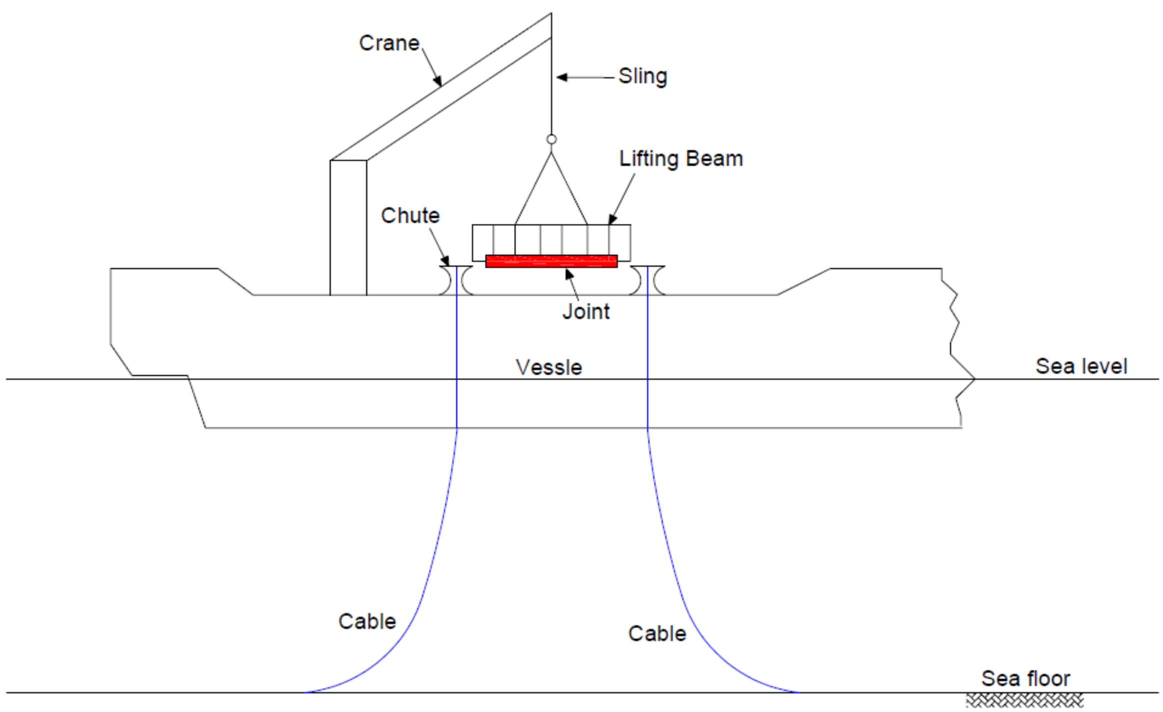

Figure 13: Schematic illustration of Step-2-b

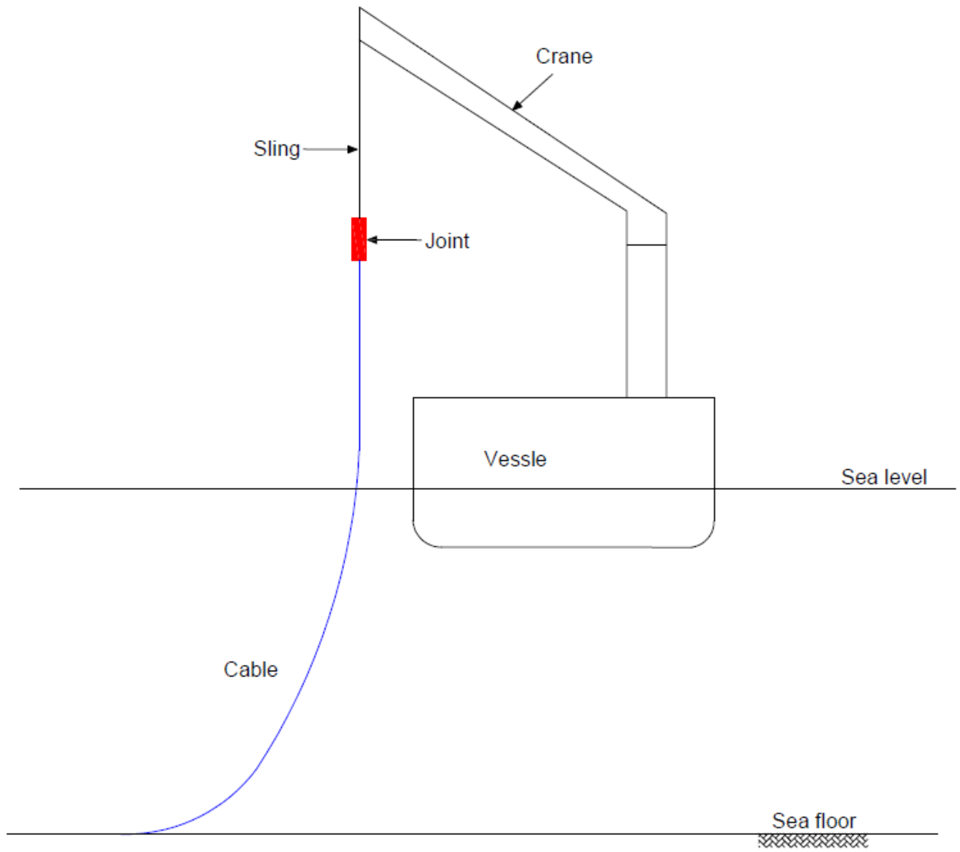

Figure 14: Schematic illustration of Step-3

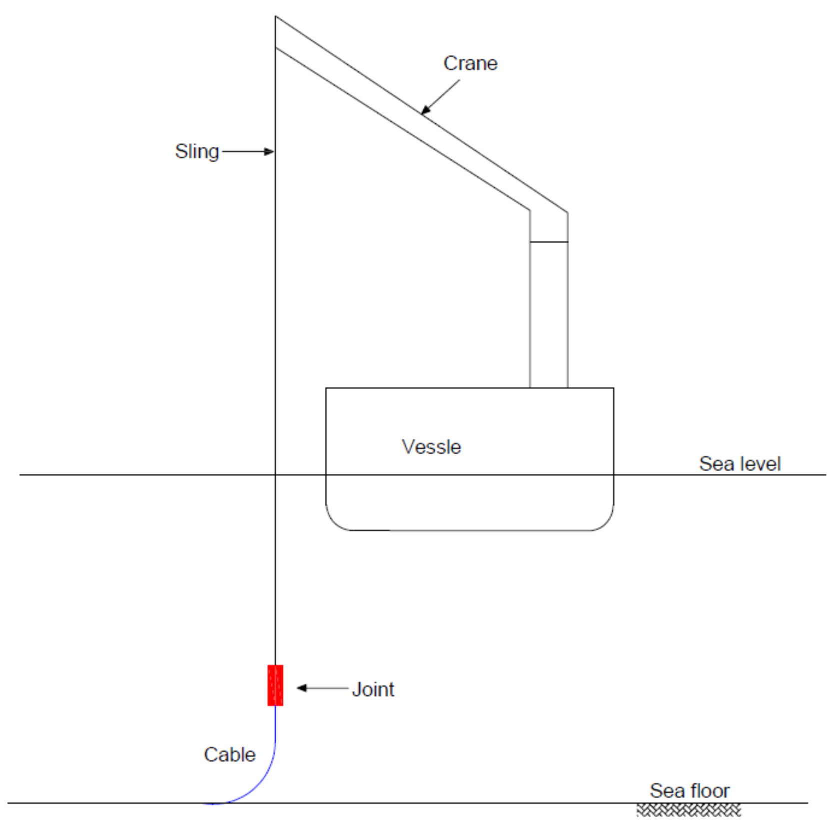

Figure 15: Schematic illustration of Step-4

7.0 Stress Analysis During The Mid-Line Omega Deployment of OFJ

The outside diameter of the HVAC (High Voltage Alternating Current) 132 kV Submarine Cable is 195 mm . Dynamic analysis, using finite element methods, was performed to determine the maximum axial load at the location, shown in Figure 16 and 17, during deployment operations.

Static and dynamic simulations were carried out to establish the likely maximum loads expected on the cable as well as the joints. The dynamic analyses undertaken have considered the effects of the wave, wind, and currents as well as vessel motion and displacement and has conservatively accounted for the worst case scenario.
These loads obtained from the finite element analyses were then applied on the rigid joint during the on-land testing simulation. A load factor can be applied during the test to account for any uncertainties. As it can be seen in Figure 16, the axial load was applied to the ends of the joint via the use of weights attached to the cable sections below the Chinese fingers.

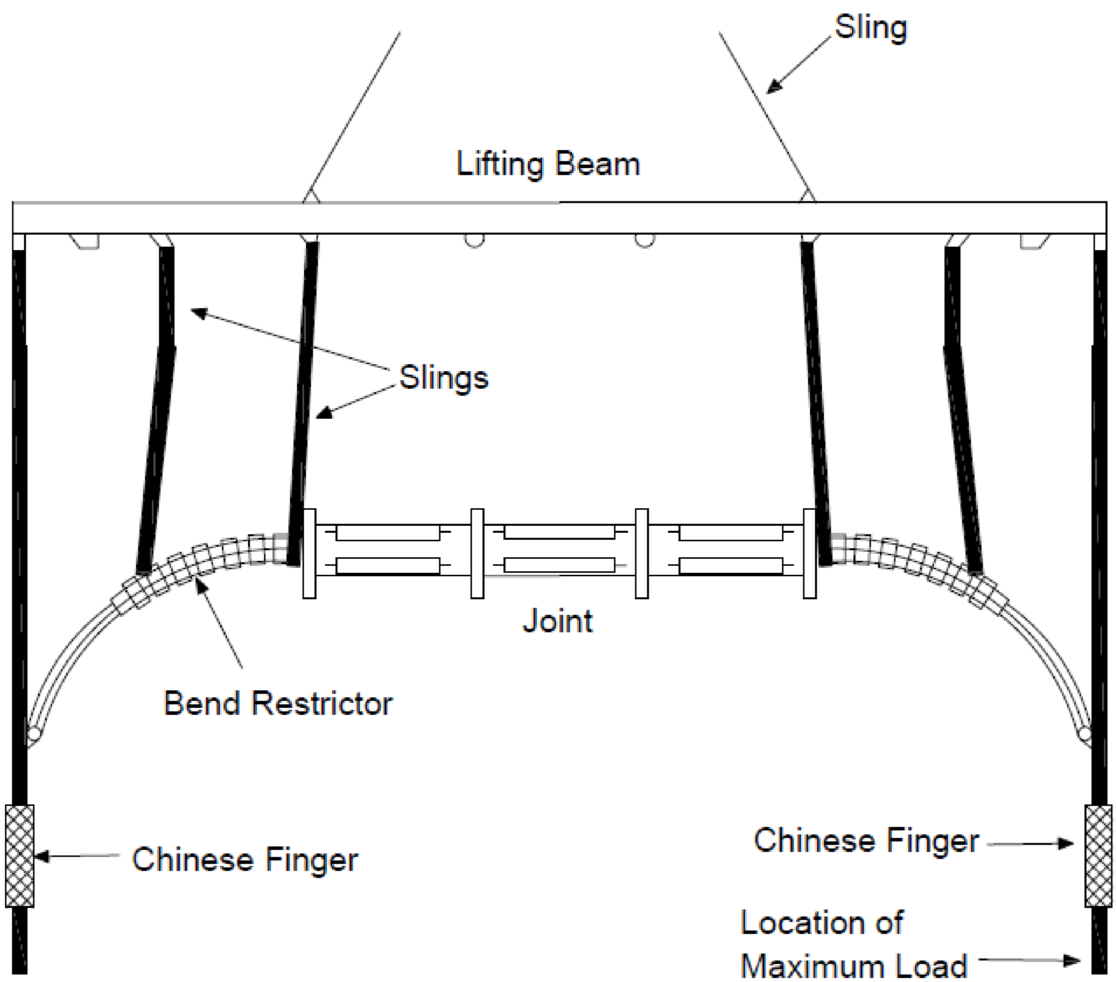

Figure 16: Location of maximum load

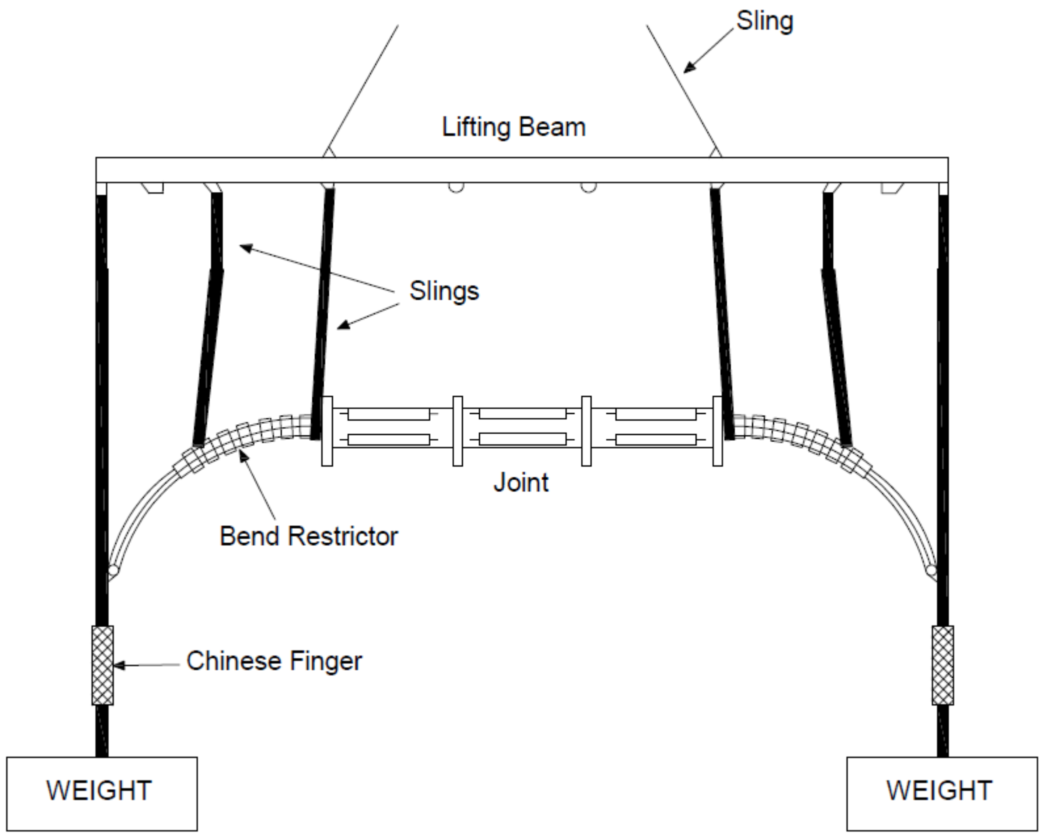

Figure 17: Offshore field joint deployment rigging arrangement for Omega laying (Hanging position).

8.0 Testing Concept for Omega Laying

The installation rigging arrangement shown in Figure 18 was proposed by the installation contractor. Therefore, for the purposes of the onshore simulation the same dimensions are made as per the installation contractor's arrangement shown in Figure 18 . In this figure, the distance between the chutes is **M**, the length of the offshore field joint is **L** , the radius of the roller way is **R** and the distance between the field joint and the roller is **X** .
In order to mimic the same conditions during the lifting operation on the vessel, the cable is bent horizontally before the lifting stage. The cable is bent 4 m after the joint housing. Noting that during the lifting operation, bending will occur in the vertical plane.

The Omega deployment is simulated via three procedures as follows:

1. Joint lifting: Lifting the joint from the initial position to the hanging position. The offshore field joint is lifted using the crane in the same way the lifting/ rigging arrangement will be used offshore. The lifting is shown in Figure 17.
2. Stress loading: Each cable end is connected to block weights with this load having been determined from finite element simulations. Then lifting of the entire set-up takes place.

Free rotation of the cable is prevented by welding the cable ends as illustrated in Figure 19 and Figure 20. After lifting, the load is maintained for 15 minutes.

3. Laying down on ground: Laying down the joint on the ground is performed as per the offshore procedure. In this step, the cable ends are kept fastened to eliminate torsion as shown in Figure 19.

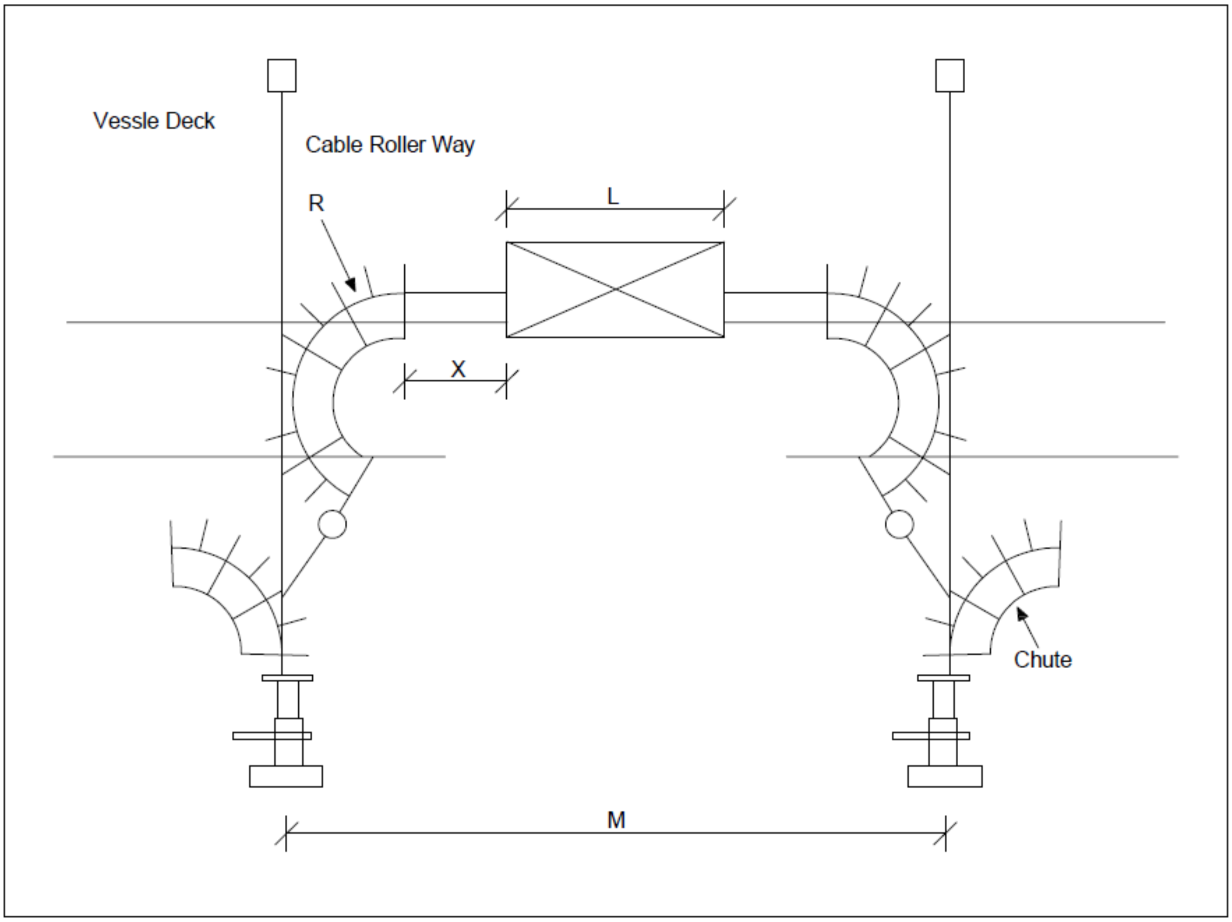

Figure 18: Offshore field joint arrangement on vessel (Plan view).

In summary, the simulated mid-line Omega procedure consists of two separate types of tests:

- Mechanical stress test. This includes tensile force, bending, torsion and rotation of the joint during lifting.
- Non mechanical investigation/checks.

Table 2 summarizes the mechanical tests, which can be applied during the onshore simulation to mimic the offshore deployment procedure, in order to ensure that the mechanical integrity of the joint will not be jeopardized.

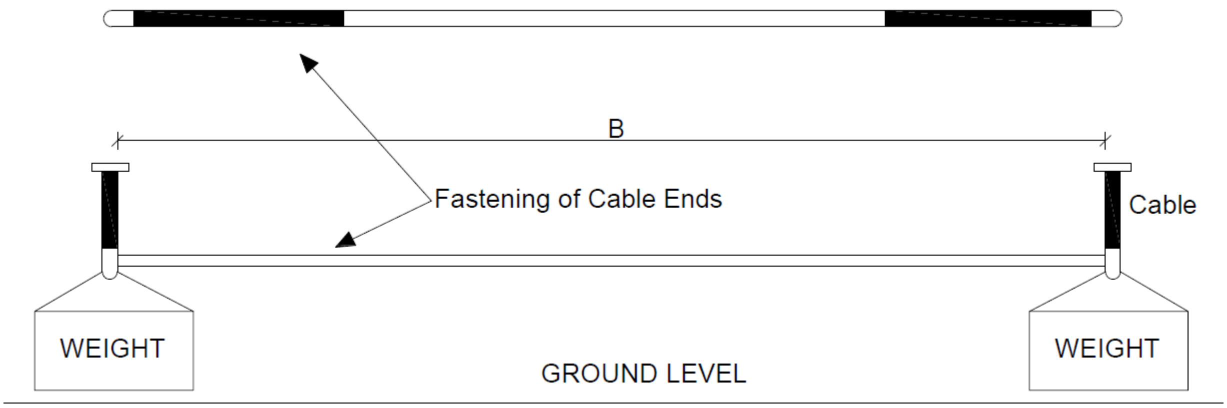

Figure 19: Top and front views with end fastening (with center welding point)

Figure 20: Fastening of the cable end

Table 2: Summary of Mechanical Tests applied during offshore field joint deployment.

Installation Procedure	Mechanical Stress	Values Applied	Remarks
Omega	Tensile Force	blocks with weights equivalent to the loads obtained from finite element analysis (hold for 15 minutes)	Force by hanging load
	Bending	Approximately 90 degrees by lifting and laying down	Stresses are identical to offshore lifting / deployment procedure.
	Torsion	Torsion of the cable is prevented	Cable laid on the seabed will eliminate torsion
	Rotation of joint during lifting	No rotation due to the use of slings with choker type of lifting offshore field joint	Stresses identical to offshore lifting / deployment procedure.

Noting that before, during and after the simulations the attenuation of the fiber optic cable is measured and recorded. During the simulation, the torsion of the cable especially at the end of the bend restrictors is monitored. In case the torsion is greater than the allowable value, an additional load cycle is to be applied to the joint. Upon the completion of the simulation, the movement of the cable at the armor pot is measured. In case of movement beyond the allowable limit, an additional load cycle is to be applied to the joint.

Finally, the joint is dismantled carefully to investigate the inside components to ensure that there is no sign of movement. Furthermore, a water penetration test for the pre-molded joint is conducted, with the pre-molded joint having been taken out of the steel casing of the joint. Other investigations are carried out to test the joint after the simulations. All the tests and the corresponding acceptance criteria are discussed in section 9.4.

9.0 Overview of Test Procedure:

9.1 Installation

1. The offshore field joint is installed in a straight arrangement as shown in Figure 18. During the installation, the inner cores of the joint are marked in order to assist in detecting any axial movement, twisting or displacement associated with the cable cores which may take place during the deployment simulation. Additionally, the outer yarn at the armoring pot is marked to detect any axial or angular movements of the cable at the armor pot position.

2. Both armoring cable ends will be terminated by a pulling eye.
3. After installation, the cable ends are bent by 90 degrees to obtain the same condition as that on the offshore vessel. This is shown in Figure 21.

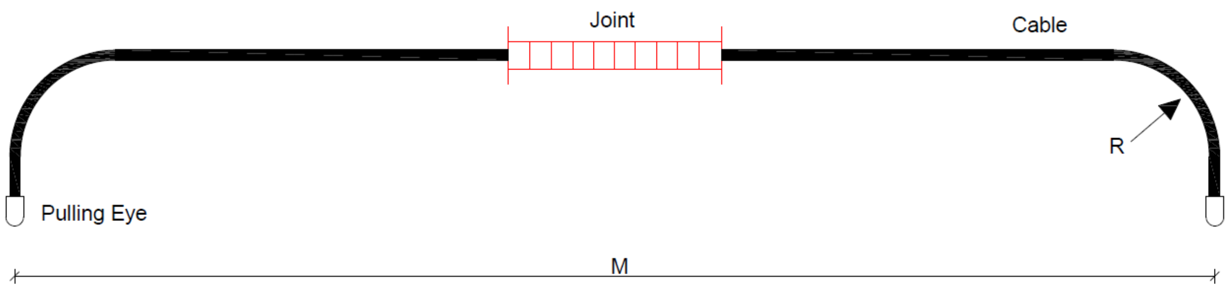

Figure 21: Cable-joint arrangement after installation.

9.2 Tests Required during Deployment Simulation

Steps for these tests are briefly outlined below:

1. Use the crane to lift up the beam. The lengths of fastening slings by the turnbuckles are adjusted until the final position is achieved as highlighted in Figure 22. During the simulation/test, the fiber optic loop attenuation is continuously measured.
2. Throughout the test, the torsion of the cable is to be checked by taking a straight line marked on the cable surface as shown in Figure 23.
3. Once the final hanging position is achieved, additional weight is added to achieve the final load (below the Chinese finger) at each side of the cable. The final load is equal to the load obtained from the finite element analysis (refer to Figure 18).
4. When the configuration is in the free hanging position as shown Figure 22, this position is kept for 15 minutes during which the torsion is measured. If the torsion at the end of the bend restrictor is greater than the allowable limit in circumference, then three heating voltage test cycles is to be performed as per [15] before conducting the test specified in section 9.3.
5. In order to mimic the deployment of the Omega joint, the stages shown in Figure 24 to Figure 27 are to be followed until the joint housing is laid on the ground. Once the joint housing reaches the ground, all slings are to be disconnected. The fiber optic attenuation test is then stopped.
6. Start the tests detailed in section 9.3.

9.3 Non Mechanical stress tests

1. Once the joint housing is placed on the ground, the following tests will be undertaken as per Table 3. The field joint housing and bend restrictor are inspected visually for any signs of damage or cracks.
2. The bend restrictor is then opened. The movement of the cable at the armor pot location is measured and compared with the measurements taken before conducting the simulation.
3. If the movement of the cable at the armor pot location is greater than the allowable limit in circumferential, then three heating voltage test cycles will be performed as per [15] before conducting the test specified in section 9.3. After the completion of the mechanical tests on the Omega joint, the offshore field joint is dismantled and inspected.
4. The offshore field joint is carefully dismantled and the inner cables and the pre-molded joint is freed from the compound filling without any additional significant bending or mechanical stress being applied.
5. The following tests are performed:
    a. The axial and circumference displacement of the cable cores are measured and recorded.
    b. The plumbing area located between the cable lead sheath and copper housing is visually examined for any cracks or deformations.
    c. At one pre-molded joint, a water pressure test is carried out to investigate the tightness of the pre-molded joint after the deployment simulation. The test is performed similar to that described in [6]. The end of the cable is sealed by metal covers, and the joint is placed in salty water in a pressurized vessel.
    d. After 24 hours, the joint is released from the water, and inspected for any water ingress and damages.
    e. A dimensional check is performed on the pre-molded joint.

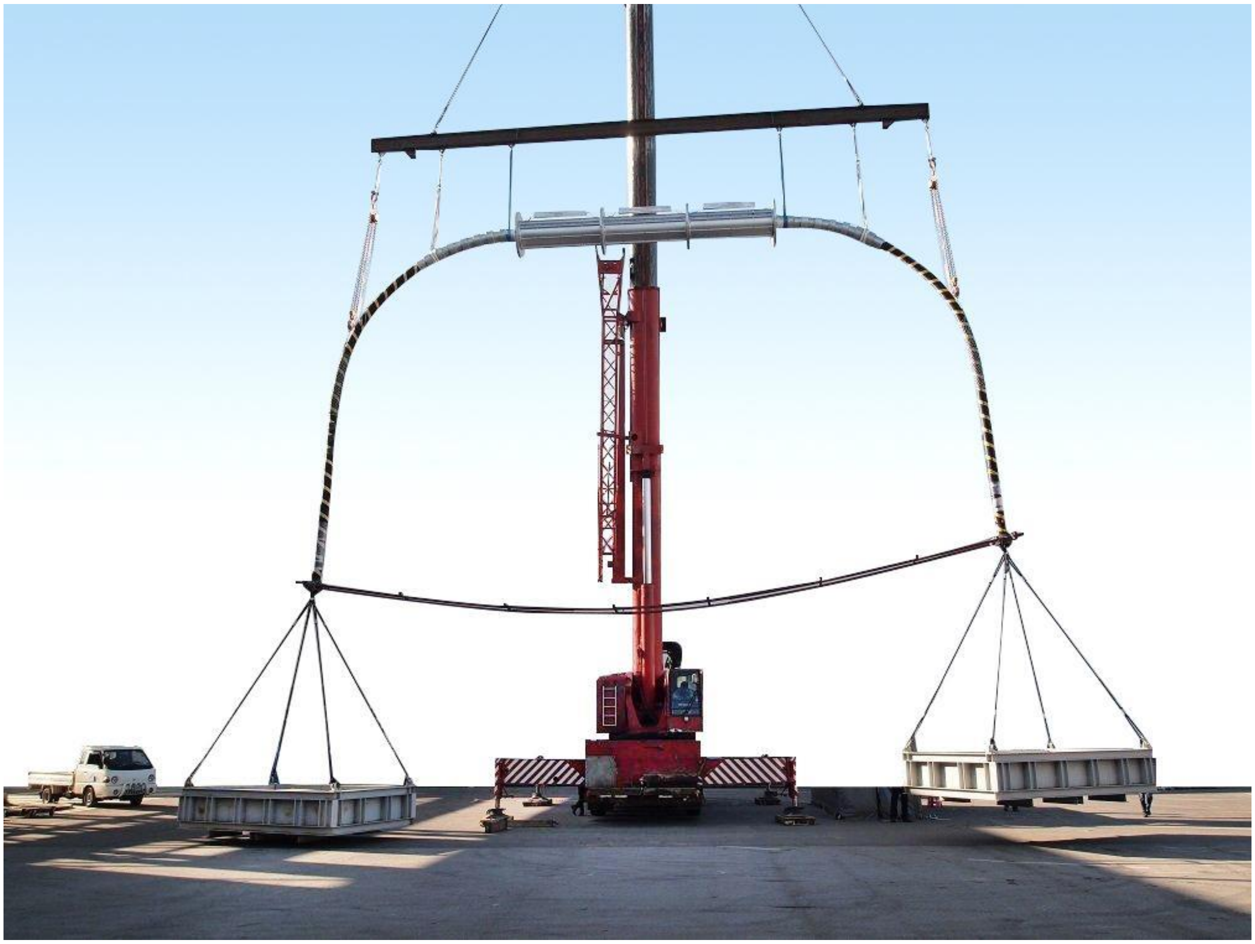

Figure 22: Final hanging position for mechanical stress Tests (free hanging with additional load)

Figure 23: Marking on Cable

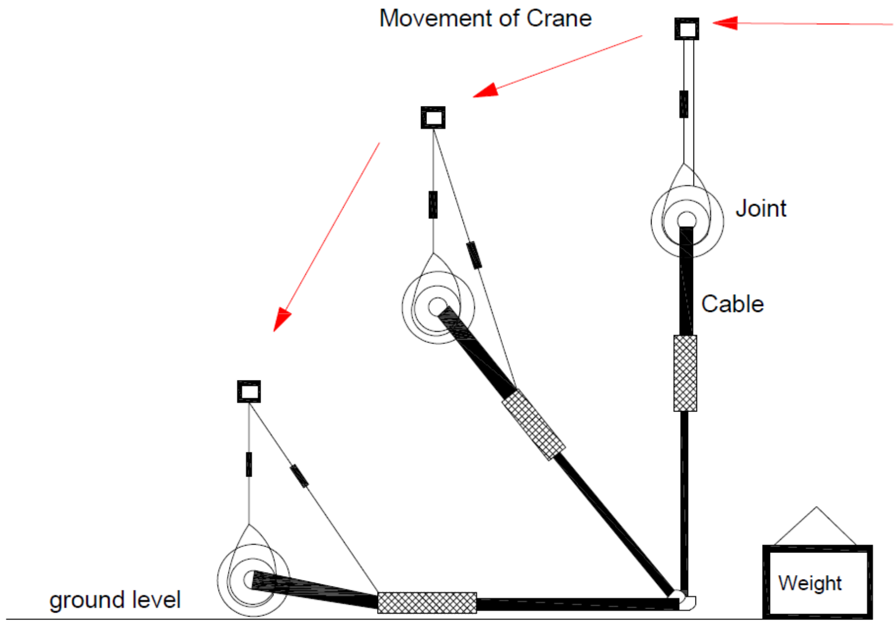

Figure 24: Deployment of offshore field joint (3 stages combined)

Figure 25: Deployment of the joint- stage-1

Figure 26: Deployment of the joint- stage-2

Figure 27: Joint on the ground-stage-3.

9.4 Mid-Line Omega Test Plan and Acceptance Criteria

Table 3 presents the tests performed during the deployment simulation as well as after the completion of the onshore deployment simulation in addition to providing the acceptance criteria for each test.

Table 3. Summary of mid-line Omega test plan & acceptance criteria

Test	Acceptance Criteria
1. **Fiber optic attenuation test** Continuous fiber optic attenuation check during the test	Ensure that the increase of the attenuation before and after the test remains within the allowable limits.
2. **Torsion measurements of cables** Check the change of the torsion angle at the straight line marking between the bending restrictor and the pulling eye as shown in Figure 23 for : • Before lifting • After lifting • After loading • After deployment	No cable rotation during the test larger than the allowable limit at the end of bending restrictor. If yes, then three heating voltage test cycles is to be performed as per [15] before conducting the test specified in section 9.3.
3. **Visual Checks** Visual inspection for housing, armor pot as well as bend restrictor.	No visible cracks or deformation
4. **Measurement of external displacement of cable at armor pot (axial and angular-angular is measured in circumference displacement)** This test is to be carried out after the completion of the simulation	No displacement caused by the test (axial and circumference movement) If yes, then three heating voltage test cycles is to be performed as per [15] before conducting the test specified in section 9.3.
5. **Leakage Test** Leakage test on one pre-molded joint including the plumbing areas, 24 hours water pressure test.	No water inside the joint.
6. **Visual check of plumbing area** Visual check of the plumbing area. The plumbing area is located between the copper housing (three joints) and the cable sheath.	-No visible crack. -No hole in the plumbing area. -No visible gap between plumbing, lead sheath and copper housing
7. **Dimensional check on pre-molded and OFJ used**	Dimensions are in accordance with the manufacturing tolerances and drawings.

Conclusion

This paper summarizes a rigid cable joint onshore testing scheme for Omega deployment. The proposed testing scheme can be employed to confirm that the integrity of the offshore field joint during the deployment process will not be compromised.

The proposed testing platform uses the design loads, determined from finite element analysis, to qualify the joint in air. When the load tests are applied, the joint will be subjected to a water penetration test. This testing technique offers an alternative to sea/offshore trials.

The on-land simulation can be used to mimic the corresponding mechanical forces and handling of the lifting equipment for the "Omega-laying" procedures.

The objective of the test is to ensure that the offshore joint combined with the bend restrictors and the cable can accommodate the installation loads that arise during the deployment operations. The paper presents a testing plan which should be conducted onshore to replace the sea trials in order to validate the design of the field joint as well as to prove that the design is fit for the intended purpose.

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