ICOE 2018 12 / 14 JUNE CHERBOURG FRANCE

Analysis of mooring line failure in real sea conditions

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Abstract- Prior to open sea trials, mooring system design is a major concern for technology developers. The main focus for designer engineers is to ensure that the extreme forces experienced during exceptional weather conditions are adequately taken into account. Consequently, as these are seen as the main enemies of the system, calculations based on such forces form the basis of on-paper design work.

However, five-year's practical experience at BiMEP test site shows that mooring systems do not usually fail due to their reaching, or exceeding, the maximum stresses they could theoretically withstand. Having analysed the behaviour of several single mooring marker devices deployed at BiMEP, it can be observed that there are other reasons for mooring line failure. Primarily, these are related to the choice of material, component selection, design geometry and the installation process.

Placing insufficient importance on variables other than extreme forces at the design stage can be responsible for mooring line failure.

***Keywords*—**Test sites, mooring systems, failure, extreme forces.

I. INTRODUCTION

The potential for Marine Renewable Energy to make a significant contribution to Europe's energy mix is well recognised. As the sector moves from the prototype stage to pilot and demonstration projects, the key challenge facing Marine Renewable Energy is lowering the cost of energy generation [1].

The creation of open-sea facilities responds to the need for developers to test their devices and ancillary equipment in real sea conditions. Test facilities help to reduce demonstration costs, technological risks and uncertainties by providing on-site monitoring and testing infrastructures [2].

The Biscay Marine Energy Platform (BiMEP) is one such facility, set up to support research, technical testing and commercial demonstration of pre-commercial prototype utility-scale floating MREDs [3, 4]. The project started in 2007 with a conceptual study and the selection of the most appropriate coastal location. Situated on the Basque coast, Armintza was found to offer favourable wave conditions for the testing of devices and relatively low exposure to potentially damaging extreme waves.

Fig. 1 Location of the BiMEP Test Site

BiMEP occupies a 5.3 km^2 marked-off area with restricted maritime access, and is located 1,700m (at its minimum distance from shore) close enough for fast access. The total power handling capacity of the installation, 20 MW, is distributed through four offshore connection points of 5 MW each.

The connections to its onshore substation are made via dedicated three-phase undersea cables linked in series with three-phase land lines, all at 13.2 kV. The onshore electricity substation houses electrical protection systems, measurement systems and two transformers, allowing any electricity generated to be eported to the national power grid. The four connection points are fitted with commercial power and fibre optic connectors to enable swift connection and disconnection of MREDs, thus reducing offshore work time as far as possible [5].

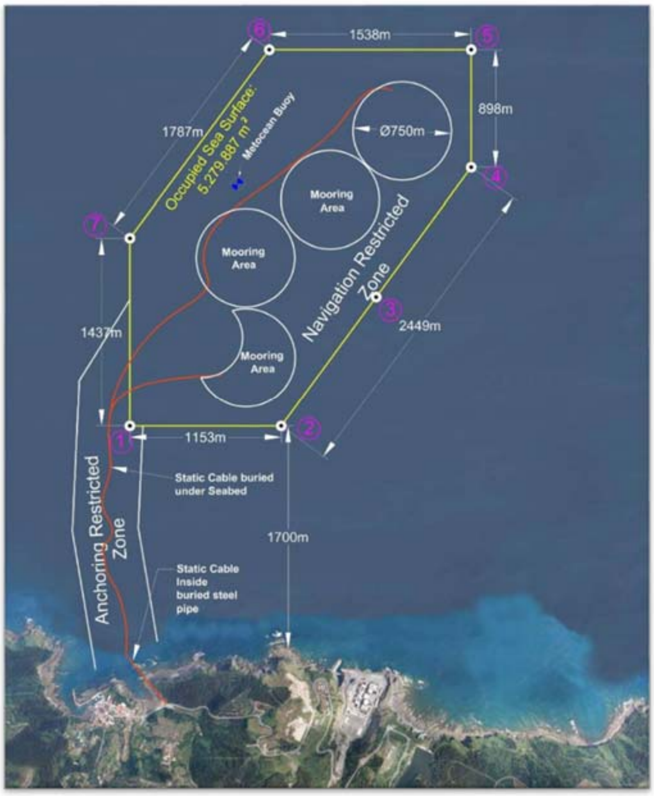

Fig. 2 Main elements of the BiMEP test facility

II. PROBLEMS WITH MARKER DEVICE MOORINGS

A. Subsea connectors marker buoy moorings

As mentioned above, each undersea cable terminates with a dry-mate connector, which is marked with a floating buoy. The mooring system of the floating buoy is used for the connector recovery manoeuvre whenever a connection or disconnection operation is required. This is designed to ensure buoy floatability and stability of position, while allowing for the lifting of the subsea connector and part of the undersea static cable.

Mooring description:

The mooring system is a combination of wire rope and chain that connects the floating buoy with an anchoring mechanism, in this case a sinker on the seabed.
The design of the berth depends on the mooring location water depth.
The specifications of the 1066 IALA Guidance for the design of floating aid to navigation moorings were followed for the design of the mooring systems [6].
The mooring system consists of:

- One buoy Ø1150mm and 276kg
- One steel sinker of 1,5Tn
- 20mm wire rope
- 26mm stud link anchor chain
- Shackles
- Swivels
- Master links
- Connector sling

The length of the first section of 20mm wire rope, the riding wire rope, (see Figure 3) varies between 55 and 85m, depending on water depth at the location.

B. Perimeter marker buoy moorings

The open sea area occupied by BiMEP is marked by seven perimeter buoys, whose main function is to delimit the zone where navigation is prohibited (see Figure 2). In this case, the single line mooring system is designed to ensure buoy floatability and stability of position.

Mooring description:

The mooring system is a combination of different sections of chain that connect the floating buoy with an anchoring mechanism, in this case a sinker on the seabed.
As for the subsea connector marker buoys, the design of the mooring system depends on water depth at the mooring location and consists of:

1. One concrete sinker of 6Tn
2. 36mm riding chain
3. 48mm ground chain
4. Kenter shackles
5. High resistance shackles
6. Swivels
7. One buoy Ø3m, 5.55m high and 2622.94kg

The length of the 36mm riding chain (see Figure 4) varies between 27.5 and 82.5m, depending on water depth at the location.

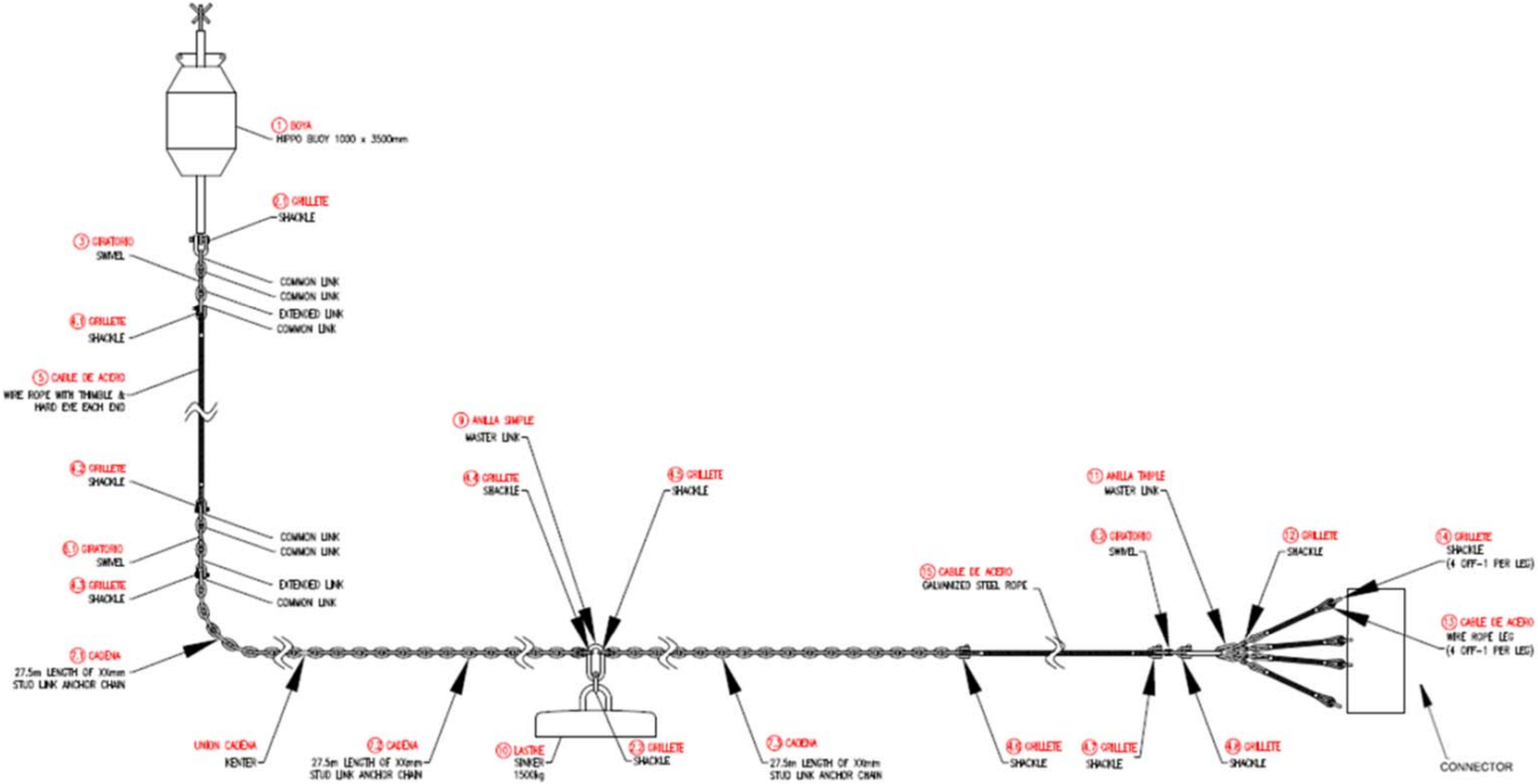

Fig. 3 Subsea connector marker buoy mooring system

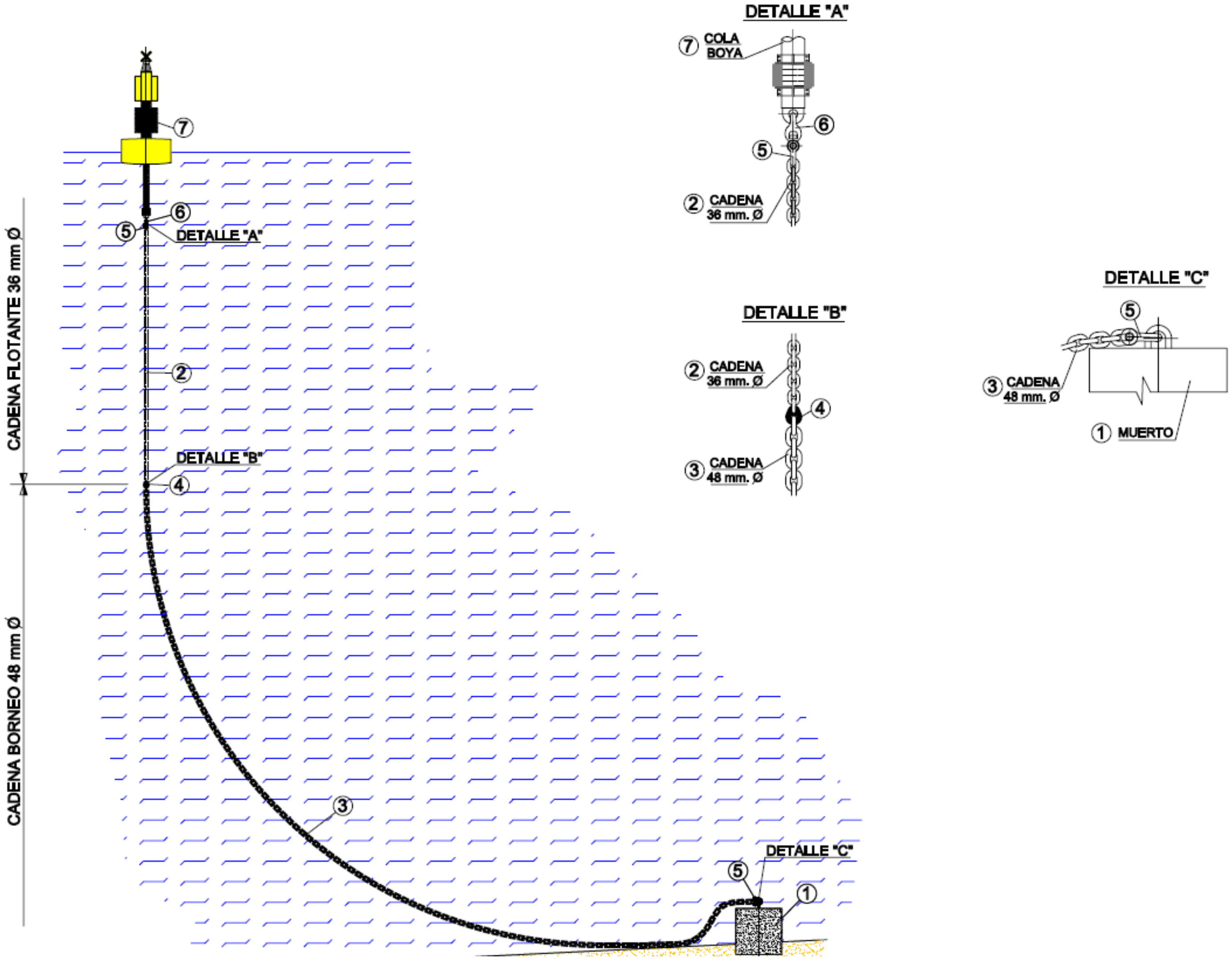

Fig. 4 Perimeter marker buoy mooring system

C. First problems

The laying of the four subsea cables and their corresponding connectors took place in September 2013. During the first winter three of the four subsea connector marker buoys broke their moorings. These were all recovered and reinstalled in spring 2015. However, in the following months the four connector marker buoys broke their moorings and by spring 2016 no buoy was in place. This complicated and seriously extended the lifting works of subsea connector number 4, and consequently the connection operation of the MARMOK-A5 device that took place at that time.

Fig. 5 Connector marker buoys that had broken their moorings found along the French coast

Regarding the perimeter marker buoys, the mooring lines of four failed up to five times in five years, causing the buoys to lose position. With the exception of one badly damaged buoy that was found in a coastal cave, the others were tracked by BiMEP's surveillance team and recovered by tug-boats based in the surrounding area without causing any damage to navigation.

III. FAILURE IDENTIFICATION

The repetitive loss of marker buoys suggested that a major problem was affecting the mooring systems. Consequently, a comprehensive investigation into the possible causes behind the failures was undertaken.

After recovering the subsea connector marker buoys, visual inspection revealed that all the wire ropes appeared to be suffering the same problem of corrosion. To verify this, Tecnalia's technical services division was engaged to carry out an analysis of the end loop locking sleeve. Their subsequent report revealed that the end loop locking sleeve was made of aluminium, and that it had suffered galvanic corrosion in service, i.e. an inappropriate material had been used [7].

Fig. 6 Aluminium locking sleeve showing corrosion evidence

However, in the case of the perimeter marker buoys there were no signs of corrosion. The analysis that was carried out to identify the reason why the mooring lines had broken shows that in all cases one of the Kenter shackles had opened up or broken. This led to the investigation of Kenter shackles in mooring lines finding that while these are normally used for linking sections of chain, their use is discouraged for permanent mooring lines where long term corrosion and wear issues could occur [8]. In addition, even though the riding chains were dimensioned according to the water depth at the location, it was found that the damaged Kenter shackles were located at points where they continually struck the seabed due to the action of waves, wind currents and tidal range. In other words, the design geometry of the mooring lines took into account average water depth at different locations but failed to take into account the variations caused by waves, wind currents and tidal range. In addition, it was also found that some mooring lines were not working correctly for two different reasons. Firstly, although the mooring line installation operation had apparently been carried out successfully, inspection dives found that the ground chain had wrapped itself around the sinker during descent, effectively shortening its length. This went undetected until the loss of the buoy was investigated. Secondly, bad winter weather conditions had prevented buoy cleaning operations from being carried out. As a result, chain weight combined with biofouling overloaded the system making it unable to work as it should have done.

IV. IMPLEMENTED SOLUTIONS AND MEASURES

In view of the results from the analysis of the material used in the subsea connector marker buoy mooring lines and considering that both wire rope sections of each mooring system (all 8 wire rope sections) would suffer the same deterioration, it was decided to replace them all. The solution chosen mixed innovation and tradition, consisting of 18mm Dyform ropes married with plaited end loops. Dyform is an exclusive material specifically designed for use in marine environments with twice the sectional strength of conventional cable. Even though plaited end loops are little used today, they have a clear advantage in that the possibility of corrosion due to contact with other material is eliminated.

Fig. 7 Ground wire rope replacement operation

With respect to the perimeter marker buoys, the design geometry of each of the mooring lines was modified: the length of the ground chain was increased in order to make part of it work as riding chain, i.e. not in contact with the seabed, assuring that the link between chains is always floating and not being struck against it. In addition to that, the ground rope which had originally been made up of three 27.5m sections linked with shackles, was replaced by a bespoke 82.5m chain without any intermediate connecting shackles, so as to reduce the probability of failure.

V. CONCLUSION AND LESSONS LEARNT

The first lesson learnt from the experience is that in complex projects in hostile environments, the importance of details that may appear to be minor must not be underestimated. Such evident factors as extreme weather conditions are always going to be taken into account when designing mooring systems, but this should not be done at the cost of the more minor aspects. In our case, if more consideration had been paid to the end loop sleeve material used in the mooring systems, the subsea connector marker buoys may not have broken free. In addition, the mooring lines of the perimeter buoys were designed according to the i-forms to resist extreme loads, but waves, wind, currents and tidal range influenced mooring line movement, causing some linking shackles to strike against the seabed eventually leading to fatigue breaks in the mooring lines.

Our experience also shows that existing technology and materials on the verge of being phased out can continue to serve when combined with incoming solutions. More specifically, the corrosion problems found in the wire ropes were solved by replacing them with a symbiotic solution that combined the tradition of plaited loop outs and the innovation of Dyform ropes.

In addition, in order to detect any irregularities such as the mooring line wrapping itself around the sinker, a supervised installation of the system is crucial for respecting design geometry and the correct functioning of all components.

The operation and maintenance of devices installed in open sea is always challenging and can sometimes be delayed or even made impossible in the worst cases. For this reason, it is important to carry out preventive maintenance operations, specifically those related to biofouling, to avoid overloading the structures and components to the point that they may fail.

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