THE CLASSIFICATION OF PIPE-LAY VESSELS AND HEAVY-LIFT CRANE VESSELS

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SUMMARY

Pipe-lay vessels, heavy-lift crane vessels and dual purpose heavy-lift and pipe-lay vessels are distinct in many ways from other types of ships or offshore units. The unique functions that these vessels carry out can impact directly on the overall safety of the vessel, the personnel on-board and the potential to pollute the environment. This paper outlines some of the hull and machinery safety assurance considerations for classification and design pertinent to pipe-lay and heavy-lift operations. The considerations that are discussed in this paper include the implications of classing the vessel as a ship or an offshore unit; the interaction between classification and marine warranty; general arrangement; station-keeping; structural assessment and the interaction between safety critical systems. Specific hazards for pipe-lay vessels and their use of chemicals on-board are also discussed.

1. INTRODUCTION

Pipe-lay vessels and heavy-lift crane vessels are without a doubt both interesting vessels to design because the naval architect and marine engineer must go beyond their classic lectures in ship design. The North Sea would certainly be a very different place without such vessels; there would arguably be very few subsea pipelines, and decommissioned platforms would be abandoned rather than removed. This paper outlines some of the safety assurance considerations for classification and design which are unique to the functions or missions of these vessels. The reader may wonder why these two distinct vessel types are covered in one paper; this is because there are a small number of heavy-lift crane vessels which also carry out pipe-laying. This helps the owner to maximise usage of the vessel. The designer of such vessels has to simultaneously address the safety of both missions at the design stage. However these missions are unlikely to occur simultaneously and so these vessels may have pipe-lay equipment which is not permanently installed i.e. it is installed as and when it is required, and removed thereafter. Where this is the case, all modes of operation with and without the pipe-laying equipment fitted are to be approved by the class society.

Although directly related, the safety assurance of pipe-lay equipment and offshores cranes is not considered in this paper.

In relation to classification, this paper makes specific reference to the approach and rules of Lloyd's Register, being the first class society to publish dedicated rule requirements for pipe-lay vessels and heavy-lift vessels. However, the general principles are relevant to all class societies operating in this sector.

2. CONSIDERATIONS COMMON TO BOTH VESSEL TYPES

2.1 SHIP OR OFFSHORE UNIT

Historically Lloyd's Register, who has classed many pipe-lay vessels and heavy-lift crane vessels, has classed some as ships, but others as offshore units (for example the Seven Arctic heavy construction and flex-lay vessel owned by Subsea 7 was classed as a ship in 2017, whereas the Sleipnir heavy-lift crane and pipe-lay vessel owned by Heerema Marine Contractors was classed as a mobile offshore unit in 2018). This may sound inconsistent but there is good logic behind this which is useful to discuss. Ships are designed to rules for ships whereas offshore units are designed to rules for offshore units. Therefore, the decision of whether to class as a ship or as an offshore unit comes down to the choice of which rules to use. Rules for offshore units (Lloyd's Register, July 2018) provide a more stringent basis of design for the hull (50-year return period loads and 25-year minimum fatigue life compared with, for ships (Lloyd's Register, July 2018): 20-year return period loads and no compulsory fatigue assessment).

Since pipe-lay vessels and heavy-lift crane vessels do not carry out missions in heavy-weather and are able to abandon missions, in theory designing to rules for ships should provide adequate safety for the hull. This is certainly the case where the vessel is a mono-hull barge or ship. Here, either rules for ships or rules for offshore units can be used and it is for the owner to decide which is the best option taking into account the financial implications of the decision on CAPEX and OPEX. However, where the vessel is a column-stabilised semi-submersible, has twin hulls or is a jack-up (e.g. jack-up heavy-lift vessel) the vessel must be classed as an offshore unit using rules for offshore units. This is because the specific structural assessment requirements for the hull configurations of these vessels are only covered by these rules and are not considered in rules for ships. The latter are limited to assessing a hull globally as a beam and locally as stiffened panels. This approach is not sufficient alone for twin hull or jack-up configurations. It is the role of the class society to ensure that the rules chosen are appropriate for the particular design. Where there is a choice between rules for ships or rules for offshore units then the deciding factors to consider are as follows:

2.1 (a) Building to rules for ships

This would result in lower CAPEX because the hull would be lighter in steel weight due to lower design loads and potentially lower corrosion additions. Rule corrosion margins assume 20 year service life. If the owner is looking to operate the vessel for 20-40 years (which is certainly the case for many bespoke vessels) then the owner would need to consider and specify owner's extras, otherwise increased OPEX will come later in life from the necessity to carry out steel renewal which may be extensive. CAPEX would also be reduced by quicker design and approval. The absence of a fatigue assessment and the need to locally strengthen and improve connection details in order to meet fatigue requirements would shorten the design process considerably in addition to saving weight and fabrication costs. However, with the absence of a fatigue assessment combined with a lighter hull, the owner runs a higher risk of expensive OPEX necessary to address any fatigue cracks in-service.

2.1 (b) Building to rules for offshore units

This would result in higher CAPEX because the hull would be heavier in steel weight due to higher design loads and potentially thicker corrosion additions. Rule corrosion margins are calculated specific for the service life, which can be of any duration but no less than 25 years. CAPEX would also be increased by a longer design and approval duration. Revising a design to meet fatigue requirements may take between six months to a year alone. Detail design for fatigue resistance introduces extra costs for fabrication and survey. Accidental load cases would also be considered in great detail, often requiring expensive consultancy studies. However, with the extra design upfront and a heavier hull, the OPEX should be tangibly lower.

2.2 GENERAL ARRANGEMENT

The general arrangement of the vessel has to permit safe operation and evacuation. It is preferable to divide the vessel into functional areas which are separated and protected from each other. The main functional areas are:

- Areas for pipe-laying operations and pipe-storage.
- Areas for crane operations, including areas for laydown, cargo securing and storage of equipment.
- Areas for main and auxiliary machinery.
- Living quarters area.
- Areas for evacuation including lifeboats.

Furthermore, as persons falling from height and dropped objects falling onto persons, e.g. pipe runs, have led to serious injury on these vessels, the vessels should be designed to have preventive measures to protect personnel from such hazards. Such measures can include safety nets around the perimeters of raised work platforms to act as fall arrestors and colour coding areas of the vessel into zones, typically:

(a) Green Zone:
Area where there is a low risk of being injured by dropped objects.

(b) Yellow Zone:
Area where there is a risk of being injured by dropped objects.

(c) Red Zone:
Area where there is a significant risk of being injured by dropped objects.

2.3 CLASS OR MARINE WARRANTY

Pipe-lay vessels and heavy-lift crane vessels are prime examples of vessels which at times require the involvement of a class society and a marine warranty surveyor (Note. A marine warranty surveyor may not always be required for vessel operations). The parties may be involved at different stages of the vessel's life or at times simultaneously in preparation for a particular mission. As a result of two different parties being tasked with looking at what can appear from a top level perspective to be the same thing (i.e. the integrity of the vessel), there is sometimes a lack of understanding of what the remit and responsibilities of each party are. The safe operation of the vessel is dependent on this understanding. Therefore, an essential consideration for the vessel is to establish who is checking what, when and why. This matter is further complicated by the fact that the marine warranty surveyor is normally working on behalf of insurers, with a different objective to that of the class society. The scope of the class society is generally fixed, whereas that of the marine warranty surveyor can vary considerably according to the particular operation.

The class society approves the strength of the vessel based on theoretical loading conditions. Once the vessel enters service, before each real operation the marine warranty surveyor will review calculations and procedures to confirm that the strength of the vessel will not be exceeded at any stage of the operation. Therefore, in order to reduce the possibility that the marine warranty surveyor encounters missions for which the vessel has inadequate strength, it is necessary for the class society to have considered representative, and preferably more onerous loading conditions at the initial design approval. The marine warranty survey may also extend to monitoring the loads at sea during the actual operation in order to confirm that they do not exceed those that the marine warranty surveyor has reviewed. The class society is unlikely to be involved in this stage and would only be notified in the event that loads have been exceeded and/or if damage to the vessel has occurred. The class society would have no involvement in the procedural aspects of a real operation e.g. manning levels, crew competence, monitoring environmental conditions, operational and emergency procedures. As such the class society does not approve actual operations.

In short, the class society approves load case envelopes for the extreme operational conditions and the marine warranty survey confirms that for a particular real operation, the loads fall within that envelope. Where a real operation is determined by analysis to be close to or exceed the class envelope then the class society must become involved in order to review the mitigation measures which may include temporary or permanent modifications to the hull to provide addition strength. Such structural modifications will need to be approved. Mitigation measures may also be procedural, e.g. limiting operations to fair weather conditions, which would be preferable to physically modifying a vessel. Provided appropriate procedural measures can be agreed between all parties directly involved in the operation (including the marine warranty surveyor), the class society need not be consulted for procedural aspects.

For vessels in service, the marine warranty surveyor is not responsible for checking that the hull is welded together correctly, is absent of cracks and defects, that the correct plate thicknesses are used and that the corrosion allowance has not been consumed. These are class issues which would be covered by the periodic class surveys.

2.4 STATION KEEPING

A class 3 dynamic positioning system is the preferred method of station keeping for new construction pipe-lay vessels and heavy-lift vessels. This system calculates forces from the wind, waves and currents acting on the vessel and the thrust required to balance them. Pipe-lay towers and heavy-lift cranes present significant areas exposed to wind. In order to calculate accurate wind loads on these structures, the positions of the pipe-lay tower and heavy-lift cranes (boom and slew angles) are required to be known and input into the control model. In addition to the environmental forces, pipe-lay vessels have a tension force acting on them from the pipe being laid. This force also has to be determined and input into the control model. The force will vary according to the type of pipe (rigid/flexible, pipe and coating thickness and material), the type of lay (S, J, reel or carousel) and the stages of the lay (pipe lay initiation, lay down and recovery).

Earlier designs of vessels may carry out operations with temporary mooring arrangements, in which case the mooring analysis also has to consider the pipe tension and wind loads on the pipe-lay tower and heavy-lift cranes.

2.5 INTERACTION BETWEEN SAFETY CRITICAL SYSTEMS

An important piece of work, which is worth mentioning here despite usually being outside of the remit of the naval architect and marine engineer is an assessment of the interaction of electrical, instrumentation, control and software systems for the cranes, pipe-lay equipment, dynamic positioning and other marine systems which often are running simultaneously. This is by no means an easy piece of work and because it requires open collaboration between the suppliers of each piece of equipment. The assessment would typically comprise the following stages:

- Identification of all elements (electrical, control, instrumentation and software) of the system, their internal interactions and interactions with other elements.
- Identification of operational scenarios including normal and degrade modes and what constitutes a safe state.
- Identification of software lifecycles.
- Identification of hazards.
- Assessment of risk.
- Deciding on control measures.
- Demonstration of adequacy of solutions.

3. PIPE-LAY VESSELS

3.1 HAZARDS

The process of laying pipes at sea by a pipe-lay vessel can be broken down into a number of stages or operations. These include pipe handling and transfer, bevelling, welding and cutting, NDT, repair, field joint coating, pipe-lay initiation and laying, abandonment and recovery. Pipe-lay operations are usually limited to fair weather conditions and so it is necessary for the vessel to be able to abandon the operations when heavy weather is forecast and subsequently to recover the pipe string and resume operations once the weather settles. The vessel may also need to recover and repair the pipe string if it becomes damaged during its lay, e.g. buckled. In addition to pipe-laying, some vessels are equipped to carry out pipeline pre-commissioning. Each stage of the pipe-laying and pre-commissioning process along with the storage of pipes, welding consumables and coatings brings with it its own hazards for the vessel, the crew and the environment e.g. NDT may involve the use and storage of radioactive isotopes. Some of the main hazards are discussed in the following sub-sections.

3.2 FIRE AND EXPLOSION RISKS FROM OXY-ACETYLENE CUTTING/WELDING PLANTS

Automatic gas metal arc welding is a preferred method of welding steel pipe runs to be laid from the pipe-lay vessel. Electrical welding systems would be designed consulting the national and international standards given in sub-section 6.1. Regarding pipe cutting, plasma is an option for cutting pipe thicknesses up to 25 mm, whilst for greater thicknesses oxy-acetylene cutting using compressed gas cylinders is used. An oxy-acetylene plant may also be used for welding. This sub-section discusses some of the safety considerations around oxy-acetylene plants.

Although national and international standards (examples listed in sub-section 6.2), which have been developed for land-based oxy-acetylene plants, exist for aspects of the plant e.g. pressure regulators and general fire safety, these need to be brought together and applied within the confines of the pipe-lay vessel. The role of the class society is to address this safety aspect, in particular the plant's piping, storage of cylinders and venting arrangements.

Acetylene can significantly increase the risk of fire and explosion on-board the vessel. This is a result of its high flame temperature (an acetylene/oxygen flame burns at about 3,500°C), its wide flammability range (from 2.5% to 81%) and its potential to explode when exposed to raised temperature, pressure or simply mechanical shock.

Mechanical shock can largely be addressed by storing the cylinders upright and well secured. Keeping the cylinders upright prevents them rolling around but also aims to prevent fire spread from cylinder to cylinder (at 98°C the pressure relief fusible metal plug on the top of the cylinder begins to melt which can release a torch). To limit the spread of fire from the outlet station (where the welding/cutting takes place) to the cylinders, outlet stations need to have safety devices (flash back arrestors) against backfire and gas backflow. Storing the acetylene and oxygen cylinders in separate locations can reduce the temperature of the fire as acetylene burns with around half the flame temperature in air compared with in oxygen. Unlike at a land-based plant, the cylinders may be stored at some distance away from the welding station. Therefore, pipes in between will need to be introduced. The welding station will operate at a much lower pressure than the respective pressures at the acetylene and oxygen cylinders. Most layouts adopt a high pressure pipe run from the cylinder manifold to a pressure regulator and then a low pressure pipe run from this regulator to the outlet station.

The selection of pipe materials is an important consideration for oxy-acetylene plants, specifically for the high pressure branch where seamless pipe rated to 300 bar is required (related to a maximum gas cylinder filling pressure of 200 bar at 15 °C). Rust and scale in steel pipes can be ignited due to friction from high velocity flow rates. This leads to a preference to use copper for oxygen-carrying pipes. Stainless steel may be considered provided the pipes are regularly purged to ensure there is no foreign material inside. However, pipes carrying acetylene can only be stainless steel because acetylene can react with copper producing explosive copper acetylide. The need for effective venting is emphasised by the wide flammability range of acetylene. Safety valves fitted at gas supplies must vent to a point on the open deck at least 3 m above the deck. Areas where plant piping is purged/blown-through during maintenance also need to be adequately ventilated.

Generating acetylene on-board is an alternative to using gas cylinders. Such a plant would need to be designed to accommodate the accelerations, hull deflections and angles of inclination of the vessel.

3.3 CHEMICALS ON-BOARD

Chemicals are often used for field-joint coating and pipeline pre-commissioning; where a pipe-lay vessel carries out these activities it will be necessary to bring such chemicals on-board, typically in offshore containers (portable tanks) that have been certified. It should be noted that the certification scheme for the container does not assess the adequacy of the means to secure the container nor the supports on the hull. These fall under the responsibility of the class society and hence the owner should notify the class society when it is proposed to bring containers on-board. Certified containers are required to be inspected annually by visual inspection and where necessary with NDT every four years. Therefore, where it is intended to keep a container on-board for more than one year, provision must be made in the general arrangement to ensure sufficient access around the container to allow its inspection and repair in-situ, including load testing of the lifting sets where these are present to raise or move the container to an accessible position.

Chemicals can bring the risk of pollution and create a hazardous work environment. Therefore, the designer must make provision to limit their spread on the vessel, and to prevent their discharge into the sea, e.g. equipment for mixing or distributing chemicals which require maintenance are to have adequate spillage catchment arrangements.

Alternatively, chemicals may be stored in tanks integral to the hull. Such tanks are usually coated carbon steel but less reactive materials may also be used. Corrosion margins for such tanks need to be determined on the basis of the corrosiveness and reactivity of the stored chemical with the tank material. Consideration has to be given to the nature of the chemicals being stored, including their corrosiveness, reactivity, toxicity and flammability. Good tank design will consider how to clean, inspect and if necessary repair the tank. Safety arrangements such as fire protection and venting are in general to comply with the IMO International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk.

3.4 STRUCTURAL ASSESSMENT

Pipe-lay operations are unlikely to govern the global strength of the vessel and so the hull can be designed by a traditional design wave approach. However, this assumption should be confirmed by a screening analysis supported by representative model tests to determine the effects of operations on the motions of the vessel. For certain, the local strength of many areas of the vessel will be governed by loads from the pipe-lay equipment and operations onto the hull. These loads may be amplified due to global hull girder deflections. The local strength of the hull and support structures will need to be assessed and be suitably reinforced in way of and supporting:

- Abandonment and recovery systems and arrangements, including winches, fairleads and sheaves for abandonment and recovery wire routing;
- Basket and reel carousels;
- Hang-off arrangements;
- Heavy lift cranes and other lifting appliances;
- Mooring attachments for attending pipe-carrier vessels/tender barges and supply vessels;
- Pipe-handling/transfer systems;
- Pipe-lay towers and ramps;
- Pipe storage equipment, arrangements and areas;
- Roller boxes;
- Systems handling in-line and pipeline end termination or manifold structure;
- Stinger and stinger handling frames;
- Stations for pipe bevelling, welding, NDT, repair and field joint coating;
- Winches and tensioners.

4. HEAVY-LIFT CRANE VESSELS

4.1 STRUCTURAL ASSESSMENT

Lifting load cases for ships or offshore units with cranes not carrying out heavy-lifts are relatively simple to assess. This is because the load on the cranes does not give rise to significant stress beyond the crane pedestal interface with the hull. Therefore, only a local model of the interface needs to be considered. However, this is not the case for heavy-lift crane vessels where the loads due to lifting are so great that they extend into the hull far beyond the crane pedestal area. Many of the lifting cases may govern the global strength of the vessel which means that lifting cases have to be included in the global strength assessment. Heavy-lift crane vessels carry out a variety of different heavy-lift operations; these include the loading and offloading at quayside, the transportation at sea and the installation and removal offshore of jackets, connecting bridges, topsides, foundations, moorings and other structures. Some heavy-lift crane vessels are also equipped to install wind turbines offshore with modified cranes or dedicated handling equipment. The variety of operations gives rise to a significant number of operating conditions that could be critical for the strength of the vessel. In sub-section 2.2 it was stated that the class society approves load case envelopes for the extreme operational conditions. For heavy-lift crane vessels what are these limiting conditions? Regrettably, there is no shortcut to arrive at a definitive list, it is simply a case of producing a matrix of credible operations and carrying out a thorough process of whittling down the various load combinations until the most onerous have been identified and assessed. The global structure must be designed for all lifting and non-lifting modes of operation. As there are many variables and credible scenarios care must be taken not to inadvertently miss some critical conditions. The limiting conditions must be determined by considering:

- Single crane lifts and combined crane lifts (where more than one heavy-lift crane is installed).
- Lifts with maximum loads resulting from crane operations taking into account all significant load combinations, crane configurations, and crane positions (e.g. luffing angles, slewing angles). All combinations of maximum horizontal forces, vertical forces and overturning moments and slewing moments should be considered in relation to the crane load versus radius diagrams/charts.
- Crane lifts in sheltered water, shallow water and deep water and the effect on the motions of the unit, as applicable.
- The stages/sequence of crane unit operations, set-down and transportation.
- Limits of stability.
- The range of draughts and metacentric heights (GM). Note. Lifting at shallow draughts may result in higher global loads. A large GM may result in a higher pitch and roll accelerations with higher forces acting on the securing devices.
- Load cases with and without heavy payload on deck. Note. Load cases without heavy payload may have higher hydrostatic loads to maintain the same draught.
- The effect of wind heeling.
- Coupled dynamics of the unit, the barge from which the object is lifted and the object itself, as applicable.
- The type of objects to be lifted and whether the lifts take place in air, in water or through both.
- Survival and transit conditions including the transportation of payload on deck.
- Tank loading patterns.
- Float-on float-off loading conditions, if applicable.
- Roll-on roll-off loading conditions, if applicable.
- Skid-on skid-off loading conditions, if applicable.
- Any other foreseeable operational or emergency scenarios and related loads and loading conditions (e.g. gross overload, emergency load release).

As may be gathered from these loading conditions, the deck plating can be exposed to considerable wear from movement of cargo and cargo securing devices. Therefore, the owner should consider increasing the deck plating thickness to account for wear i.e. a wear allowance in addition to a corrosion allowance.

In recent times, heavy-lift crane vessels have been used for the removal and transport of jackets. Load cases which assess these operations must consider:

- All structural and non-structural jacket items.
- Rigging arrangements.
- The degrees of freedom at the jacket restraints.
- Spring stiffness for the jacket restraints, crane tips and boom.

In addition to the global strength assessment, a number of local strength assessments will need to be carried out for foundations and supporting structure to any major mission equipment, e.g. crane boom rests and hydraulic power units for pile hammers and grippers. Fixed cargo securing fittings and arrangements will also need to be assessed, e.g. jacket restraint structures for the securing of jackets for transportation.

4.2 RAPID BALLAST SYSTEMS

In order to carry out a crane lift more quickly (necessary for example to meet its weather window), the operator may use ballasting operations in addition to lifting with the winches (whose speed is limited). As such, ballast systems on heavy-lift crane vessels are designed for rapid filling and discharge. This may be achieved by installing piston valves which can dump water much faster than the flow rates seen even on the largest ships. Although unlikely to reach high stress levels, the strength of the foundations of these rapid ballast systems should be confirmed by calculation.

5. REFERENCES

1. Lloyd's Register *Rules and Regulations for the Classification of Offshore Units*, July 2018.
2. Lloyd's Register *Rules and Regulations for the Classification of Ships*, July 2018.

6. APPENDIX

6.1 STANDARDS FOR ELECTRICAL WELDING EQUIPMENT

The following standards assist the safe design of electrical welding plants for pipe-lay vessels and cover inter alia aspects such as power sources, torches and installation. Note. The reader should always check the validity of standards before use, noting they are subject to withdrawal and revision.

BS EN/IEC 60974-1 Arc welding equipment – Part 1: Welding power sources.
BS EN/IEC 60974-7 Arc welding equipment – Part 7: Torches.
BS EN/IEC 60974-9 Arc welding equipment – Part 9: Installation and use.

6.2 STANDARDS FOR COMPRESSED GAS UTILITY SYSTEMS

The following standards assist the safe design of oxy-acetylene welding and cutting plants for pipe-lay vessels and cover inter alia aspects such as storage, ventilation, signage, testing and materials selection. Note. The reader should always check the validity of standards before use, noting they are subject to withdrawal and revision.

BCGA Guidance Note 2 Guidance for the storage of gas cylinders in the workplace.
BCGA Code of practice CP7 The safe use of oxy-fuel gas equipment (individual portable or mobile cylinder supply).
BCGA Guidance Note GN11 Reduced oxygen atmospheres.
BS EN 730-1 Gas welding equipment. Safety devices. Incorporating a flame (flashback) arrestor
BS EN 1089-3 Transportable gas cylinders. Gas cylinder identification (excluding LPG). Colour coding.
BS EN ISO 7225 Gas cylinders. Precautionary labels.
BS EN ISO 7291 Gas welding equipment. Pressure regulators for manifold systems used in welding, cutting and allied processes up to 300 bar
BS 1710 Specification for identification of pipelines and services.
NFPA 51 Standard for the Design and Installation of Oxygen – Fuel Gas Systems for Welding, Cutting, and Allied Processes.
NFPA 55 Compressed Gases and Cryogenic Fluids Code.
ISO 2503 Gas welding equipment – Pressure regulators and pressure regulators with flow-metering devices for gas cylinders used in welding, cutting and allied processes up to 300 bar (30 MPa)
ISO 9090 Gas tightness of equipment for gas welding and allied processes
ISO 9539 Gas welding equipment – Materials for equipment used in gas welding, cutting and allied processes
ISO 14113 Gas welding equipment – Rubber and plastics hose and hose assemblies for use with industrial gases up to 450 bar (45 MPa)
ISO 14114 Gas welding equipment – Acetylene manifold systems for welding, cutting and allied processes – General requirements
IMO MODU Code 2009