DEEPWATER PLEM - Deepwater Pipeline End Manifold Design Challenges

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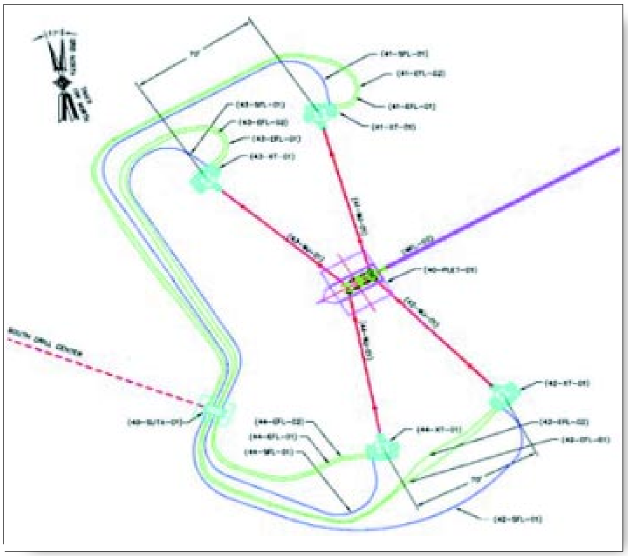
Pipeline End Manifold (PLEM) is one of a number of subsea equipment utilized in deepwater field development. PLEM is the item of subsea equipment which connects flowline and subsea facilities, i.e. subsea manifold and/or subsea tree. A water injection PLEM is used as the model for case study in this paper.

The paper will focus on the selected design:

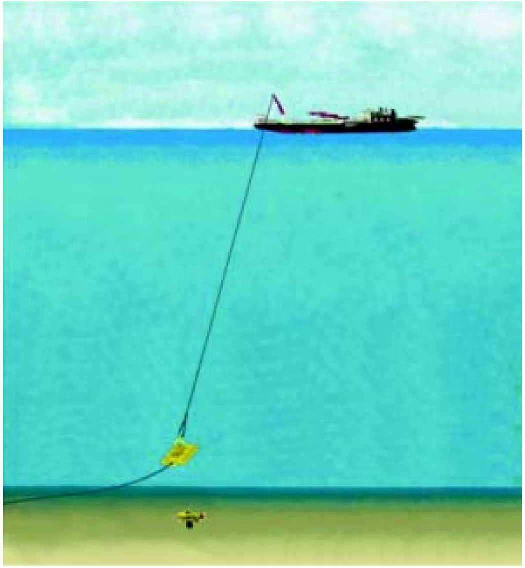
- Field layout architecture
- Installation
- In place
- Transportation and handling

The material derived from fundamental application of code and design practices to solve multiple design challenges in confirming PLEM design optimization.



Field Layout Architecture

The subsea development is based on four subsea water injection trees tied into flowline jumper to Pipeline End Manifold (PLEM) via through in-field pipeline that tied back from FPSO. The subsea layout comprises of a PLEM and well cluster arrangement trees; with rigid flowlines jumper connecting to the PLEM as well as the associated control system umbilical such as umbilical termination assembly and subsea distribution unit that distribute hydraulic and electrical flying lead to dedicated trees. The control system umbilical and PLEM is tied back to the FPSO. Since each drill center layout has been planned and determined in terms of location and layout arrangement challenges associated with PLEM design is normally related to installation considerations.

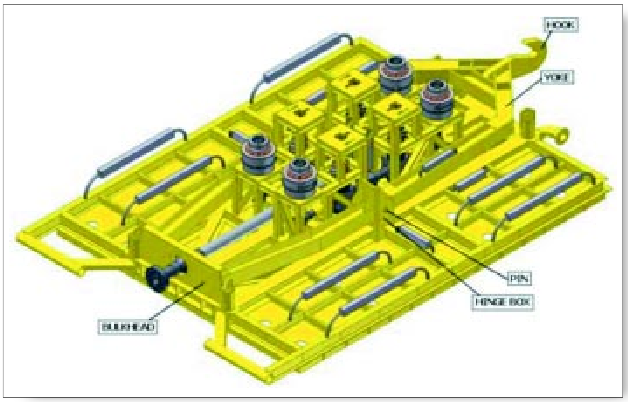


Deepwater installation barge must be positioned in the right coordinate and bearing position. Flowlines that tie in to PLEM must be laid down to the designated location of drill center during the installation process. Its crucial for the PLEM to land at the landing point and the distance between PLEM and subsea trees must be within the field layout requirement. Any dislocation of the PLEM will cause problems during the installation of the jumper connector. The PLEM piping and connector positions are designed based on field layout and also takes the number of trees into account.

Installation

During the installation of PLEM in deepwater environment challenges in defining loads of tension, bending, and torsion acting on the tie in and rigging point are based on flowline tie-in submerged weight all the way down to extreme water depths and barge movement during installation and the hostility of the environment.

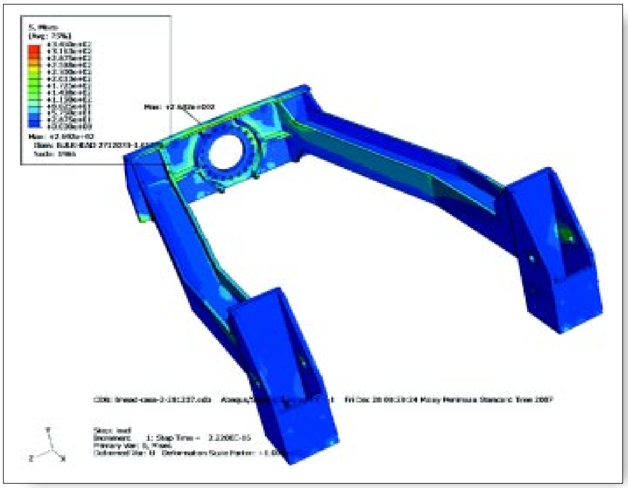
These scenarios will create a high tension, bending and torsion load during the installation phase. A special critical frame or structural components of PLEM has been designed to handle the loading. These frames are Yoke, Hook, Bulkhead and Hinge Box/Pin.



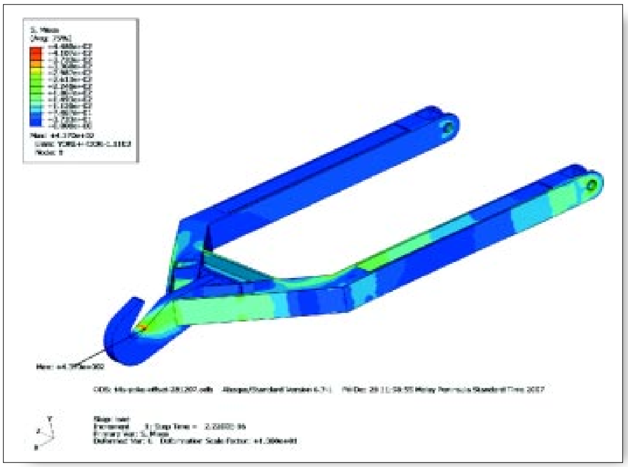
In the PLEM design these critical structures have to be designed such as to withstand extreme loads during installation. Multiple load arrangement has been checked in designing these critical structures. In doing so, structural analysis computer program and finite element analysis were executed using SACS and ABAQUS software to simulate a structural integrity under extreme loads conditions. Due to maximum installation loads, a couple of iterations on components

was conducted until design optimization was successfully achieved. Since these major structural components face high critical stresses during installation, the selection of material must be based on high strength and yield capability to handle the high stress.

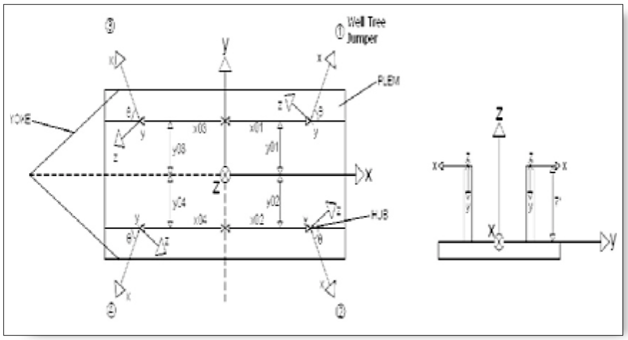
A part of the installation loads, another challenge in the PLEM design is to control the weight and center-of-gravity (COG). COG of the PLEM is positioned as close as the hinge box pin and PLEM geometric centre. During installation and laydown of the PLEM, excessive bending moment and torsion is bound to occur on the PLEM. By positioning COG at hinge box pin and geometric centre, we can eliminate torsion, twisting or moment effect that can damage structure and flowline connections. Due to these challenges, the PLEM structure and piping system has to be designed and arranged accordingly to achieve the desired COG position and geometric symmetrical center.



Controlling the weight in PLEM design is another installation challenge in terms of foundation geotechnical effect by PLEM during its installation on the seabed. A geotechnical foundation engineering study needs to be conducted in addressing the soil characteristic, landing impact, short and long term settlements. Special mudmat foundation should be designed against bearing capacity, sliding and torsion of PLEM.



Challenges in selecting suitable foundation size and skirt depth are important to make sure the mudmat foundation size meets the project geotechnical requirements. Each load case provides factors of safety for bearing, overturning, sliding and torsion. Challenges in determining the optimum foundation size will depend on allowable safety factor under a worst case scenario. Initial settlement occurs within hours or days following PLEM installation which is defined as *pre-metrology*. The challenges faced in pre-metrology mainly focus on defining initial settlement limitation during PLEM landing and the allowable range of short term settlement that is required. After pre-metrology the other challenge is to determine a long term settlement for the mudmat foundation to settle in the duration of PLEM operational design life which is defined as *post-metrology*. During pre and post-metrology, PLEM foundation must be able to settle within the allowable maximum settlement. Weight of the PLEM needs to be controlled for avoiding additional footprints of the mudmat design. An increase in design weight will effect design optimization and the structural integrity of PLEM.



Challenges for mudmat foundation to penetrate the weak seafloor soil require skirts that need to be installed around the perimeter and internal to the mudmat. Skirts help to force the sliding failure plane below the weaker seafloor soil into stronger soil below the skirt tips. The mudmat foundation also needs to be designed to cater for PLEM retrieval. PLEM mudmat deck must allow for displacement of soils by consolidation and strengthening of soil below the mudmat. Special holes are placed around the mudmat to reduce breakout forces during PLEM removal.

In Place

In place design challenges cover few areas that need to be addressed, defined and determined.

These challenges are:

- Connector jumper loads, installation loads, work over load of tree, preliminary PLEM weight and pipe data
- Load combination analysis
- Piping and fitting design
- Material for piping, fitting and welding requirement
- Dropped object protection

Since PLEM is connected to the trees by jumpers, loads derived from the jumper are from the expansion of pipe during operational and installation alignment of jumpers from trees to PLEM, and tree workover activity. These loads must be correctly defined and required for load combination analysis of PLEM. The load combination analysis needs to be determined also for the geotechnical foundation engineering study.

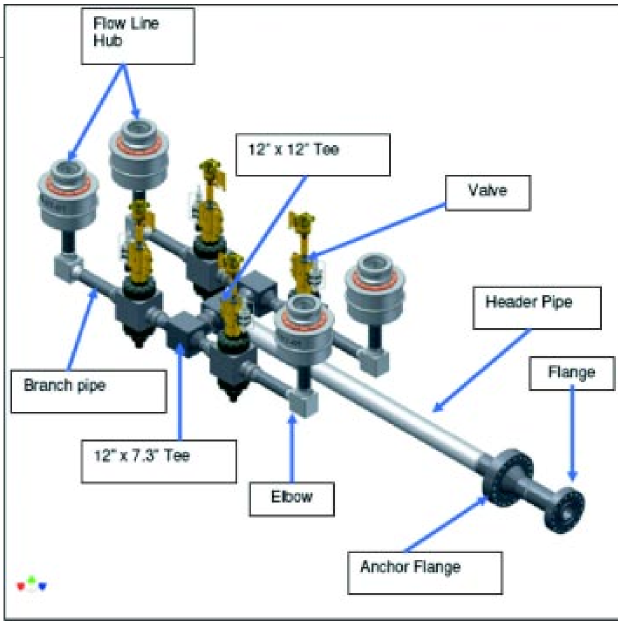
Challenges in the load combination analysis are to determine the most critical foundation loading conditions for the PLEM foundation design. The worst case scenarios are evaluated for two extreme cases. First extreme cases determine vertical, sliding, shearing, overturning and torsional loads for the bearing capacity analysis. Second extreme case studies are related to pre-metrology and post-metrology operations for the settlement analysis. Under each load condition, maximum or worst case overturning, shear, vertical and torsional loads will be defined as global loads acting on the foundation geometrical center. After completely defining all the worse-load cases, the data will be used to resolve or determine the mudmat sizing for the geotechnical foundation engineering study.

PLEM piping arrangement is designed based on the requirement of drill center field layout. P&ID has to be finalized and achieved. Based on the P&ID information for the 4 slot water injection PLEM, multiple design concepts were addressed until the desired concept proposal for the piping and equipment arrangement was achieved. Solving the optimum piping layout configuration required various iteration in identifying appropriate location for hub, valve, main header, branch line, flange, anchor flange and fitting. The PLEM piping layout required a fundamental understanding of the PLEM design arrangement and constraint.

The major considerations in the piping layout configuration are:

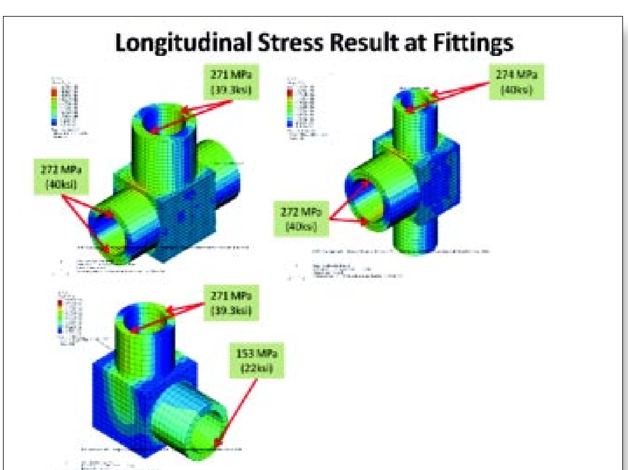
- Hub spacing for connection running tool and ROV accessibility
- Fitting spacing for welding and NDT inspection
- In place operational requirement in term of operating temperature and pressure
- Bearing of connector from PLEM to subsea tree

Apart from the piping layout configuration, a special F22 high material grade pipe fitting is used in the design to handle the high temperature and pressure acting on the



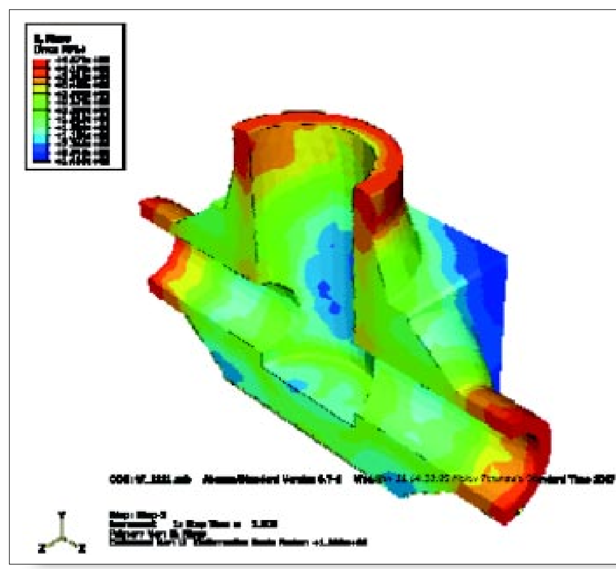
piping system. Since pipe fitting is designed in a certain constraint spacing, normal material such as X65 cannot not sustain the expansion during hostile in-place operation. The reason for using F22 material is because it gives a much higher yield stress than the X65 material. Unfortunately, F22 material has welding limitations and requires special attention in addressing buttering welding requirements. Buttering welding needs to fulfill the NDT requirements although it fits within the spacing constraint in the pipe fitting process. F22 pipe fitting material requires a special forging and machining process. PLEM piping system is also clad for corrosive protection as water is used as the medium of transportation.

The stress that each component of the PLEM fitting process undergoes is evaluated for conditions of operation under external and internal pressure loads as well as thermal expansion load and hydrotest conditions. The pipe fitting analysis is done to evaluate stress that will occur in the piping system of the PLEM during operation and hydrotest conditions. Linearized stress optimization has been used in solving the pipe fitting design. The stress distribution in the PLEM fitting components had to meet



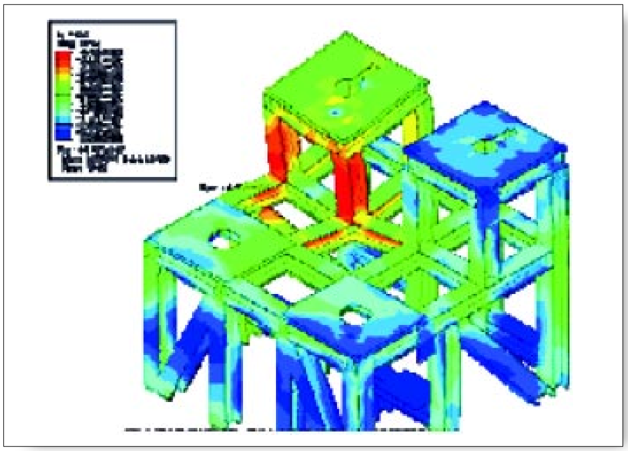
design codes. For weld design at the fitting material welding area, the longitudinal stress must be less than 2/3 of the yield stress of the fitting material requirement. Also in order to meet the welding NDT requirements, the minimum length for the fitting neck straight section needs to be measured and determined.

To solve pipe fitting design, FEA analysis was again performed using ABAQUS software as a tool to determine PLEM piping integrity. The piping system is evaluated based on the design code acceptance criteria. All the piping and fitting components are made out of carbon steel material. A beam element is used to simulate the piping system in the ABAQUS model. The analysis includes installation, hydrotest (onshore and offshore) and operation cases of external and internal pressures, thermal expansion loads and external loads from flowline jumpers. Maximum stress in the whole system is required to be lower than the allowable stress values and displacements of piping at the valve positions should within the movement limit of the valve base.



In order to design a structure for supporting and holding the piping system, PLEM in-place analysis was performed to ensure that the structures were capable in normal operating conditions throughout the design life of the PLEM. Challenges in solving the in-place analysis were to simulate worst operational cases in order to optimize design in terms of pipe supports. The objective of the in-place static analysis was to obtain joint deflections, nominal member-end forces and moments support reactions.

Dropped objects analysis is part of the structural protection requirement which is needed for a PLEM design. In

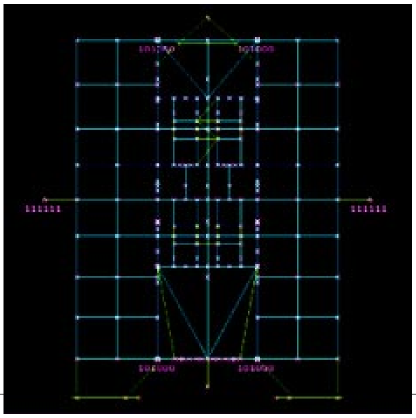


solving this design challenge, the PLEM support structure and top cover plate is designed to sustain impact energies over an area of a designated diameter. FEA is again performed to simulate dropped objects analysis using non-linear static analysis.

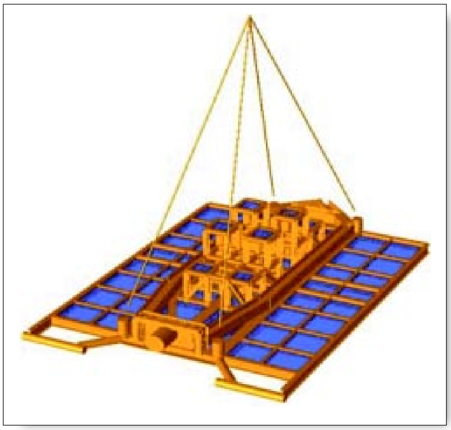
Transportation and Handling

Challenges in transportation and handling of PLEM design need thorough investigation and consideration that are related to the following factors:

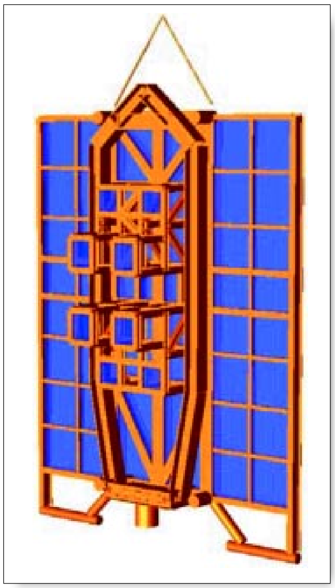
- Lifting of PLEM from fabrication yard to barge before final load out operation. Constraints are loads acting on PLEM that need to be determine and structural integrity check for each sequence such as 4 point, 2 point and single point lifting.
- Structural integrity of PLEM due to barge/vessel motion during lifting operation that contributes high Dynamic Amplification Factor (DAF). When PLEM is resting on barge, PLEM was simply supported at all skirts contact point to the barge.
- Inter connection consideration to flowline during tie-in operation where PLEM tie-in points need to be designed for easy accessibility and safety handling during installation.
- PLEM needs to have an interface frame for resting on vessel deck supporting frame before pipeline tie-in. Interface frame must be able to withstand DAF loading from barge motion and self weight of PLEM.
- System Integration Test (SIT), Factory Acceptance Test (FAT), ROV accessibility study and other procedures related to transportation, in place and installation need to be fully confirmed, checked and certified.



In terms of lifting analysis for PLEM, there are three lifting cases that require structural integrity investigation which are four (4) point lifting case, two (2) point lifting case and single (1) point lifting case. Four (4) point lifting is the horizontal lifting from transportation to barge using 4 lifting padeye. Challenges in the design are to maintain structural design optimization and integrity in the aspect of structural span length, PLEM COG and self weight that needs to be consistent and maintained throughout the design process.



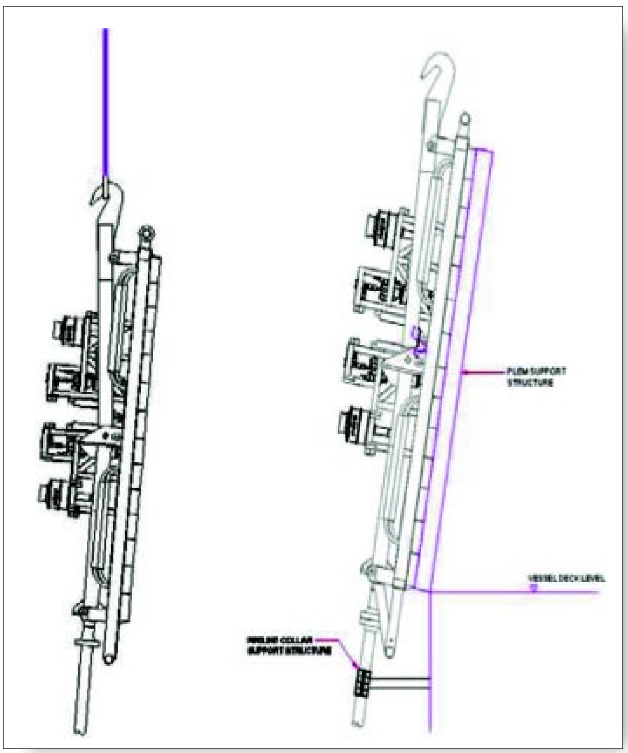
Single point lifting is the transportation process for the load out operation once the pipeline is completely tied in to the flange. The main rigging point is transferred to single hook lifting point of the yoke and the PLEM is ready for loading out from the barge. During this operation, maximum installation loads occur at single point (hook). Challenges in solving this design issue requires finite element analysis (FEA) check that are extensively performed using ABAQUS software to stimulate hook plate structural integrity under maximum installation loads. Due to maximum installation loads, a couple of iterations on hook were conducted until a yoke hook design optimization was successfully achieved.



Two point lifting is the vertical upending of the PLEM before being transferred to the main rigging point which is the single point hook lifting of the Yoke frame. Since the flange is located outwards of the PLEM to cater for pipeline tie-in and installation handling, a protection guide/frame needs to be installed and supported for the other main frame member of the PLEM.

This protector is described as the 'flange protection structural system.'

The challenge in designing the flange protection structural system is due to the fact that by adding more members it will increase the weight where the foundation design will be affected and if the protection frame is being supported by a weaker member it will further affect the integrity of the overall frame. Selection of members must be located at the right location. In order to achieve a structural integrity for flange protector and PLEM members, extensive structural iteration checking process is required.

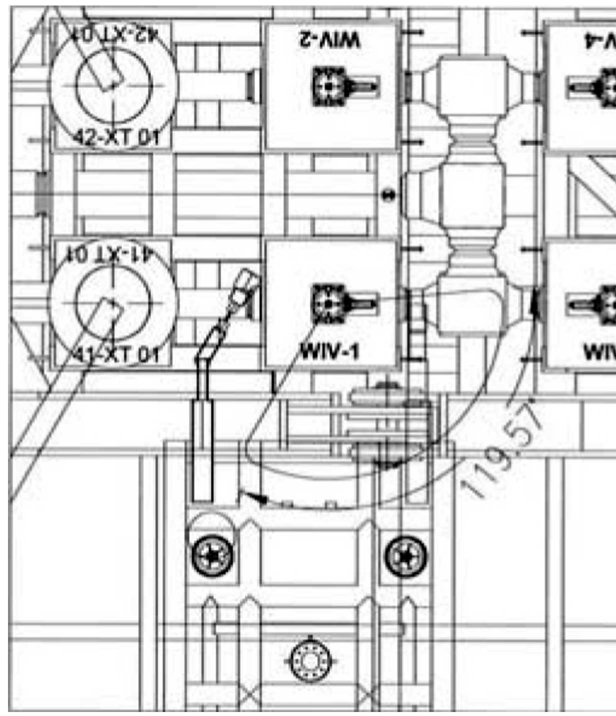


The challenges in Factory Acceptance Test (FAT) procedures are to ensure that the PLEM piping system meets the design requirements.

The following tests need to be considered for the PLEM FAT:

1. PLEM Hydrostatic Test to confirm the pressure integrity of the working pressure PLEM piping with PLEM test pressure.
2. Connector Interface Test to verify the jumper hubs and receiver structures on the PLEM function per design. This includes pressure testing with a connector on each hub.
3. Electrical Continuity Test to ensure that all components of the PLEM assembly are cathodically protected. This will be verified by checking electrical continuity.
4. PLEM System Lift Test to ensure that the yoke on the PLEM operates smoothly and without any interference, and that the PLEM can be lifted using the 4-point lifting sling.

Besides the FAT procedure, PLEM load out procedure and PLEM installation and retrieval procedures must also be addressed in the PLEM design. It is important to make sure the PLEM is safe and protected during load out from the fabrication yard towards the final offshore site and also during pipeline installation.



ROV interventions in deepwater application provide significant challenges in PLEM design accessibility requirement. Due to this, the ROV accessibility study was developed to control ROV activities while approaching the PLEM on the seabed. The maximum lowering speed and ROV distance from the seabed are controls to avoid an accident or impact on the PLEM during a ROV operation. ROV also has to keep a minimum distance from the PLEM structure. ROV accessibility study should cover sufficient rotating angles during operating valve, and the marking system on ROV panel should be clearly defined. PP

This paper was presented by Ir Saladin Jaszle Jasmin, Senior Subsea Engineer, OPE Malaysia at the 6th PetroMin Deepwater & Subsea and Underwater Technology Conference 2008.