

Evaluation of Tabular Leg Structure of Mobile Offshore Production Unit (MOPU) Life Extension using Condition Assessment Method

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ABSTRACT

A Mobile Offshore Production Unit (MOPU) is any type of portable structure that can be reused when procuring oil and gas from the seabed. There are few reasons why MOPU is chosen over the conventional fixed offshore platforms, mainly due to its ability to be installed and relocated in a short period, low installation, and abandonment cost, and providing adequate time to evaluate new reservoirs properly. In certain circumstances, MOPU may be required to remain at the same location for a more extended period beyond its designed life. This paper explains the method of life extension (LE) assessment to extend the useful life of the MOPU. A MOPU with a three-legged jack-up rig in cruciform shape designed and constructed based on the American Bureau of Shipping (ABS) Classification requirement with a design life of 5 years, which currently in laid-up mode after 14 years in operation. The legs will be the focus of the condition assessment for the LE of the MOPU. The MOPU was constructed with 3 tabular legs with each 92200 mm length, 3500 mm diameter, and 55 mm thickness operate under tensile and shear stress, standing with simply supported at the one-end with hull hanged at the tabular using jacking-pin at the equal elevation of 77,600 mm. The method of assessment used is Non-destructive Tests (NDT). No severe defects or cracks were recorded at the identified stress concentration points. All NDT measurements were found within the acceptable ranges with no recorded anomalies.

Keywords: *Condition Assessment; Life Extension; MOPU; Tabular Leg; NDT*

Introduction

Mobile Offshore Production Unit (MOPU) is a primary candidate for shallow water early production applications. MOPU offer a cost-efficient solution for short life fields, compared with conventional jacket structure. Advantages in terms of mobility enable ease of installation, hook up, and commissioning and decommissioning costs, in comparison with a traditional jacket structure [1]. For a newly build MOPU, the cost must be weighed against the cost of installation, hook-up, commissioning, and decommissioning. For an existing jackups as a MOPU conversion candidate, the cost is not as much of an issue as the cost of acquisition. MOPU has the added advantage of relocation and re-use at less cost [2, 3].

MOPU has proven its ability to accelerate the monetization of the newly discovered oil field. The first MOPU was installed in the Ekofisk Field in Norway, utilizing the Gulftide type (Figure 1) jackups as an early production system. Production began in 1971, in just 18 months after discovery while permanent were being designed and build. The Gulftide remained a MOPU until the permanent production facilities were installed in 1975, at which time it returned to drilling [4].

Offshore structures are subject to very harsh marine environment [5]. Deterioration of offshore structure commonly caused by forces such as wind, ocean wave's buoyant forces, current loading, and marine growth [6]. The most critical component in MOPU to ensure it can stand at the location safely is the legs, where it can directly affect the overall performance of the unit. There are 2 types of leg construction, as shown in Figure 2 [7].

In offshore oil and gas operation, a temporary or permanent structure equipped with necessary operational equipment is required before the commencement of the production. The living quarter module is part of the facility attached to the structure to man the structure for operational and maintenance purposes. In certain cases, the unmanned structure was installed, which operates remotely. The design of the structure deployed is depending on the depth of the seawater and as per the requirement [8].

Offshore exploration and production require a massive amount of investment. An optimal solution is always a desirable option in making sure of a profitable investment. There are three main economic reasons that usually taken into consideration to decide the use of MOPU: schedule, cost, and risk [3, 9, 10]. MOPU has limitations in terms of operational conditions. It is suitable to operate only at shallow water with a water depth of less than 152.4 meters [6]. To optimize the useful life of the structure, it has to be maintained and inspected as per Class guideline such as American Bureau of Shipping (ABS), Bureau Veritas (BV), China Classification Society (CCS), Croatian Register of Shipping (CRS), DNV GL (DNV GL), Indian Register of Shipping (IRS), Korean Register of Shipping (KR), Lloyd's Register of Shipping (LR),

Nippon Kaiji Kyokai (NK/ClassNK), Polish Register of Shipping (PRS), Registro Italiano Navale (RINA), and Russian Maritime Register of Shipping (RS).



Figure 1: Gulftide MOPU [4].

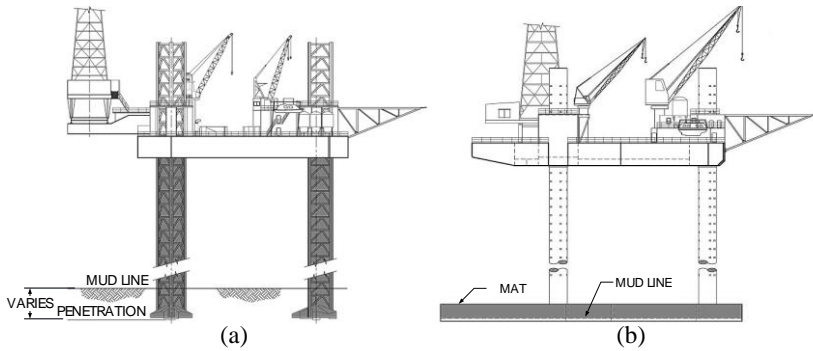


Figure 2: Type of jack-up legs [7]; (a) open-truss legs made of tabular steel sections that are crisscrossed and (b) open-truss legs made of huge steel tubes.

Generally, offshore structures must be able to safely function for a design lifetime of 25 years [5, 6]. Life extension (LE) program is commonly applied to offshore oil and gas installation. LE program is the lucrative end-of-life assets management strategy to extend the useful life (UL) of the assets beyond the design limit (DL) at the current installation location. Over half of the offshore assets at the North Sea and Mexico Gulf and it is more than 50%

of the offshore installation in UK Continental Shelf (UKCS) has exceeded its design life [11, 12]. The number of offshore installations that exceeded the design life expected to be continually increasing over time as most of the oil and gas offshore facilities are reaching their end-of-life period [13]. In China at the South China Sea, the first offshore installation that reached the original Design Life (DL) was in 2008, which still in operation. It is expected 43.8% of the offshore installation will reach its DL by 2021 [14].

LE program is also being well accepted in the other part of the world such as Malaysia [15] and Indonesia [16]. In Indonesia, Time Based Inspection (TBI) for offshore installations been regulated since 1977. The Indonesian government encourages for Risk-Based Underwater Inspection (RBUI) to be adapted over TBI. The risk will be the factor to determine the inspection interval, where the higher the risk is, the shorter the inspection interval will be [16, 17]. As been explained earlier, most of the offshore installation was designed conservatively, and RBUI opens up the opportunity for the extended useful life of the installations beyond Design Fatigue Life (DFL) provided the installation has never been exposed to the load exceeded the design envelope.

Life Extension

For this study, the MOPU as Figure 3, is a three-legged jack up rig with 3,000 tons holding capacity for each and constructed in cruciform shape assembled from 2 barges. It was designed and constructed based on the American Bureau of Shipping (ABS) Classification requirement with a design life of 5 years. The facility was commissioned in March 2006 and operated with a valid ABS Classification certificate society certificate until 2011. The class was renewed and transferred to the Russian Marine Register of Shipping (RS) Classification certificate prerequisite by executing Underwater inspection In-lieu of Dry-docking (UWILD) [18]. The renewal has enabled MOPU to be operated until March 2016. The MOPU operation was ceased in March 2016 due to unfavourable economic reasons. Before the Classification certificate expiry in March 2016, the MOPU has successfully being laid-up under RS Class, in which RS has granted MOPU Classification certificate under Laid-up mode until 2021, subjected to an annual verification survey.

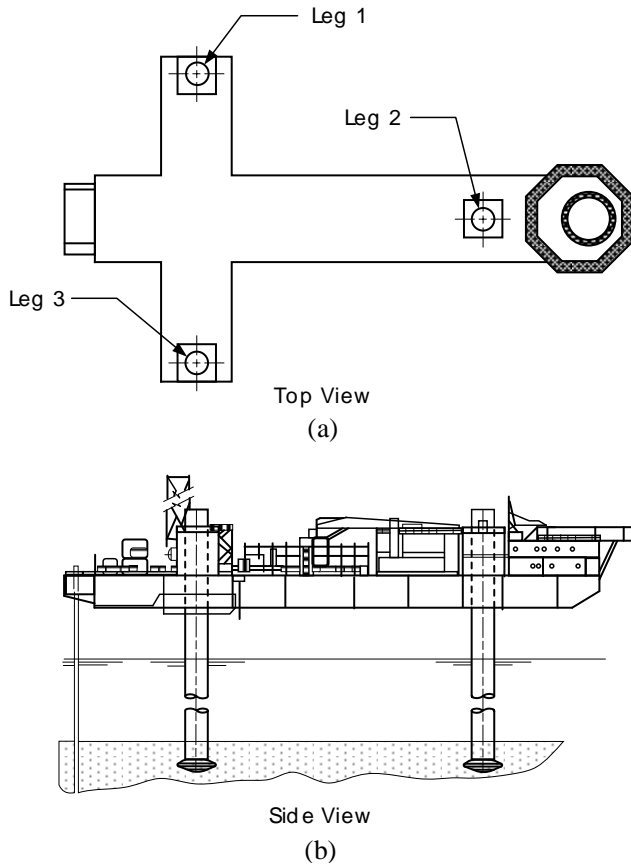


Figure 3: General arrangement of MOPU; (a) top view and (b) side view.

To maximize the asset useful life, LE exercise is a common method used in the industry. DFL normally developed by using conservative theoretical data. With that, there is always a chance to prolong the DFL by putting in the asset into a LE program. The concept of Life Time Extension (LTE) is that there is a time or an amount of duty when the installation would be normally considered for retirement, but where, certain processes and criteria, life can be extended without a reduction in margins below safe operating limit [8]. A typical operational timeline for an offshore oil and gas asset illustrated in Figure 4. Asset life begins at time $t=0$, where the asset commences for operation after successful of commissioning. The asset operates until time $t=t_0$, where t_0 denotes the end of DFL and marks the beginning of the LE. In order asset to be granted an extension of operational

period $l_e (>l_o)$, the asset owner is obliged to meet some regulatory requirement [11]. Re-certification by Classification body is one of the main regulatory requirements that must be met. While many offshore structures exceed their original design life, the safety of the operations on these structures needs to be guaranteed. This safety is warranted during the re-certification process [19].

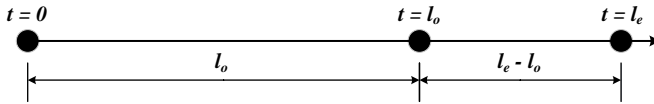


Figure 4: The original design life and the extended life of an asset.

The conventional end-of-life (EOL) asset management strategy; decommissioning or replacement gives a negative social impact as it closely relates to loss of jobs and a threat to the natural environment. LE program on EOL assets creates an added value to the economic, technical, social, and environmental. The decision to proceed with the LE program requires the asset owner to understand the existing processes and issues. Life extension processes include the definition of premises for the life extension program, assessment of asset condition, estimation of remaining useful life (RUL), evaluation of different strategies for life extension, obtaining regulatory approval, and implementation of the program [20].

Remaining useful life (RUL) is the critical elements that need to be predicted before the decision of life extension (LE) to be made. RUL can be estimated using the physic-based approached and data-driven approach [11]. Towards the end of the DFL, due to the constant exposure to the operational loadings, and environmental impact, the structure may suffer some form of material deterioration and damage (usually, but not necessarily, associated with time in service) with an increased likelihood of failure over the lifetime. Identified defects or damages require restoration such as strengthening, modification, and repair (SMR). Offshore restoration works are typically expensive. Inappropriate method selection will cause high cost and result in low effectiveness. SMR can be optimized to determine an appropriate activity for the restoration [21].

Effective LE requires input from all the stakeholders, including designers, system engineers, manufacturers, material specialists, operators and maintenance technicians, health and safety professionals, financial and economic analysts, and human factor researchers. Therefor LE should not only analyze the economic factor i.e., operating expenses (OPEX) & capital expenditures (CAPEX), but the availability and survivability of the Safety Critical Element (SCE) [22].

LE requires regular inspection, assessment and maintenance, which fatigue, and fracture degradation are the main elements that need to be well understood. RUL can be predicted with S-N Curve approach, which conducted during the design stage and Fracture mechanic (FM) approach can predict RUL when S-N Curve analysis gives a low RUL to components. Inspection interval developed based on the prediction to detect crack that grows to a critical level and caused a catastrophic failure [23].

Condition Assessment

Condition assessment is a vital part of the marine industry, regulated by the United Nation (UN) under the supervision of IMO and being adopted by the marine industry worldwide. As a specialized agency of the United Nations, IMO is the global standard-setting authority for the safety, security, and environmental performance of international shipping. Its primary role is to create a regulatory framework for the shipping industry that is fair and effective, universally adopted and universally implemented.

Inspection activity includes coverage above and underwater locations at specified points. It is focusing on the effectiveness of structure protection system, i.e., cathodic protection, coating system and measuring the deterioration of the legs. The inspection categorization:

- i. General visual inspection (GVI); As found visual inspection, video & photo.
- ii. Close visual inspection (CVI); Surface cleaning, Non-destructive Test (NDT) & measurement.
- iii. These surveys were conducted to find any defects and correctly and accurately record:
- iv. the type of defect
- v. the location of the defect
- vi. the dimension of the defect

The leg comprises of 3 main components; tabular, tabular-to-spud can flange, and spud can as shown in Figure 5. Critical hotspots or stress concentration points for MOPU has been pre-identified during the design stage as per below; however, the inspection location is not limited to the hotspot's points:

- i. Pin holes near lower guide
- ii. Lowest pin holes near to mud line
- iii. Welding connection at flange to the tubular pipe
- iv. Flange and bolt connection
- v. Spudcan

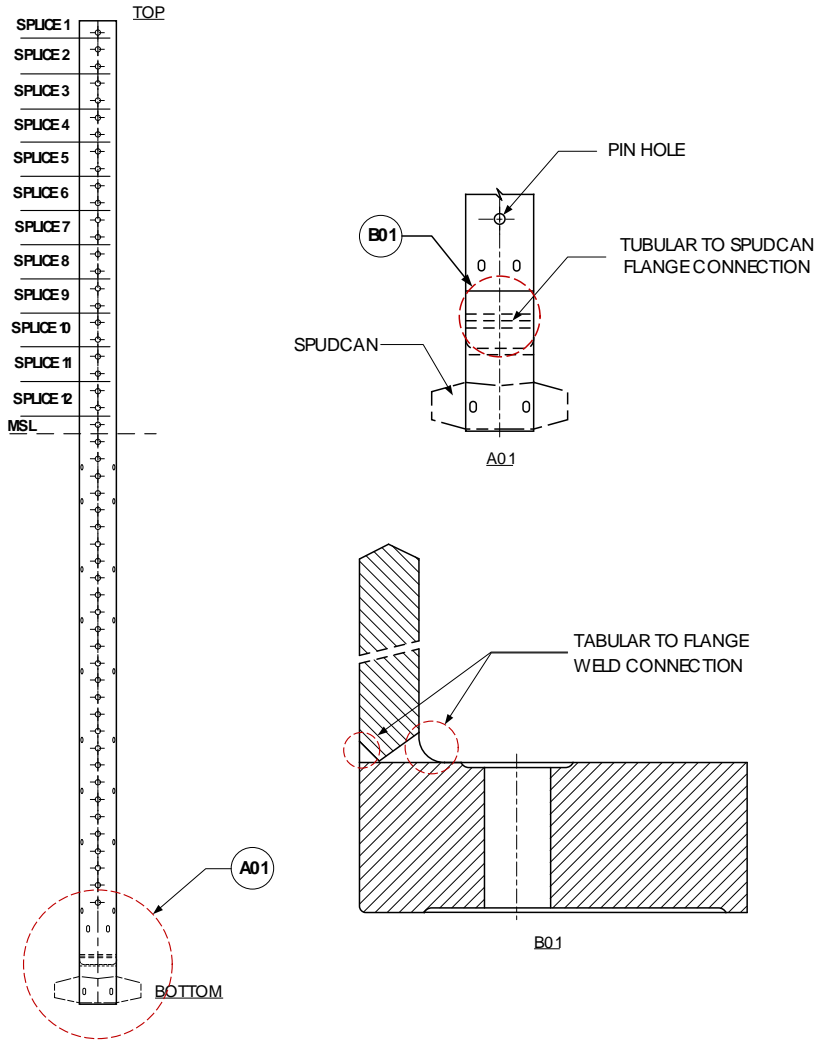


Figure 5: MOPU leg assembly.

Spud can be classified as uninspectable point and will be assess using numerical method. Location and method of inspection were categorised as listed below:

- i. Hybrid Acoustic Technology System (HATS) diagnostic testing of the three legs (subsea and above water) to inspect the overall structural condition.

- ii. General Visual Inspections (GVI), Close Visual Inspections (CVI), and Eddy Current Inspections (ECI) of above water weld joints and pinholes in all three of the MOPU's legs.
- iii. General Visual Inspections (GVI), Close Visual Inspections (CVI) inspections of the underwater weld joints and pinholes in all three MOPU's legs.
- iv. Alternating Current Field Measurement (ACFM) inspections of the underwater
 - v. Weld joints and pinholes in MOPU's legs number 2.
- vi. CVI or voltage measurement of the MOPU's Cathodic Protection (CP) System.

Assessment Method

The proposed method for life extension, as shown in Figure 6 comprises of 2 phases: 1) preparation and 2) implementation. The critical tasks in each of the three phases are described in the following subsections.

Phase 1: Preparation

The first phase in the LE process is the preparation stage which includes two tasks of data gathering and development of essential criteria.

Data gathering

The operational integrity of the MOPU legs LE depends on the accuracy and quality of the data from how it has been designed, constructed, commissioned, operated, and maintained over the original lifetime [22]. Design Fatigue Life (DFL) study carried out during the design stage used as a basis to determine the highest stress concentration points. Maintenance history of the MOPU inclusive of incident reports were analyzed to identify any significant incident that may have to the structural integrity and affects the stress concentration points. Pass inspection reports were analyzed to develop the inspection plan. Method of inspection determined by the defects that prone to be happening on the legs i.e., loss of metallic area, surface crack, sub-surface crack, and insufficient voltage for the Cathodic Protection for locations at above and underwater.

Development of essential criteria

Essential criteria developed based on the Classification guidelines. In this study the classification guideline used are from American Bureau of Shipping (ABS) and Russian Marine Register of Shipping (RS). Classification guideline provides the acceptance criteria such as allowable percentage of general metal loss, localized metal loss and coating breakdown [18].

Inspection specifications developed based on the anticipated defects at the stress concentration points. Suitability of the inspection method depends on the location of the stress concentration points either it will be above or underwater. Certified inspectors from various accredited examination body such as American Petroleum Institute (API), CSWIP and ASNT were used to carry out the inspection works at the points identified.

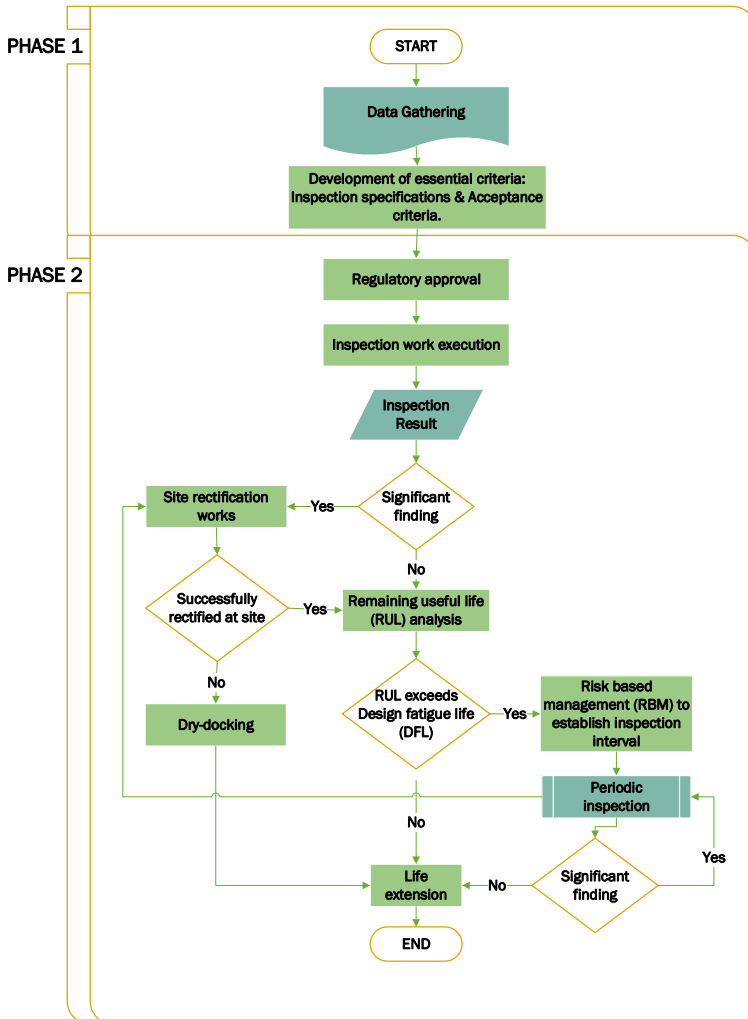


Figure 6: Assessment process flow.

Phase 2: Approval and implementation

The second stage of the LE process focuses on regulatory approval process and implementation measures.

Regulatory approval

Main regulatory body that oversees the marine activity is the Flag State Marine Administration (FSMA) who responsible to issue the final approval for the MOPU to operate within their water territory. Classification body is responsible to ensure the integrity of the MOPU is intact to continue operation.

Inspection work execution

All the surveys and inspections of the MOPU were conducted considering that the facility is in “Laid-Up” mode as classed by RS, non-operational and clear of hydrocarbons. The inspection divided to two; above water and underwater. Based on the anticipated defects and inspection parameter, method of inspection as shown in Table 1.

Table 1: Method of inspection

Anticipated Defect / Inspection Parameter	Method of Inspection	
	Above Water	Underwater
General metal loss	UT	UT
Localize metal loss	UT	UT
Coating breakdown	Visual	Visual
Surface crack	Visual, EC	ACFM
Sub-surface crack	EC	ACFM
Depletion of anode	Visual	Visual
CP voltage measurement	Voltmeter	N/A
Area/Surrounding survey	N/A	Visual/ROV
Overall thickness screening	HATS	HATS

Site rectification work

Found defects that exceeded the allowable limit require rectification. Rectification at the site is a preferred method aligned with the LE intention to maintain the MOPU location beyond design life.

Remaining useful life (RUL) analysis

There are few methods used to determine the remaining period for MOPU to safely stand at the existing location. RUL will be based on the DFL calculation where the safety factor may be reduced depending on the inspection result [24].

Risk-based management

Risk-Based Management (RBM) on assets consists of the execution of risk assessment and the development of an inspection plan. The assessment and the inspection may cover the whole assets or only focus on certain equipment or component. Risk ranking was developed to define the requirement of the inspection requirement and the intervals [25].

Dry-docking

Dry-docking is a term used for repairs or when a ship is taken to the service yard. During dry docking, the whole ship is brought to dry land so that the submerged portions of the hull can be cleaned or inspected. In the event where site rectification work is not doable, dry-docking is the only method for the rectification works to be executed.

Result and Discussion

The topsides and underwater leg surveys found minor weld bulges, anode depletion, and coating variations on all three legs. However, no severe defects or cracks were recorded at the jacking pinholes or indeed anywhere else. Ultrasonic Testing (UT) and Cathodic Protection (CP) surveys of each leg were carried out. All readings for ultrasonic thickness gauging and cathodic potential were found to be within acceptable ranges with no recorded anomalies.

Condition assessment

Critical hotspots or stress concentrations as identified by the analyses and recommended to be inspected have been inspected in accordance with the schedule of inspections and resulted in no significant findings other than corrosion. The hotspots remain unchanged due to no excessive load or forces being applied to the structure i.e.: collation with vessels, earthquakes, etc.

Hybrid acoustic technology system survey

Hybrid Acoustic Technology System (HATS) can detect and record an anomaly's size, severity, and number and then classifies it according to the type of anomaly, e.g., corrosion, metal loss, crack. HATS diagnostics were conducted to the entire length of the legs and recorded the relevant data.

Dormant cracks cannot be detected with the HATS diagnostics (such as fatigue cracks which have stopped propagating, i.e., remain the same in time, and therefore have no significant effect on the overall integrity of the structural member). However, active defects including fatigue cracks that are still developing in time can and would have been detected by this methodology.

According to HATS acoustic diagnostic results, external anomalies were detected on the inspected legs. A summary of the HATS diagnostic results as recorded for the inspected legs is presented in Table 2. All anomalies are less than 10% metal loss [18]. From observation of the defects recorded in Table 2, there is no fatigue cracks have been found.

Table 2: Summary of HATS defects per leg

Part	Anomalies			Metal Loss [%]
	Type	Number	Min. Depth [mm]	
Leg 1	Corrosion	54	0.7	< 10
Leg 2	Corrosion	37	0.5	< 10
Leg 3	Corrosion	44	0.6	< 10

Above water inspection

The following findings from the above water surveys and inspections that were undertaken on each leg are summarized below:

- i. Inspections (GVI and CVI): Leg external visual inspection from the inside of the Jack House and from the top of the Jack House to leg top.
Findings: In general, during the external visual inspections of the legs, only minor coating damage, corrosion stains, and surface corrosion were recorded. There were no severe defects/flaws found.
- ii. Inspection (CVI): Internal visual inspection via abseil of all welds (circumferential and vertical) and pinholes from sea level to leg top.
Findings: During the internal visual inspection of the jacking legs, damage to the paint coating with surface corrosion of the exposed bare metal was observed together with some active corrosion, especially between splice zone no. 11 and 12 of leg number 3, just above the main sea level (MSL) as depicted in Figure 7 with tag no (45), (46), (47) and (48). No indication of weld flaws was observed on both, the circumferential and the longitudinal welds.

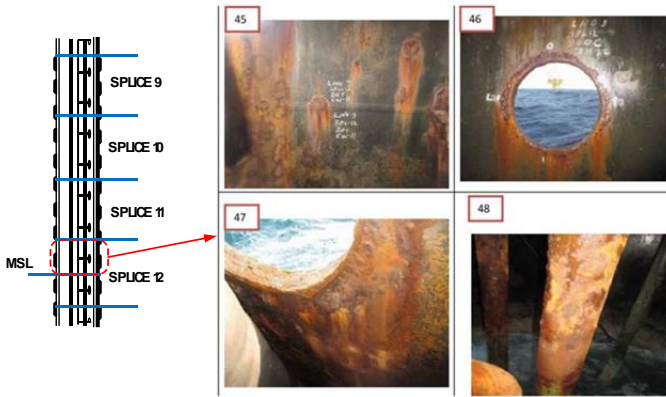


Figure 7: Observed paint damage and surface corrosion at leg 3.

- iii. Inspection: Ultrasonic thickness measurements of the legs were carried out at four main areas namely, within their splash zone area, at points below the shear pin location of leg 1 and 3, and areas above the shear pin location of leg 2.
Findings: No significant reductions of the wall thicknesses were observed during the measurements. Thickness measurements were within the range 53.9 mm to 56.2 mm. The design thickness is 55 mm. Table 3 provides the thickness measurements for all three legs.

Table 3: Leg thicknesses (above water)

Part	Thickness [mm]			
	Design Value	Min. Measured	Max. Measured	Average Measured
Leg 1	55.00	53.90	56.20	55.56
Leg 2	55.00	54.70	56.00	55.41
Leg 3	55.00	54.10	55.90	55.57

- iv. Inspection: Eddy Current Inspection of the legs at designated areas of the jacking holes circumferential and longitudinal welds.
Findings: No significant flaws/defects were observed during the ECI.
- v. Inspection (UFD): Ultrasonic Flaw Detection to be carried out on MOPU legs at designated areas of Jacking holes, circumferential and longitudinal welds.

Findings: No recordable Indications were observed during the inspection.

Under water inspection

The GVI to the subsea parts of the legs was carried out by divers aiming at inspecting the coating condition and at finding any abnormalities such as cracks and other defects. The following findings from the underwater surveys and inspections that were undertaken on each leg are summarized below:

- i. General Visual Inspection of the legs, the full leg length (from MSL to seabed) was reported to be covered with hard marine growth. No cracks/flaws were found. The CVI of the subsea parts of the legs has been carried out by divers on the jacking holes of the splash zone area all the way to the lowest reachable jacking holes (No 52) to identify cracks (if any present) on all three legs. Prior to the commencement of CVI, cleaning of all jacking holes was carried out using HP water jet, hand scraper, and wire brush. No crack initiation indications were reported during the Close Visual Inspection of the jacking pinholes. A considerable amount of metallic debris was found in close vicinity of leg 1 and 3 which can compromise the cathodic protection of the underwater leg structure by creating overprotection or under-protection voltages of the legs. This concern, however, has been assessed and eliminated on the grounds provided by the following facts:
 - a. The debris has been in the same location for several years as recorded from previous surveys.
 - b. The cathodic protection (CP) measurements recorded by the surveys of the years 2013, 2014, 2015 and 2017 have been consistent and with voltage values within the normal range of protection.
 - c. No active corrosion has been recorded at these locations.
- ii. Marine growth thickness was measured by a mechanical measurement technique which recorded an average thickness of 25 mm and 41 mm at depths of 48.5 m and 10 m below the MSL respectively.
- iii. Ultrasonic thickness measurements of the legs were carried out for four measurement points at specified underwater areas. No significant reduction in the wall thickness was observed during these measurements. Thickness measurements were within the range 53.9 mm to 56.0 mm. The design thickness is 55 mm. The thickness measurements for all the legs are given in Table 4.
- iv. Alternating current field measurement (ACFM) was employed on leg 2 to determine the weld presence in the joint as well as determine underwater crack sizing. The ACFM underwater survey of weldments and jacking pinholes was performed by divers. No crack initiation indications were recorded while carrying out ACFM.

Table 4: Leg thicknesses (underwater)

Part	Thickness [mm]			
	Design Value	Min. Measured	Max. Measured	Average Measured
Leg 1	55.00	55.10	55.90	55.35
Leg 2	55.00	55.70	55.90	55.62
Leg 3	55.00	55.20	56.00	55.18

Inspection of the MOPU's anode cathodic protection system

The Sacrificial Anode Cathodic Protection (SACP) system was checked with GVI as well as NDT methods by measuring the current voltage potential across the system. Twenty-seven sacrificial anodes (circular shape inscribed within the leg thickness) were inspected on each leg at various water depths confirming the anodes presence as per the original design. However, three sacrificial anodes on leg 3 were depleted with the depletion range of 90%-100%, and one sacrificial anode on leg 3 was depleted with the depletion range of 70%-80% (only the vertical bracket, designed to support the anode in place was visible). Except for these four anodes, no other serious depletions were reported during the remaining general visual inspection. The particulars of the over 70% depleted anodes are shown in Table 5. Voltage reading of Cathodic Protection (CP) taken (Table 6) on each leg suggesting the existing anode still giving an adequate protection to the structures.

Table 5: Summary of anode inspection findings

Part	Water Depth [m]	Jacking Hole Reference	No. of Anode >70%	Depletion Range [%]	Attachment
Leg 3	35.60	45/46	1	70-80	Firmly secured
Leg 3	6.00	26/27	2	90-100	Firmly secured
Leg 3	9.00	28/29	1	90-100	Firmly secured

Table 6: Voltage reading

Part	Voltage [mV]
Leg 1	-925
Leg 2	-917
Leg 3	-920

Conclusion

MOPU that designed for 5 years of design life was found intact after 14 years in operation. Based on the condition assessment result, there is an opportunity to extend the life of the structure as no anomalies found. Based on CP reading shown in Table 7, each of the legs are above the minimum voltage limit. This shown all the legs are protected against corrosion caused by the environment. It was also reported that the anode is depleted. Depletion of anode is a good sign that the CP system is in good working condition. It is recommended to replace the anode that depleted more than 70%. Table 7 also indicate that the overall wall thickness measurement and flaw detection using HATs on the tabular wall loss is less than 10% and there is no sign of active flaw at any of the legs.

Table 7: Overall inspection result

Part	Cathodic Protection System		Tabular Wall Loss (HATs)	
	Voltage, [mV]		[%]	
	Limit	Finding	Limit	Finding
Leg 1	> -850	-925	< 10	< 10
Leg 2	> -850	-917	< 10	< 10
Leg 3	> -850	-920	< 10	< 10

CVI for the above water and underwater is complementing HATs by utilizing different approach or method. Focus is given at the hotspot point and at the adjacent area. Table 8 depicted that none of the minimum thickness value recorded using Ultra-sonic Thickness Measurement (UTM) is beyond the minimum limit set. Eddy Current Inspection (ECI) was used for subsurface crack detection. No anomalies were found.

Table 8: Above water inspection result

Part	A/water Tabular Wall (UTM)		A/water Flaw Detection (ECI)	
	Thickness [mm]		No. of Anomalies	
	Limit	Finding	Limit	Finding
Leg 1	> 49.5	53.90	0	0
Leg 2	> 49.5	54.70	0	0
Leg 3	> 49.5	54.10	0	0

As per Table 9, none of the minimum thickness value recorded using Ultra-sonic Thickness Measurement (UTM) is beyond the minimum limit set. Alternating Current Field Measurement (ACFM) was used for subsurface crack detection. No anomalies was found. Based on the design, Leg 2 received the highest loads compared to others. Thus, only Leg 2 has been considered for ACFM. In case of any flaw detected at Leg 2, ACFM will be expand to the other legs.

Table 9: Underwater inspection result

Part	U/water Tabular Wall (UTM)		U/water Flaw Detection (ACFM)	
	Thickness [mm]		No. of Anomalies	
	Limit	Finding	Limit	Finding
Leg 1	> 49.5	55.10	N/A	N/A
Leg 2	> 49.5	55.70	0	0
Leg 3	> 49.5	55.20	N/A	N/A

Recommendation

For MOPU useful life to be extended, there is an engineering assessment that required to take place such as: i) Remaining Useful Life (RUL) Assessment and ii) Risk Assessment. RUL at each of the hotspot has to be calculated to establish the inspection interval based on the remaining years of life. Based on the condition assessment result that shows no significant anomalies, thus Reduced Fatigue Design Factor (FDF) can be applied in the RUL calculation [24]. Hotspots that have exceeded the RUL require further extensive engineering assessment i.e.: Finite Element Analysis to predict the deterioration rate or pattern. The risk on each hotspot has to be assessed to firm up the inspection interval. A risk-based structural assessment considers that structures of a higher risk require more frequent and more detailed levels of inspection than those with a lower risk.

Acknowledgement

The authors of this work would like to express their sincere gratitude to Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM) for facilitating this research.

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