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Local Stress Analysis on Pipeline End Manifold (PLEM) Due to Pipeline Walking in Subsea Pipeline

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ABSTRACT

The Pipeline End Manifold (PLEM) is a key component in offshore oil and gas subsea systems that serves as a distribution point for fluid flow from subsea pipelines. One phenomenon that can affect its structural integrity is pipeline walking, which is the progressive axial movement of a pipeline caused by pressure and temperature cycles during operation. This study aims to evaluate the effect of pipeline walking on the stress and deformation of a PLEM structure. Numerical modeling was carried out using AutoPIPE to determine the axial displacement of the pipeline, while ANSYS based on the finite element method was used to analyze the structural response of the PLEM. The results show that pipeline walking produces a maximum axial displacement of 78.5994 mm. The maximum Von Mises stress of 61.222 MPa occurred in the 10-inch piping section, while the maximum deformation was 0.1305 mm. These values indicate that the structure remains within safe limits and possesses sufficient stiffness under the analyzed loading conditions.

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Keywords: ***Pipeline End Manifold (PLEM), Pipeline Walking, Subsea Pipeline, Stress Analysis, Finite Element Method***

1. INTRODUCTION

Subsea systems are essential components in the offshore oil and gas industry, supporting efficient hydrocarbon production and transportation. The components of a subsea system serve as connections between equipment located on the seabed during the production and distribution processes of oil and gas. The produced hydrocarbons generate pressure that drives the flow of fluids through the distribution network. One of the key components responsible for fluid transportation is the subsea pipeline. Subsea pipelines are widely used to transport hydrocarbon production fluids, including oil and gas, from offshore fields to processing facilities or other subsea infrastructures [1]. This arrangement is illustrated in Figure 1.

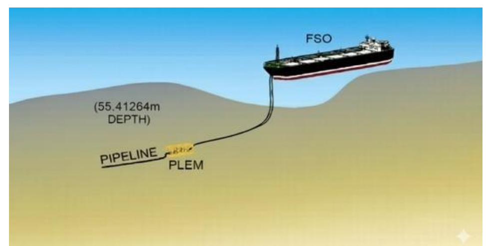

Figure 1. Subsea System

The role of subsea pipelines in hydrocarbon transportation presents numerous operational challenges. These challenges may arise from the transported fluid, pipeline stability issues, and environmental conditions surrounding the pipeline. Such factors can lead to several failure modes, including global buckling, local buckling, fatigue failure, and subsea pipeline instability [2]. One of the phenomena affecting the entire pipeline system is pipeline walking, which refers to the cumulative axial displacement of a subsea pipeline caused by repeated operational cycles (Hong & Liu, 2022). This axial movement is influenced by several factors, including temperature variations, soil properties, and seabed profiles with significant slopes [3]. Excessive axial displacement of a subsea pipeline may compromise the integrity of connectors and adjacent subsea structures [4]. One of the structures directly connected to a subsea pipeline is the Pipeline End Manifold (PLEM).

A Pipeline End Manifold (PLEM) is a subsea structure used to connect one subsea pipeline to another pipeline or to other subsea facilities. It functions as a flow diversion and distribution unit, serving as an interface between subsea pipelines and offshore production systems, such as buoy loading systems or risers connected to a Floating Production Storage and Offloading (FPSO) unit, as well as onshore terminals [2]. The PLEM considered in this study is illustrated in Figure 2.

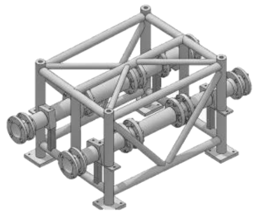

Figure 2. PLEM Object

Previous studies have investigated the effects of thermal expansion on pipeline walking behavior. The results indicated that pipeline walking could reach an axial displacement of approximately 0.21 m within one year of operation [3]. Although numerous studies have significantly contributed to the understanding of subsea structures and associated risks, limited attention has been given to the influence of subsea pipeline axial displacement on the local stress distribution within a PLEM. Axial movements resulting from phenomena such as pipeline walking may induce complex axial and transverse loads at the connection between the pipeline and the PLEM, potentially leading to stress concentrations in critical structural regions. However, this aspect has rarely been investigated in previous studies, particularly from the perspective of local stress analysis and its implications for the long-term structural integrity of PLEM systems.

Therefore, this study aims to address this research gap by investigating the local stress response of a PLEM subjected to axial displacement of a 16-inch gas subsea pipeline located in the southern waters of Madura. The analysis considers the combined effects of maximum internal loads, including pressure and temperature, as well as maximum external loads, including ocean current, ambient temperature, and hydrostatic pressure. The findings are expected to provide a better understanding of the structural behavior of PLEM systems under pipeline walking conditions and contribute to the assessment of subsea infrastructure integrity and reliability..

2. METHODOLOGY

The research commenced with a comprehensive literature review and the collection of technical data related to subsea systems, Pipeline End Manifolds (PLEMs), pipeline walking phenomena, stress analysis theories, and relevant design standards such as DNV-ST-F101. The collected data included pipeline dimensions, fluid characteristics, and the material properties of the PLEM structure.

Subsequently, a subsea pipeline model was developed by incorporating geometric parameters, boundary conditions, internal and external pressures, and temperature effects to determine the resulting stress response and axial forces acting on the pipeline. The modeling results were then evaluated through stress checks and displacement checks to verify the operational integrity of the pipeline under the specified loading conditions. Based on these results, a pipeline walking analysis was conducted to determine the cumulative axial displacement occurring throughout the operational period.

The next stage involved the integrated modeling of the subsea pipeline system and the PLEM structure using ANSYS Structural software. The axial forces obtained from the pipeline analysis were applied as boundary conditions to the PLEM structural model in order to evaluate the resulting stress distribution and structural deformation. This analysis aimed to identify critical regions with the highest stress concentrations that may be susceptible to structural damage or failure.

Finally, the results obtained from all analyses were used to formulate conclusions and recommendations regarding the influence of pipeline walking on the structural integrity of the PLEM. Furthermore, risk mitigation measures were proposed to enhance the reliability and safety of subsea pipeline systems subjected to axial displacement effects.

3. ANALYSIS AND DISCUSSION

3.1 Pipeline Route

The general arrangement of the pipeline system is presented in two perspectives: the plan view and the isometric view. The plan view provides an overview of the overall horizontal layout of the pipeline network, including the locations of major components such as the Pipeline End Manifold (PLEM), as well as key connection and branching points that are important for analyzing fluid transportation pathways.

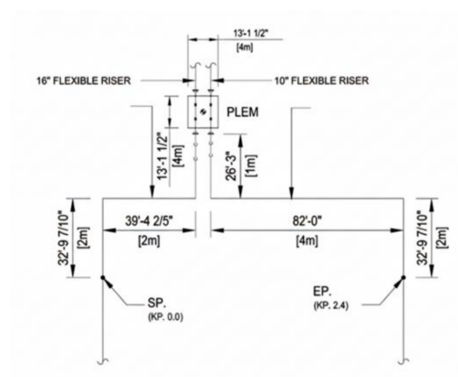

Figure 3. Pipeline Route

Figure 3 illustrates the general arrangement of the subsea pipeline system connecting the Floating Production Storage and Offloading (FPSO) unit, X Station, and Y Platform. The figure shows a 16-inch gas export pipeline extending from the FPSO to the metering station and a 10-inch multiphase pipeline connecting Y Platform to the FPSO. Both pipelines are connected through flexible risers to accommodate environmental loading and vessel motions. The two flowlines converge at the PLEM, which functions as a central flow management and distribution point within the subsea system.

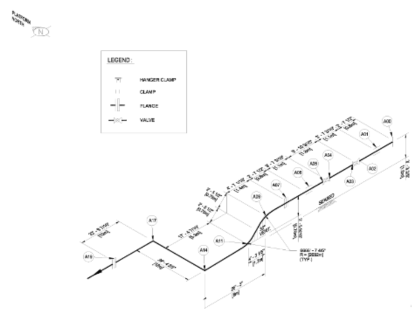

Figure 4. Isometric Drawing of 16-inch Pipeline

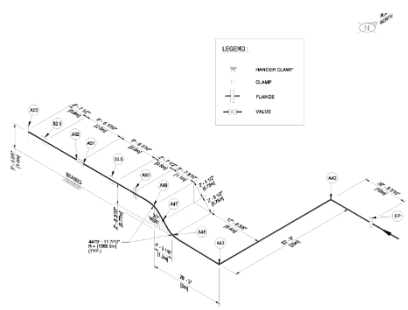

Figure 5. Isometric Drawing of 10-inch Pipeline

The dimensions and configuration of the Pipeline End Manifold (PLEM) connected to the pipeline system are also presented. The corresponding PLEM drawing is shown below.

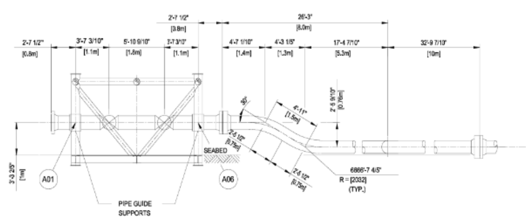

Figure 6. Side View of PLEM Drawing

Pipeline drawing data were used as the primary basis for the analyses and calculations conducted in this study. These engineering drawings provide comprehensive information regarding the pipeline characteristics, including principal dimensions, pipeline length, construction materials, and seabed routing configuration. Furthermore, the drawings contain details of supporting components, connections, and other relevant structural information required to ensure that the analyses are performed accurately and in accordance with applicable design standards. The drawing data also serve as essential references for developing the numerical models and defining the boundary conditions used throughout the study.

3.2 Pipeline Modelling

This section discusses the modeling of pipeline walking, a phenomenon characterized by the axial movement of subsea pipelines resulting from the combined effects of thermal loading, internal fluid pressure, and frictional interaction between the pipeline and the seabed. Pipeline walking commonly occurs in pipelines operating over extended periods under elevated fluid temperatures and fluctuating pressure conditions throughout their service life.

The objective of this modeling is to understand the pipeline's structural response to these operational conditions and to estimate the magnitude of cumulative axial displacement that may develop over time. Furthermore, the analysis is essential for evaluating pipeline stability and assessing the potential loss of equilibrium caused by the accumulation of axial stresses. Excessive pipeline walking without adequate control or mitigation measures may lead to increased deformation, elevated stress levels, and potential failures in structures directly connected to the pipeline system. In the context of this study, the primary structure of concern is the Pipeline End Manifold (PLEM), whose operational integrity may be compromised by excessive pipeline displacement.

The pipeline model was developed by considering the relevant geometric properties, material characteristics, operational loads, and environmental conditions. These parameters were incorporated to simulate the interaction between the pipeline and the seabed and to capture the axial forces generated during operation. The resulting axial displacement and force responses were then evaluated to determine their potential impact on the connected subsea structures.

In the model, the pipeline end directly connected to the PLEM is represented by Point S2. This location serves as the critical interface between the pipeline and the PLEM and is therefore selected for detailed analysis. The axial force obtained at Point S2 is subsequently used to evaluate the load transferred to the PLEM structure and to assess its influence on the local stress distribution and structural integrity of the manifold system.

3.2.1 10-Inch Multiphase Pipeline Modeling

The pipeline was modeled using an isometric representation to provide a three-dimensional visualization of the piping system. This modeling approach offers a more comprehensive understanding of the pipeline route, elevation variations, and the spatial relationships among pipeline segments along the entire pipeline corridor. The isometric model of the 10-inch multiphase pipeline is presented in Figure 7.

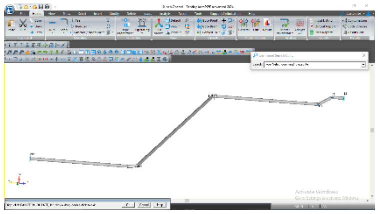

Figure 7. Isometric View of the 10-Inch Multiphase Pipeline Model

The developed pipeline model serves as the basis for evaluating the structural behavior of the pipeline under operational and environmental loading conditions. Based on this model, analyses of pipeline axial movement and global stress response are conducted. The axial movement analysis aims to determine the magnitude and distribution of pipeline displacement resulting from thermal expansion, internal pressure, and pipeline–seabed interaction. Meanwhile, the global stress analysis is performed to assess the overall stress distribution along the pipeline and to verify compliance with the applicable design criteria and allowable stress limits. The results of these analyses provide essential input for assessing the integrity and operational reliability of the subsea pipeline system.

3.2.2 16-Inch Export Gas Pipeline Modeling

The pipeline was modeled using an isometric representation to provide a three-dimensional visualization of the piping system. This modeling approach enables a more comprehensive understanding of the pipeline routing, elevation changes, and the spatial relationships among pipeline segments throughout the pipeline corridor. The isometric model of the 16-inch export gas pipeline is presented in Figure 8.

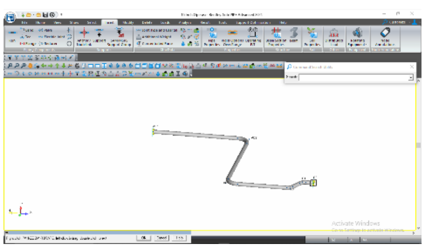

Figure 8. Isometric View of the 16-Inch Export Gas Pipeline Model

The developed pipeline model serves as the foundation for evaluating the structural response of the pipeline under operational and environmental loading conditions. Based on this model, analyses of pipeline axial movement and global stress distribution are performed. The axial movement analysis aims to quantify the magnitude of pipeline displacement resulting from thermal expansion, internal pressure, and interaction between the pipeline and the seabed. In addition, the global stress analysis is conducted to evaluate the overall stress distribution along the pipeline and to verify compliance with the applicable design codes and allowable stress criteria. The outcomes of these analyses provide essential information for assessing the structural integrity, operational performance, and long-term reliability of the export gas pipeline system.

3.3 Pipeline Walking Analysis

Pipeline walking analysis was performed on the developed pipeline models by applying both internal and external loading conditions. The internal loads include operating pressure and temperature, while the external loads consist of environmental effects and pipeline–seabed interaction. The analysis aims to evaluate the structural response of the pipeline during an operational cycle and to determine the parameters contributing to pipeline walking. The results of the analysis include the global stress distribution, pipeline displacement, and axial forces generated during a single operating cycle that may contribute to cumulative pipeline walking.

3.3.1 Pipeline Walking Analysis of the Multiphase Pipeline During a One Cycle

A displacement analysis was conducted to evaluate the movement and positional changes of the pipeline at various locations along the investigated pipeline segment. The displacement response is influenced by several factors, including internal fluid pressure, operating temperature, and external loads acting on the pipeline. These factors induce thermal expansion and axial forces that contribute to the overall movement of the pipeline during operation.

The displacement analysis provides valuable information regarding the magnitude and direction of pipeline movement, allowing the identification of critical locations where significant axial displacement may occur. Understanding the displacement behavior is essential for assessing the potential effects of pipeline walking and its impact on connected subsea structures. The results of the displacement analysis are presented in Figure 9.

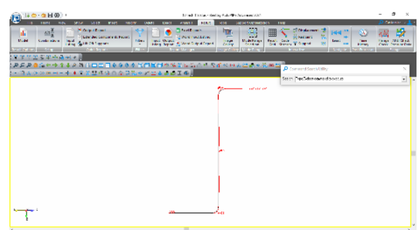

Figure 9. 16-Inch Pipeline Displacement

The displacement analysis results for the multiphase pipeline are summarized in Table 1. The table presents the pipeline displacement values at various locations along the pipeline route, illustrating the positional changes that occur under the applied loading conditions. These displacements result from the combined effects of internal pressure, operating temperature, and external environmental loads acting on the pipeline.

The displacement data provide insight into the movement behavior of the pipeline and help identify sections that experience significant axial displacement. Such information is essential for evaluating the potential occurrence of pipeline walking and assessing its influence on the structural integrity and operational performance of the subsea pipeline system.

Table 1. Displacement Analysis Results of the Multiphase Pipeline

Displacement Data		
Point Name	Load Combination	Translation Axial (mm)
A01 F	MAX LOAD	9.2659
A02	MAX LOAD	7.0329
A04 F	MAX LOAD	3.4671
A04 N	MAX LOAD	2.7335
A01 N	MAX LOAD	1.7421
B1 N	MAX LOAD	0.2246
B1 F	MAX LOAD	0.1972
S1 N	MAX LOAD	0.0823
S1 F	MAX LOAD	0.0549
A00	MAX LOAD	0.0000
S2	MAX LOAD	0.0000

Table 1 presents the displacement analysis results of the multiphase pipeline under the maximum loading condition (MAX LOAD). The analysis evaluates both pipeline translation and rotational response at various measurement points distributed along the pipeline segment. The translational displacement is measured in the axial direction and reported in millimeters.

At Point A01 F, the axial displacement was found to be 9.2659 mm. This result represents the axial movement of the subsea pipeline during a single operational cycle under the specified loading conditions. The observed displacement is primarily attributed to the combined effects of internal pressure, operating temperature, and external environmental loads acting on the pipeline. The displacement response obtained from this analysis serves as an important parameter for assessing the potential accumulation of axial movement that may contribute to long-term pipeline walking behavior.

Following the displacement assessment, a global stress analysis was performed on the 10-inch multiphase pipeline by considering the combined effects of maximum internal and maximum external loads. This analysis aims to evaluate the overall stress distribution along the pipeline and verify its structural integrity under the most critical operating conditions. The results of the global stress analysis are presented in Figure 10.

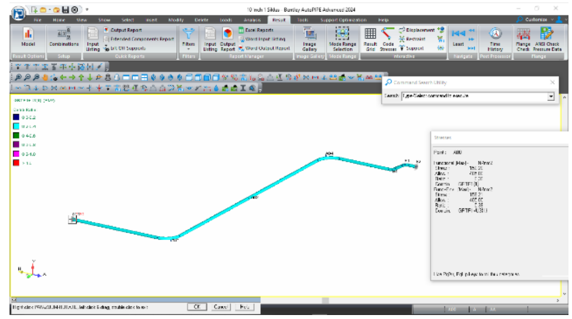

Figure 10. Stress Analysis Multiphase Pipeline

The maximum stress recorded in the analysis was 158.2061 N/mm², which is significantly lower than the allowable stress limit of 405.0000 N/mm². A comparison between the maximum stress values and the allowable stress criterion is presented in the Ratio column, which represents the proportion of the calculated stress relative to the allowable stress limit.

The stress ratio varies slightly among the measurement locations; however, all recorded values are consistently around 0.390632. This indicates that the maximum stress experienced by the pipeline corresponds to only approximately 39% of the allowable stress limit. Consequently, a substantial safety margin remains between the operational stress levels and the design allowable stress.

These results demonstrate that the pipeline operates within acceptable stress limits under the investigated loading conditions. The calculated stresses are considerably below the threshold associated with structural failure, indicating that the pipeline maintains adequate structural integrity and is capable of safely withstanding the combined effects of maximum internal and external loads. Therefore, from a global stress perspective, the 10-inch multiphase pipeline satisfies the applicable design requirements and does not exhibit any indication of overstressing that could compromise the reliability of the pipeline system.

3.3.2 Pipeline Walking Analysis of the 16-Inch Export Gas Pipeline During a One Cycle

A displacement analysis was conducted to evaluate the positional changes of the export gas pipeline during its operational cycle. The analysis measured pipeline displacement at various locations along the investigated pipeline segment under a single loading cycle. According to API 570 Pipeline Inspection Code, pipeline inspections are commonly performed within a five-year inspection interval. The displacement response is influenced by several factors, including internal fluid pressure, operating temperature, and external environmental loads acting on the pipeline. The displacement analysis results for a single operational cycle are presented in Figure 11.

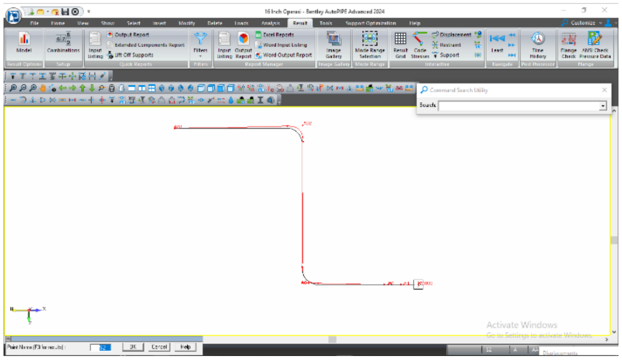

Figure 11. Displacement Analysis of the Export Gas Pipeline During a One Cycle

The displacement analysis results are summarized in Table 2, which presents the positional changes occurring along different sections of the pipeline under the applied loading conditions.

Table 2. Displacement Results of the Export Gas Pipeline During a One Cycle

Displacement Data		
Point Name	*Load Combination*	*Translation Axial (mm)*
A01	MAX LOAD	0.0000
A02 N	MAX LOAD	1.0242
A02 F	MAX LOAD	1.5496
A04 N	MAX LOAD	2.3488
A04 F	MAX LOAD	1.7280
B1 N	MAX LOAD	0.9015
B1 F	MAX LOAD	0.6485
S1 N	MAX LOAD	0.0136
S1 F	MAX LOAD	0.0892
S2	MAX LOAD	0.0000

Table 2 presents the displacement analysis results of the export gas pipeline under the maximum loading condition (MAX LOAD). The analysis includes both translational and rotational responses at various measurement points distributed along the pipeline route. Translational displacement is measured in the axial direction and reported in millimeters.

At Point A01 F, the recorded axial displacement is 2.3488 mm. This value represents the axial movement of the subsea pipeline during a single operational cycle. The displacement is primarily caused by the combined effects of internal pressure, operating temperature, and environmental loading. The results provide an indication of the magnitude of axial movement that may accumulate over multiple operating cycles and contribute to pipeline walking behavior throughout the service life of the pipeline.

Following the displacement assessment, a global stress analysis was performed on the 16-inch export gas pipeline by considering the combined effects of maximum internal and external loading conditions. The resulting global stress distribution is presented in Figure 12.

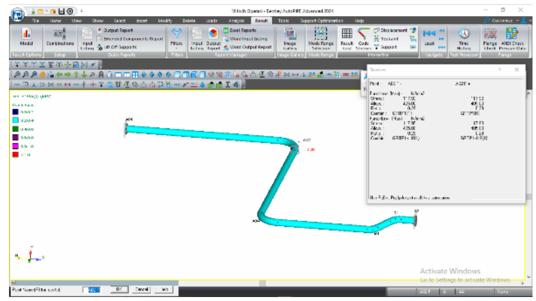

Figure 12. Global Stress Analysis of the Export Gas Pipeline During a One Cycle

Each measurement point represents the maximum stress generated by the applied loading combination (MAX LOAD). The highest recorded stress was 117.9454 N/mm², which is significantly lower than the allowable stress limit of 405.0000 N/mm². The comparison between the calculated stress and the allowable stress is represented by the Ratio parameter, which indicates the proportion of the actual stress relative to the allowable limit.

Although minor variations are observed among the measurement locations, the stress ratio remains consistently around 0.291223 throughout the pipeline. This indicates that the maximum stress experienced by the pipeline corresponds to only approximately 29% of the allowable stress limit. Therefore, a considerable safety margin exists between the operating stress levels and the design limit.

These results demonstrate that the export gas pipeline operates within acceptable stress limits under the investigated loading conditions. The calculated stresses remain well below the allowable threshold, indicating that the structural integrity of the pipeline is maintained and that no overstressing is expected under the maximum operational and environmental loads considered in this study.

A comparison of the displacement results obtained from both pipeline systems shows that the 10-inch multiphase pipeline experiences the highest axial displacement. Consequently, further analysis was focused on the multiphase pipeline by simulating four pipeline walking cycles to determine the magnitude of forces transmitted to the Pipeline End Manifold (PLEM) throughout the operational period. The force results obtained after the fourth simulation cycle are presented in Table 3.

Table 3. Pipeline Forces in the 10-Inch Multiphase Pipeline During the Fourth Cycle

Forces

Point Name	*Load Combination*	*Forces (N)*
A00	MAX LOAD	81459.1953
A01 N	MAX LOAD	1771.2708
A01 F	MAX LOAD	1477.3412
A02	MAX LOAD	694.6772
A04 N	MAX LOAD	1746.5533
A04 F	MAX LOAD	12189.1865
B1 N	MAX LOAD	12439.2129
B1 F	MAX LOAD	13629.3672
S1 N	MAX LOAD	15273.4785
S1 F	MAX LOAD	16388.8906
S2	MAX LOAD	20733.3809

The cumulative axial displacement generated by repeated operational cycles produces a progressive pipeline walking response. The resulting pipeline walking trend for the 10-inch multiphase pipeline is illustrated in Figure 13.

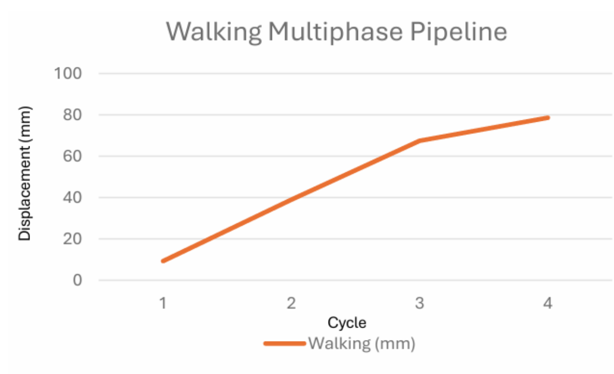

Figure 13. Pipeline Walking Rate of the 10-Inch Multiphase Pipeline

Based on the pipeline walking analysis results, a subsequent structural assessment is performed using the forces obtained at the pipeline end directly connected to the PLEM. These forces are applied as loading conditions in the PLEM structural model to evaluate their influence on the stress distribution and deformation behavior of the manifold structure. This analysis aims to determine the extent to which pipeline walking-induced loads affect the structural integrity and long-term performance of the PLEM.

3.4 Local Stress Analysis

Following the pipeline walking analysis, the next stage involved the structural modeling of the Pipeline End Manifold (PLEM). The PLEM modeling process included the geometric representation of the piping system connected to the manifold, together with associated components such as flanges and supporting structures.

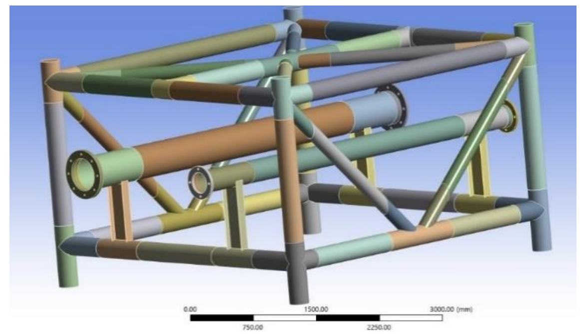

Figure 14. PLEM Model

After the modeling process was completed, the next step in the implementation of the Finite Element Method (FEM) was to perform numerical simulations to obtain the Von Mises stress distribution using ANSYS software. This stage represents the core of the structural analysis, as the model that had undergone discretization and mesh validation was subjected to the specified loading and boundary conditions.

Through this simulation process, the software calculated the structural response to the applied loads and generated the stress distribution throughout the model. One of the primary parameters evaluated was the Von Mises equivalent stress, as it is widely used as a failure criterion for ductile materials. The resulting stress distribution was visualized using contour plots, enabling the identification of critical regions experiencing elevated stress concentrations.

The maximum stress value obtained from the simulation was subsequently used as the primary indicator for structural verification and strength assessment. This value was compared with the mechanical properties of the material, particularly the yield strength and ultimate tensile strength of the piping material used in the PLEM structure. Through this comparison, it could be determined whether the structure remained within a safe operating condition, approached a critical limit, or exceeded the material's load-carrying capacity.

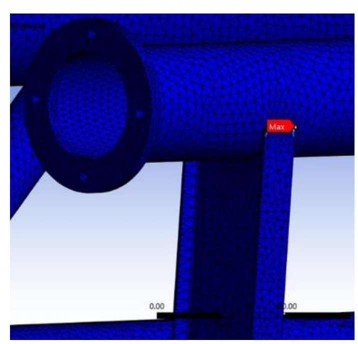

Figure 15. Von Mises Stress Distribution of the PLEM

The simulation results indicate that the highest stress concentration occurs at the intersection between the 10-inch pipeline and its supporting structure. From a mechanical perspective, this location is inherently susceptible to stress concentration due to changes in boundary conditions, local stiffness discontinuities, and the interaction between the primary structural members and the support system.

Based on the numerical analysis, the maximum Von Mises stress was found to be 61.222 MPa. This value represents the equivalent stress experienced by the material under the combined loading conditions applied to the structure and serves as the primary parameter for evaluating structural integrity. When compared with the properties of API 5L X65 steel, which possesses an ultimate tensile strength of 535 MPa, the calculated stress remains significantly below the material strength limit. This comparison demonstrates that the piping structure remains in a safe condition and is not at risk of failure under the loading conditions considered in this study.

3.4 Deformation Analysis

Following the local stress assessment of the PLEM structure, a deformation analysis was conducted to evaluate the structural displacement resulting from the applied loads. This analysis is essential because structural performance is governed not only by stress levels but also by the magnitude of deformation experienced during operation.

Using finite element simulations, the total deformation of the structure was calculated and visualized through displacement contour plots. These results provide insight into the overall and localized deformation behavior of the structure and facilitate the identification of regions experiencing maximum displacement.

The deformation analysis also serves to verify that the structural displacement remains within acceptable design tolerances. Excessive deformation may lead to various operational issues, including joint integrity problems, pipeline misalignment, and potential damage to supporting components.

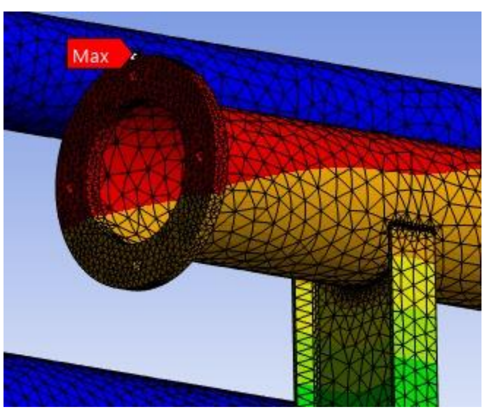

Figure 16. Deformation of the PLEM Structure

The deformation analysis revealed that the maximum displacement occurring within the PLEM structure was 0.1305 mm, localized in the 10-inch piping section. This result indicates that the area experiences the greatest displacement response under the applied loading conditions, which is primarily influenced by the boundary conditions, load distribution, and local stiffness characteristics of the structure.The relatively small deformation magnitude demonstrates that the structure possesses sufficient stiffness to withstand the applied loads. In general, sub-millimeter deformations of this magnitude are considered very small for piping systems and are unlikely to cause significant geometric changes or operational disturbances. Furthermore, the low deformation level is consistent with the results of the previous stress analysis, which showed that the induced stresses remain well below the allowable material limits. Therefore, both the stress and deformation analyses confirm that the PLEM structure maintains adequate structural integrity under the loads generated by pipeline walking..

4. CONCLUSIONS

Based on the research findings, the following main conclusions can be drawn with respect to the research questions that were posed:

1. The axial displacement of the subsea pipeline (pipeline walking) induced by the maximum loading conditions was found to be 78.5994 mm. This result indicates that the pipeline undergoes a considerable longitudinal movement as a response to the combined effects of operational and environmental loads. Such displacement represents an important parameter, as it may influence the interaction between the pipeline and the Pipeline End Manifold (PLEM), particularly in terms of load transfer and the potential generation of additional stresses within the connected system.
2. The maximum local stress within the PLEM structure was identified in the 10-inch piping section, where a maximum Von Mises stress of 61.222 MPa was recorded. This location represents a critical region characterized by stress concentration resulting from boundary conditions and interaction with the supporting structure. Nevertheless, the calculated stress remains significantly below the strength limit of the material used. Therefore, the PLEM structure can be considered structurally safe and is not susceptible to failure under the loading conditions investigated in this study.
3. The maximum deformation occurring in the PLEM structure was relatively small, with a value of 0.1305 mm, and was also localized in the 10-inch piping section. This deformation magnitude indicates that the structure possesses sufficient stiffness to withstand the applied loads without experiencing significant geometric changes. Consequently, the observed deformation is not

expected to adversely affect the operational performance or structural integrity of the PLEM system.

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