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Modelling and Stress Analysis of the Pig Loop Module of a Piping System.

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ABSTRACT*: The failure of any piping system depends on the stress analysis that was performed during the engineering design of the piping system. In designing the pig loop of a submarine manifold to be used in area Y of Niger delta in Nigeria, a proper analysis of the load to which the system could be subjected was carried out using a stress analysis software - "Triflex piping solutions." We employed ASME B31.8 piping code. Various stress values and deflections were analysed at each node to ensure that the design will be on a safe operating condition. Stress utilization was checked for hoop and longitudinal stresses for various scenarios and the worst case scenario was determined. The maximum stress utilization for the worst case scenario was found to be within the limit and thereby meeting with the safety requirement.*

Keywords: *Pig Loop Module, Piping Stress Analysis, Piping System, Submarine Manifold, Triflex.*

I. Introduction

Effective modelling, stress analysis and fabrication of a Pig Loop Module (PLM) are paramount to the successful modelling, delivery and operation of the manifold subsea equipment. In the past few decades there have been numerous pipeline and subsea equipment failure incidents, resulting in altering the normal order of production, posing threat to the safety of workers, and more so causing tremendous losses to the country's economy and national life. A great attention therefore, has been drawn to the security issues of the submarine pipeline and subsea equipment. Research has shown that a major cause of failure in piping systems boils down to the stress factor during the operation process. The stress on the turning point or section plane often tends to exceed the allowable stress due to the influence of internal pressure and external loads[1]. It is necessary therefore, to analyse the stress conditions of the Pig Loop Module of a Piping System, with a view to providing a safety basis for its design and fabrication.

In this paper, we discussed about the piping analysis of a piping system, lay bare the basis for performing the analysis of a 12-inch-ID pipe of the Pig Loop Module of a submarine manifold, determined the stress utilization of the piping system and pinpointed the load case that produced the "worst case scenario". The PLM coding and analysis were carried out in Triflex environment, using ASME B31.8 Piping code[2].

1.1 Piping System

The piping system consists of pipes and other associated components such as fittings, valves and all other specialties otherwise referred to as piping components. It is the effective method for transferring fluids from one point to another, without considerable losses in properties and quality of fluid. Industrially, all piping activities are performed with the compliance and guidelines of International and Industrial Codes and Standards as well as the laws and regulations of respective local authority[3, 4].

In any typical flow station, piping systems are the easiest components. They are subjected to different kinds of loads and hence during stress analysis, a proper analysis of the load to which the system could be subjected must be carried out. A piping system has to be flexible enough to allow thermal expansions but also stiff enough to withstand the actions imposed by operational load. This is why the stress engineer must always strive to create equilibrium between these various forces at play.

1.2 The Pig Loop

A Pig loop is usually employed for connecting two flowlines, in field developments where the production train is made up of two flowlines. The purpose of the pig loop module is to facilitate the cleaning of the flowlines by *'pigging'* during commissioning and operations, and the circulation of dead crude for hydrate prevention. The pig loop may be internal or external. Whenever there are plans of expansion of the field in the future, external pig loop module remains the better option.

Pigging refers to the introduction of a pig into the pig loop through the pig launcher, for various maintenance operations on the pipeline. These operations include but not limited to cleaning, inspecting or distributing inhibitor throughout the pipeline.

1.3 Piping Stress Analysis

Piping Stress analysis (PSA) is a term applied to calculations, which address the static and dynamic loading resulting from the effects of gravity, temperature changes, internal and external pressures, changes in rate of fluid flow and seismic activity. Codes and standards establish the minimum requirements of stress analysis[5]. The failure of any piping system depends on the stress analysis that was performed during the engineering design of the piping system. The purposes of Piping Stress Analysis therefore, are briefly comprehended in the following:

- To ensure safety of the piping system and its components
- To ensure the safety of connected equipment and its supporting structures
- To ensure that pipe deflection are within allowable limits.

When carrying out a stress analysis exercise, the analyst must not be in a hurry. Here are basic concepts to consider during piping stress analysis:

- Identify potential loads that would come on to the pipes or piping system during its design life.
- Relate each one of these loads to the stresses and strains that would be developed in the crystals or grains of the material of construction (MoC) of the piping system.
- Consider the worst three dimensional stress states that the MoC can withstand without failure.
- Get the cumulative effect of all the potential loads on the 3-D stress scenario in the piping system under consideration.
- Alter piping system design to ensure that the stress pattern is within failure limits.

1.4 Stress Classification.

Basically, stress can be classified into two categories thus:

- Primary loads
- Secondary loads

1.4.1 Primary Loads.

Primary loads are steady or sustained types of loads such as internal fluid pressure, external pressure, gravitational forces acting on the pipe such as weight of pipe and fluid, forces due to relief or blow down pressure, waves generated due to water hammer effects. Primary loads have their origin in some force acting on the pipe causing tension, compression, torsion *etcetera*, leading to normal and shear stresses. Primary stress limits are intended to prevent plastic deformation and bursting.

1.4.2 Secondary Loads.

Secondary loads are basically due to expansion. They are caused by displacement of some kind. A pipe may experience expansion or contraction once it is subjected to temperature higher or lower respectively as compared to temperature at which it was assembled. The secondary loads are often cyclic though not always.

1.5 Analysis Software.

There has been a number of software for performing piping stress analysis since the 1970s. Currently, more versatile piping stress analysis software such as Triflex, CAESAR II, AutoPIPE and CAEPIPE pervade the market. This paper employed Triflex for the stress analysis work.

Triflex is a Piping Stress Analysis software that provides user-friendly data entry screens, an extremely flexible output report generator as well as superior input and output graphics. Since 1971, Triflex has been a well-known name in piping stress analysis industry. It provides piping stress analysts with an easy-to-use program to quickly and accurately analyze piping systems for the effects of pressure, temperature, weight, and other static loads as well as a variety of dynamic loading conditions. Triflex, has been successfully used to analyze piping systems from the simplest to the extremely complex[6].

II. Design Codes and Standards

Codes are rules for the design of prescribed systems which are given the force of law through provincial, state and federal legislation.

Codes usually set forth requirements for design, materials, fabrication, erection, test, and inspection of piping systems, whereas standards contain design and construction rules and requirements for individual piping components such as elbows, valves, and other in-line items. Compliance to code is generally mandated by regulations imposed by regulatory and enforcement agencies[7]. Table 1 display codes employed in Modelling of the Pig Loop Module.

Table 1: Codes employed in the design of Pig Loop Module for Subsea Manifold.

ASME 31.8	Gas Transmission and Distribution Piping Systems (2012 Ed)
DNV-OS-F101	Submarine Pipeline system, August 2012
DNV- RP-F112	"Design of Duplex Stainless Steel Subsea Equipment Exposed To Cathodic Protection" October 2008.
DNV-OS-H103	Modeling and Analysis of Marine Operations
ASME II, Part D	Section II - Materials, Part D, Stress Tables
API-RP-1111	Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines
DNV-RP-C205	Environmental Conditions and Environmental Loads, April 2007

III. Basis for Modelling and Analysis

The modelling and analysis for Pig Loop Module were based on the relevant Specifications, Codes and Standards. The design pressure and temperature requirement for Pig Loop Module is as per relevant specification and Basis of Design documents.

The load case scenarios checked for in the analysis were: Operation (Hot and Cold), Pressure Testing during subsea Commissioning, Pressure Testing during Factory Acceptance Test (FAT), Transportation, Landing, Splash Zone and Connection/ Disconnection.

3.1 Design Pressure and Temperature

The design pressure for the subsea production system is governed by the methanol pump pressure from topside as referred from the Company Specification employed. Table 2 below gives details on the design pressure and test pressure calculated for different water depth levels.

Table 2: Design Pressure and Temperature.

h (m)	P_{ext} (bar)	P_{int} (bar)	ΔP (bar)	TP (bar)	DP (bar)	HTP (bar)	DT (^oC)
MSL	0	411	411	514	514	655	-18 / 74
1150	116	514	398	617	501	-	-18 / 74
1575	158	552	394	655	497	-	-18 / 74

Where:

h = Water Depth
P_{ext} = External Pressure due to water depth
P_{int} = Design Internal Pressure
ΔP = Operating Differential Pressure (P_{int} - P_{ext})
TP = Test Pressure for Subsea Commissioning
DP = Differential Pressure for Subsea Commissioning
HTP = Hydro Test Pressure at Onshore during Factory Acceptance Test
DT = Design Temperature
MSL = Mean Sea Level

As seen from Table 2, the highest differential pressure in the system is for minimum water depth of 1150m. Thus the analysis is run conservatively for these design pressures and test pressures for operating and subsea pressure testing conditions. For Hydro test at onshore, the maximum test pressure of 655bar is used in the calculation.

3.2 Basis for Analysis

The Pig Loop Module consist of a 12" Internal Diameter (ID) insulated piping loop integrated with Universal connector Termination head for return of the pig connecting the large bore pipe through manifold flow line Hubs. The Pig Loop Module was analysed for interchangeability requirement with any of the production manifold modules employed in the field. Thus the maximum fabrication tolerance limits for both Manifold and Pig Loop Module were considered while calculating the flexibility of the Pig Loop Module pipe. The tolerance limits were based on the critical dimension drawings for Manifold and Pig loop side according to the specifications. These tolerance limits are combined together and applied as initial deflections in the piping analysis to calculate the stresses for the Pig Loop Module. The Inboard and Outboard hub interface may have a deviation regarding translation and rotational tolerances resulting in increased pipe stress. The pig loop module has the following orientations: translation in the x-direction (dx), translation in the y-direction (dy), translation in the z-direction (dz), rotation around the x-axis (rx), rotation around the y-axis (ry), rotation around the z-axis (rz). The Triflex model obtained from the combinations is shown in Fig. 1.

IV. PLM Design, Triflex Model and Analysis

The Pig Loop Module was designed by adopting Chapter VIII of ASME B31.8[2]. The computer model of the PLM was coded in Triflex environment and the analysis was carried out for three different alternative options occasioned by the variation in the load direction imputed into "anchor Initial movements /Rotations" during coding.

4.1 Relevant Analysis Scenarios and Design conditions.

The PLM was analysed for various load cases so as to be able to determine the load case that produced the worst case scenario. Seven global "scenarios" were analysed by using Triflex.

4.1.1 Global Analysis Number One: Operation Scenario.

This scenario is to verify the integrity of the Pig loop during the Operation. The Design Loads and Settings adopted are as follow:

- Internal design pressure equal to 514 bar
- External Pressure equal to 115 bar (Min. Water depth : 1150m)
- Thus the maximum differential pressure of 399bar considered in the analysis. HISC factors selected according to DNV-RP-F112
- Base temperature of 4°C (Fabrication / Installation temperature)
- Maximum tolerance between PLM and manifold for interchangeability.
- Design temperature: -18 / 74°C
- Operation load case was checked for two Combinations:
  - Operation + Hot - PLM Operating at maximum design temp.
  - Operation + Cold - PLM Operating at minimum design temp.
- Erosion allowance deducted for PLM header piping.
- PLM self-weight including contents and Insulation density.
- Buoyancy is included.

4.1.2 Global Analysis Number Two: Pressure Testing during subsea commissioning Scenario.

This scenario is to verify the integrity of the PLM during the pressure commissioning at subsea. Design Loads and Settings adopted follows:

- Internal test pressure equal to 617bar.
- External Pressure equal to 115bar (Min. Water depth : 1150m)
- Thus the maximum differential test pressure of 502bar is considered in the analysis.
- HISC factors selected according to DNV-RP-F112
- Base temperature of 4°C (Fabrication / Installation temperature)
- PLM self-weight including contents and Insulation density.
- Buoyancy is included.
- Maximum Tolerance between PLM and Manifold for interchangeability check.

4.1.3 Global Analysis Number Three: Pressure Testing during FAT Scenario

This scenario is to verify the integrity of the PLM during the pressure testing at Onshore (FAT). Design Loads and Settings adopted follows:

- Internal test pressure equal to 655bar.
- PLM self-weight including contents and Insulation density.
- No External Pressure due to hydrostatic head.
- Base temperature of 4°C (Fabrication / Installation temperature)
- No Buoyancy considered

- No tolerance input.

4.1.4 Global Analysis Number Four: Transportation Scenario

This scenario simulates the loads acting on PLM during transportation. The PLM is supported at each termination head during transportation which is modelled in Triflex as a fixed support and the loads are checked accordingly.

The lateral movements are checked. There are 8 combinations of 1g applied in X, Y, Z direction. This is a conservative assumption since this force of 1g is acting simultaneously on all the three planes at the same time.

Design Loads and Settings adopted follows:

- PLM self-weight including contents and Insulation density.
- No Buoyancy.
- Transportation loads simulated by accelerations of 1g applied to X, Y, Z for 8 different combinations representing different directions of load.
- Base temperature of 4°C (Fabrication / Installation temperature)

4.1.5 Global Analysis Number Five: Lifting / Landing Scenario

The lifting case is covered by landing scenario due to high loads considered during landing case and no separate analysis is performed for this case.

The landing scenario was carried out to verify the loads occurring when PLM lands on the structure during installation. A maximum deceleration load of 5g is set during landing which is an extremely conservative estimate.

Design Loads and Settings adopted follows:

- PLM self-weight including contents and Insulation density.
- Buoyancy included
- Deceleration force of 5g.
- Base temperature of 4°C (Fabrication / Installation temperature)

4.1.6 Global Analysis Number Six: Splash Zone Scenario

This scenario simulates the loads acting on PLM due to the forces caused by the wave slamming during lifting / installation of the module. PLM will be lowered through the splash zone by the slings. The loads caused by wave slamming were modelled as a uniform load on the piping, acting upwards.

Design Loads and Settings adopted follows:

- PLM self-weight including contents and Insulation density.
- Wave slamming forces were modelled as uniform load on the piping acting upwards
- Buoyancy included
- No External Pressure.
- Base temperature of 4°C (Fabrication / Installation temperature)

4.1.7 Global Analysis Number Seven: Connection / Disconnection Scenario

The Connection / Disconnection of PLM with manifold is done by the sea-line stroking tool (SST) operated by hydraulic cylinder which is connected to both ends of the termination head.

Although stroking is done on both the termination heads simultaneously, as a worst case scenario, a maximum misalignment displacement of 100mm relative to each other of termination head is analysed to check PLM piping flexibility.

Design Loads and Settings adopted follows:

- PLM self-weight including contents and accessories
- Relative displacement of 100mm between two termination head.
- Buoyancy included
- External pressure
- Base temperature of 4°C (Fabrication / Installation temperature)

4.2 Triflex Model of Pig Loop Module

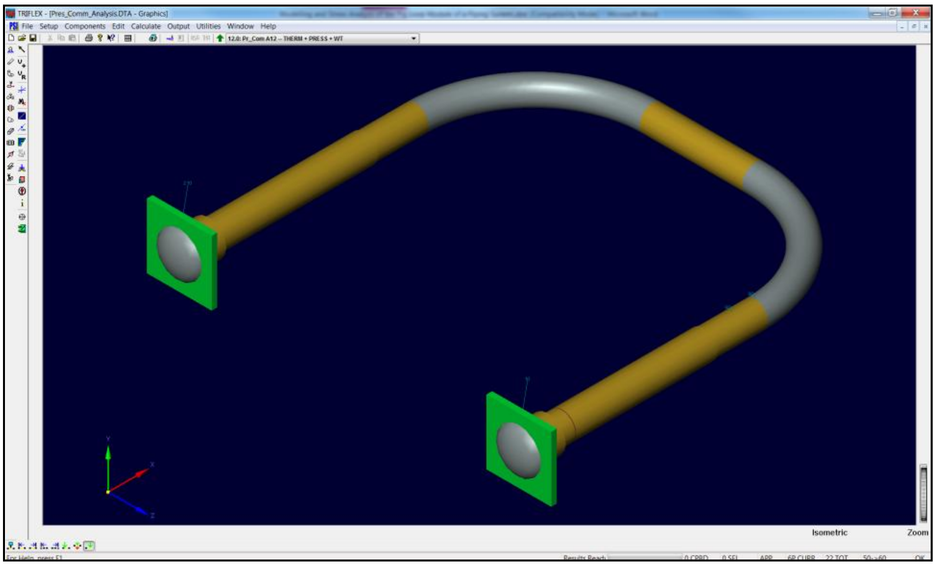

Figure 1: Model of PLM showing Orientation.

The PLM piping was split in three parts and anchored at both ends. The parts are:

- A - The Termination head Inner body made of forged F22 Grade material
- B - Transition pup of 22% Duplex material, fabricated from Seamless/Hipping process
- C - Large bore pipe of 22% Duplex material, fabricated from Trepanning process.

The Large bore pipe is further coded in parts represented by nodes. Fig. 2 shows a wireframe model of the PLM showing the nodes.

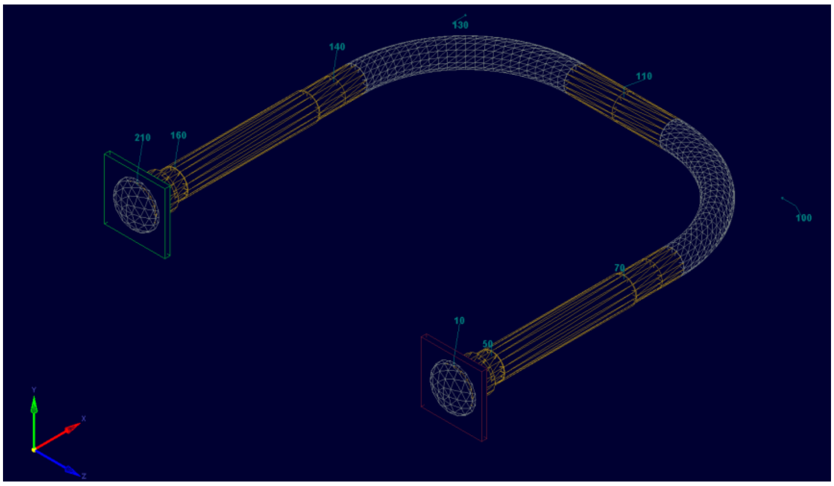

Figure 2: Wireframe Model of PLM showing nodes.

For details of properties for the various parts of the pig loop module, see Table 3 below.

Table 3: Properties of Material of Construction for PLM.

Part	Part Name	MoC	SMYS(MPa)	Material Quality
A	Termination Body	Material F22	517	No HISC
B	Transition Pulp	22% Duplex-Hipped	412	Fine grain
C	12" Large bore	22% Duplex-Trepanned	412	Coarse grain

5 Results of Analysis

Stress Utilization results for three different alternative options were checked and recorded for the various load case scenarios analysed. Whereas the detailed results are displayed in Table 4, a summarized result of the highest utilization results for the entire analysis is shown in Table 5.

Table 4: Results of utilizations of the PLM.

Scenario	S_h	S_{h*}	α	S_L	S_{L*}	β	S_Ω	$S_{\Omega*}$	γ	Node
Operation+Hot	202	280	72	199	280	71	230	280	82	130
Operation+Cold	202	305	66	195	305	64	228	305	75	130
Commissioning	254	305	88	210	305	69	259	305	85	130
Press+FAT	332	448	74	150	448	34	291	448	65	110
Transportation	0	448	0	43	448	10	43	448	10	170
Landing	0	448	0	117	448	26	144	448	32	180
Splash Zone	0	448	0	30	448	7	30	448	7	170
Connection/Dis	0	448	0	252	448	56	286	448	63	90

Where:

S_h = Hoop Stress in N/mm^2
S_{h*} = Allowable Hoop Stress in N/mm^2
α = Hoop Stress Utilization in %
S_L = Longitudinal Stress in N/mm^2
S_{L*} = Allowable Longitudinal Stress in N/mm^2
β = Longitudinal Stress Utilization in %
S_Ω = Combined Stress in N/mm^2
$S_{\Omega*}$ = Allowable Combined Stress in N/mm^2
γ = Combined Stress Utilization in %

Table 5: Summary of largest utilizations of the PLM.

Service	S_h	Scenario	S_L	Scenario	S_{Comb}	Scenario
12" ID Header	88%	Commissioning	71%	Operation+Hot	85%	Commissioning

Where:

S_h = Hoop Stress Maximum Utilization
S_L = Longitudinal Stress Maximum Utilization
S_{Comb} = Combined Stress Maximum Utilization

From results obtained, the pressure commissioning scenario is the most critical of all the load cases checked. The stress plot/ stress utilization results are displayed from Figs. 3 through 5 for Hoop Stress, Longitudinal Stress and Combined Stress respectively. Figs. 6 through 8 show the variations of Hoop, Longitudinal and Combined stresses respectively with the scenarios checked.

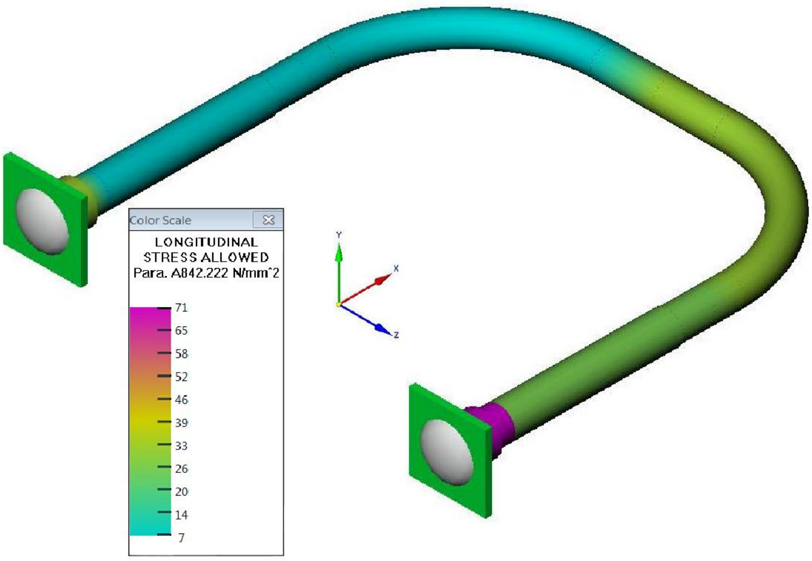

Figure 3: Stress Plot for Maximum Hoop Stress utilization during Pressure Test Commissioning Scenario.

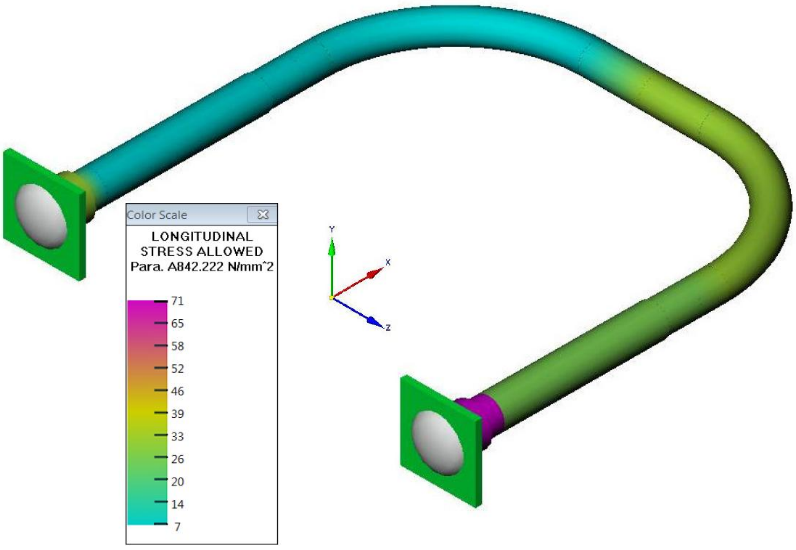

Figure 4: Stress Plot for Maximum Longitudinal Stress utilization during Operation+Hot Scenario.

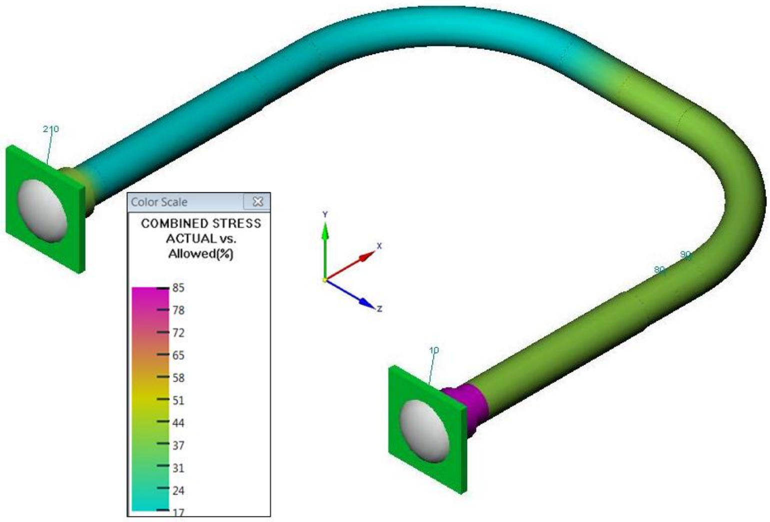

Figure 5: Stress Plot for Combined stress (Von Mises) utilization during Pressure Test Commissioning Scenario.

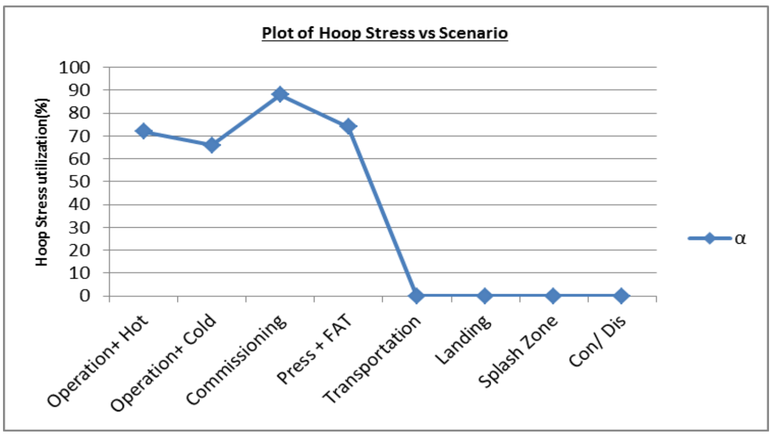

Figure 6: A graph showing variation of hoop stress for the scenarios analysed.

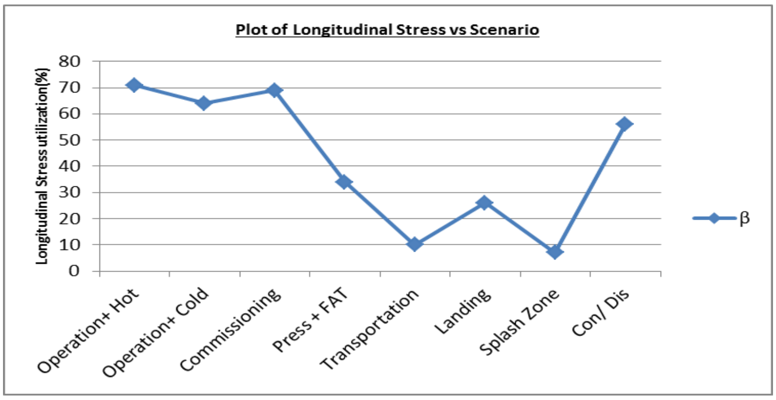

Figure 7: Variation of Longitudinal stresses of the system.

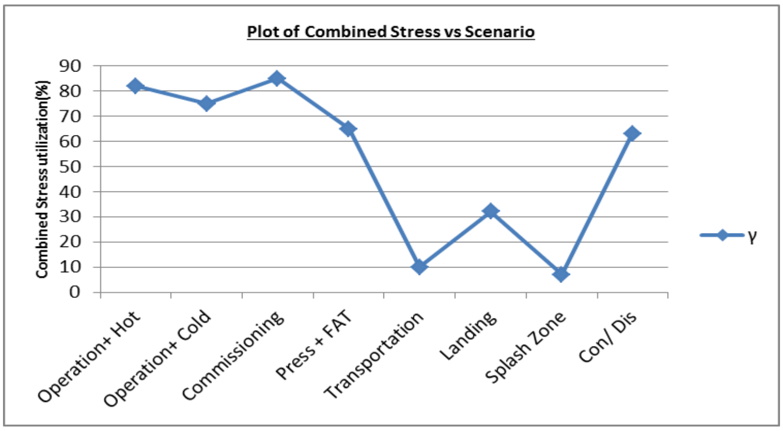

Figure 8: Variation of Combined stresses of the system.

6 Conclusion

Stress analysis has been performed for a pig loop module of a submarine manifold according to ASME B31.8 piping code, using Triflex. Various stress values were checked for different global scenarios and results of maximum utilizations obtained were noted. Since the programme used did not return any error message during the analysis, we could confirm a consistency in the geometric input and this goes to show that the system is safe for operations.

7 Bibliographical Notes.

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