Need for Sea Transportation Stress Analysis of Large Bore Pipe in a Modularized Project

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Abstract - In today's competitive environment, where costs, schedules and quality govern the market, modularization has become the most important trend in engineering. The advantage of modular project is better quality control, simpler construction at site, flexibility in scheduling and many other benefits. Modular concept is commonly used for fabrication of floating and offshore platforms for undersea oil and natural gas extraction, but in this paper we will be discussing about the land based facilities. Process equipment, process unit and pipe rack modules are generally constructed in facilities called Module yards (Mod Yard), which are equipped with special facilities. The fabricated modules are then transported from Modular yard to the construction site via different modes like sea, road or rail. During sea transportation modular piping experiences various motions due to ship acceleration, wind velocity, and deck deflecting action and deflection of structural steel due to sea waves. This calls for researching deeper into further aspects of piping behavior during sea transportation.

Transportation analysis helps in ensuring that the pipe work and its components are not overstressed and thereby preventing practical damage to the connected equipments as far as possible. This paper's intent is to understand the requirement of sea transportation analysis for large bore piping system for a safer design during transportation.

Index Terms - Modularization, Transportation analysis, Sea transportation, Barge transportation, Need for Transportation Analysis, Ocean Transportation, Piping Stress Analysis

1 Introduction

Transportation analysis refers to examination of various conditions cargo or module would experience during transit from one location to another.

For sea transportation analysis, an engineer needs to apply transit acceleration values along with the wind and structural displacements due to ship acceleration based on the past years of sea wave data received from the naval architect. These conditions shall be considered for checking maximum displacement stress range, fatigue stress, occasional stress, nozzle evaluation and piping reaction loads on support structure.

The objective of transportation analysis is to ensure the integrity of piping system and connected equipment nozzle, so that pre-installed pipes are transported safely and secured the correct location as required for construction.

2 Factors Affecting Sea Transportation

2.1 Loading Due to Ship Acceleration

Sea transportation loading are based on the extreme conditions of sea considering the seasonal storm received from marine architect department and calculated relative ship motions.

During transportation, relative motion between the ship and the water surface creates ship motions. A ship with steady forward speed in irregular short-crested sea will oscillate in six degrees of freedom divided into three types of linear motion and three types of rotational motion. Refer Fig 1.

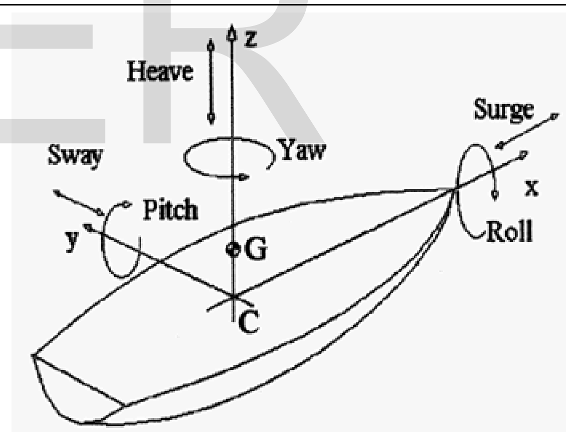

Fig. 1 - Type of Ship Movement [4b]

Ship movement can be summarized as per the table-1 given below.

Table 1 - Ship Movement

LINEAR MOTION	ROTATIONAL MOTION
Surging is motion along the longitudinal axis.	Rolling is motion around the longitudinal axis.
Swaying is motion along the transverse axis.	Pitching is motion around the transverse axis.
Heaving is motion along the vertical axis.	Yawing is motion around the vertical axis.

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These Linear and Rotational motions of ship with the wave action are applied on the module in the form of accelerations. The acceleration values depend on the shape of the surface or sub-surface ship, its beam, the position of the center of gravity and center of buoyancy and other parameters which determine the behavior of ships during transportation at sea.

During the Transportation, piping system will experience acceleration due to different types of wave condition influenced by the wind and arrangement of structures on the ships.

There are four primary wave conditions which a ship can experience during its travel. They are Head sea, Beam Sea, Following Sea, and Quartering Sea. These wave conditions are playing major role in Ship/piping acceleration. Refer Fig 2 for type of wave conditions.

A mass of wave's direction flowing directly towards ship is called head sea. This set of opposite waves will push the ship backside.

When the direction of the waves is exactly perpendicular to the ship travel direction is called Beam Sea. Because of Beam Sea, Ship experiences rolling motion.

A following sea is exactly opposite to head sea.

When heading straight downwind, with waves heading exactly in the same direction as your ship, is known as a following sea.

A Quartering sea is a wave condition in which the wave is going to strike the ship at an angle of about 45 degrees to ship's heading direction.

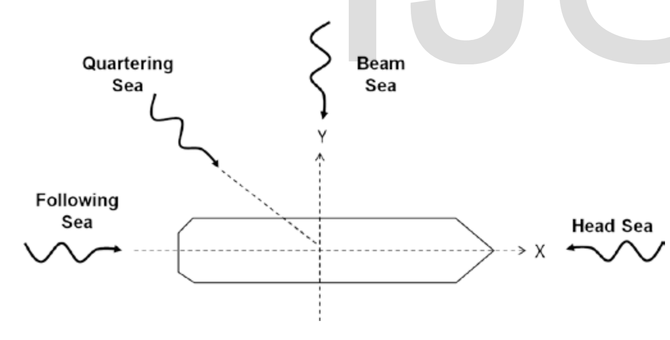

Fig. 2 - Type of wave conditions

Surge, Sway and heave accelerations are used for finalizing the ship behavior at C.O.R of ship according to GL Noble Denton. These acceleration values are provided by Maritime Administration & Maritime Safety Committee and it varies for different routes. It shall be re-calculated for local acceleration (which is called as Cargo forces) at piping location using corresponding code. Refer fig 3.

These accelerations are calculated using the loading factor equations. The loading factor is a calculated number given in terms of gravitational and dynamic acceleration which, then multiplied by the mass of a structure or equipment, determines the design load of such structure or equipment in the longitudinal, transverse, and vertical directions as a result of the accelerations of gravity and ship motion. Loading factors are dependent on the magnitude and frequency of ship motions, ship altitude, and location in the ship of the structure or equipment under consideration. [2]

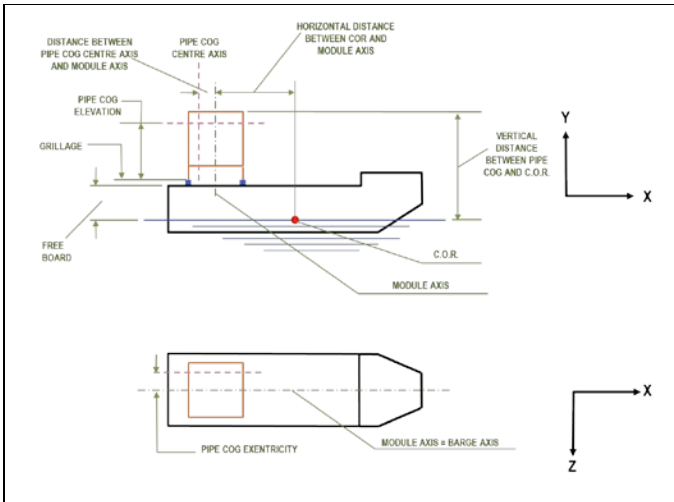

Fig. 3 - Cargo/Barge forces calculation at piping COG

To define surge, sway, and heave resultants, the equations are used as per table-2.

Table - 2 : Equations to calculate surge, sway & heave resultants [2]

$$A_x = g\sin\theta + s + \left(\frac{4\pi^2}{{T_p}^2}\,\theta^2 X\right) + \left(\frac{4\pi^2}{{T_p}^2}\,\theta Z\right)$$

...Equation (1)

$$A_y = g\sin\emptyset + \frac{1}{2}\times\left(\frac{4\pi^2}{{T_p}^2}\,\theta X\right) + \left(\frac{4\pi^2}{{T_r}^2}\,\emptyset^2 Y\right) + \frac{4\pi^2}{{T_r}^2}\,\emptyset Z$$

...Equation (2)

$$A_z = g \pm \left(h + \frac{4\pi^2}{{T_p}^2}\,\theta X + \frac{4\pi^2}{{T_r}^2}\,\emptyset Y\right)$$

...Equation (3)

where, θ = maximum pitch angle (radians)
Φ = maximum roll angle (radians)
A ( ) = Loading factor in x, y or z direction
Tp = Pitch period (seconds)
Tr = Roll period (seconds)
h = heave acceleration (meter per square second)
s = surge acceleration (meter per square second)
X = Longitudinal distance from centre of gravity (meters)
Y = Transverse distance from centre of gravity (meters)
Z = vertical distance above centre of gravity (meters)
g = acceleration due to gravity (9.807 meter per square second)
and in equation (3) for Az, + sign relates to downward force and - sign relates to upward force

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2.2 Loading Due to Ship (Hull) Deflection

Hogging and sagging describe the shape of a beam or similar long object when loading is applied. Hogging describes a beam which curves upwards in the middle, and sagging describes a beam which curves downwards. [4e]

For ships, hogging occurs when the peak of a wave is amidships, causing the hull to bend so the ends of the keel are lower than the middle. Similarly, sagging occurs when the trough of a wave is amidships, causing the hull to deflect so the ends of the keel are higher than the middle. [4f]

The stresses produced in the piping systems due to impact of Hog and Sag deflection should be within the allowable values as per applicable piping codes.

Naval architects usually provides the ship deflection data and the specific hog and sag values are to be used at support locations for the corresponding piping system with respect to module column spacing and location.

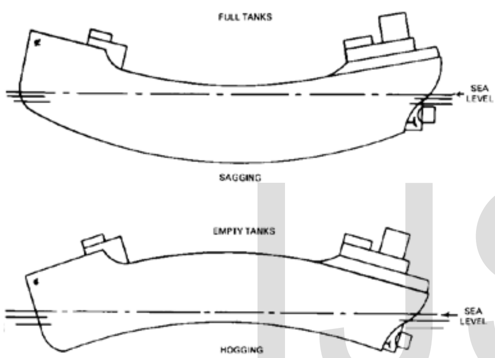


Fig. 4 - Hogging and Sagging [4c]

Generally, as a good engineering practice, the hog and sag values are applied where the module length is greater than one-third length of the ship.

2.3 Loading Due to Structural Deflection

During transportation, the module structures experiencing differential displacements/movements on horizontal axis due to hull motion. These differential displacements/movements have to be considered in piping support displacements.

Deflection of structure (D or d) should be limited to h/k for sea-transportation, where h is height of structure and k is a constant value. In general practice, it is taken as 300. This (h/k) ratio is used by structural group for module displacement calculations as per GL Nobel Denton data. We are assuming that the directions for structural deflection are proportional to the acceleration of ship.

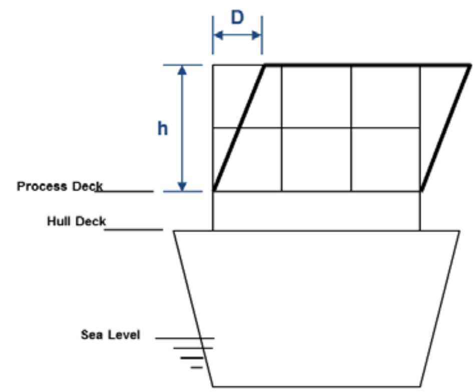


Fig. 5 - Structural Motion Generating displacements

2.4 Loading Due to Wind

The availability of Maritime transport information and the actual voyage route plays a major role in determining the wind speed.

During transportation, effect of wind has to be taken into account for the design of exposed piping system. The loading effect due to wind pressure needs to be considered to calculate the stresses generated in the piping system and the load acting on the structures.

2.5 Fatigue Loading

Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The maximum stress values are less than the ultimate tensile stress limit and may be below the yield stress limit of the material. Fatigue failure is like brittle fractures say sudden and catastrophic failure even in ductile materials. After number of cycles the object becomes too weak and finally it fails.

Hull motion and deflection are the causes for fatigue failure in ships. And this fatigue failure/fatigue life calculation is based on cumulative damage theory also known as Palmgren-Miner rule.

Table - 3 : Equation of minor rule [4d]

$$\sum_{i=1}^{2} \frac{n_i}{N_i} = c$$

...Equation (4)

where

n_i = the number of applied cycles at i^{th} level of stress

N_i = the number of cycles for failure at i^{th} level of stress

C = the damage fraction of life consumed by exposure to the cycles at the different stress levels.

i = number of level for various stress values

k = any natural number

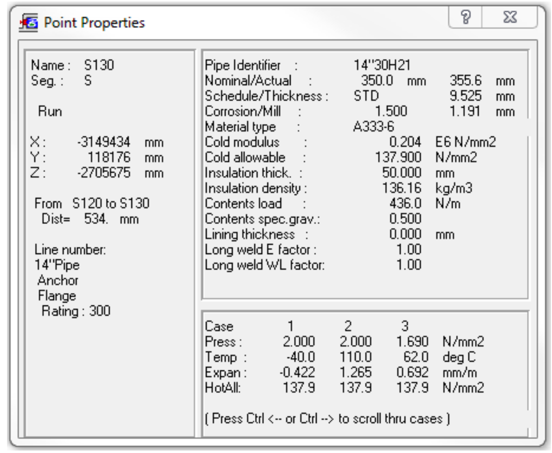
Palmgren-Miner rule assumes that total damage caused by the number of stress cycle equal to summation of damages caused by individual stress cycle. Also assumes that stress cycles with alternating stress above the endurance limit inflicts a measurable permanent damage. Equation of minor rule is given in table-3.

In general, the failure of piping system occurs when the damage fraction reaches 1.

3 Case Study

3.1 Description

The piping system considered for study is a 14" STD schedule carbon steel pipe. It is connected to vendor package at one location which is to be considered connected while transportation and on the other end, it is connected to a header on pipe rack. In order to simplify the analysis, thermal displacements at node P110 are included in the system. The node P110 will be free during transportation as the connected piping is not part of module. The piping system has a maximum design temperature of 110 degree C, operating temperature of 62 degree C and minimum design temperature of -40 degree C. It has a design pressure of 2 MPa and operating pressure of 1.69 MPa. The piping system under consideration is being fabricated at a site in South Korea and then, it will be transported via Caspian Sea. And finally, it will be erected at the construction site in Kazakhstan. Bentley Autopipe has been used as the software for the purpose of modelling and analysis of the piping system. Please refer the Fig 6 for the system considered.



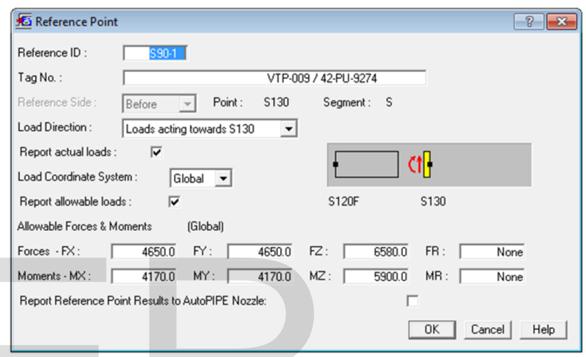
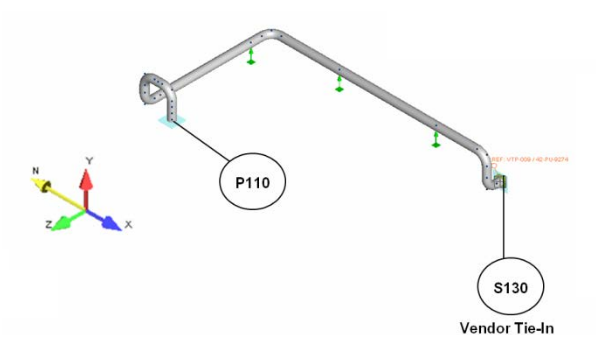


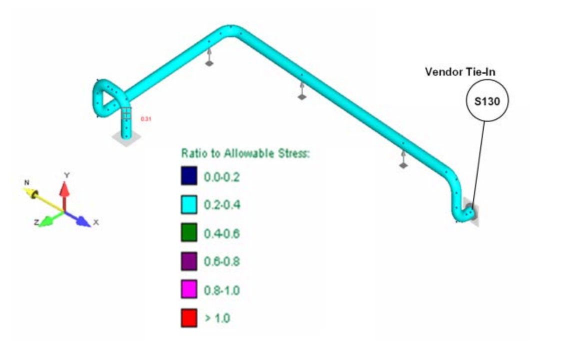
Fig. 6 - Piping system considered



THERMAL DISPLACEMENT VALUES IMPOSED AT NODE NUMBER P110 IN mm :-			
DISPLACEMENTS IN X/Y/Z AXIS ➡	DX	DY	DZ
@ 20 barg & -40 degree C	0.05	0.20	-1.10
@ 20 barg & 110 degree C	-0.50	-0.10	3.10
@ 16.9 barg & 62 degree C	-0.10	-0.10	1.80

3.2 Static Analysis

The piping system satisfies ASME B31.3 (2012) code requirements for operational analysis with the optimum number of supports as per Fig 7.



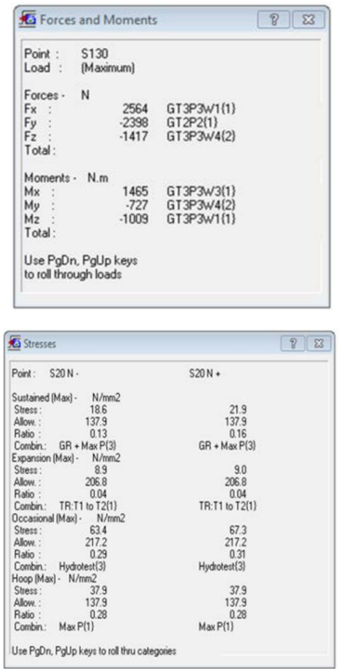


Fig. 7 - Piping system qualifying in operational analysis with adequate supports

3.3 Sea Transportation Analysis

It is assumed that the modular piping system is placed and transported parallel to the Ship axis (X direction in Auto pipe) and the longitudinal axis of the module is perpendicular to the ship axis (Z direction in Auto pipe). The relative hog and sag values along with wind and sea acceleration are calculated based on the module location from COR of ship and are applied on the piping system. The values for acceleration used are taken from the Marine Department. Also the line is considered empty with zero corrosion allowance and taking temperature as ambient (0 degree C for this case) and pressure values as atmospheric pressure (i.e. 0 MPa).

Refer Fig 8 for the hog and sag values considered.

Refer Fig 9a for hog and sag values applied in Autopipe and Fig 9b for allowable loads and moments applied at vendor tie-in point during transportation.

Imposed Support Displacements (in mm)							
Point	Case	Translation-X	Translation-Y	Translation-Z	Rotation-X	Rotation-Y	Rotation-Z
S60	T1	0	-226.0543468	0	0	0	0
S70	T1	0	-220.8749004	0	0	0	0
S90	T1	0	-219.6202458	0	0	0	0
S100	T1	0	-219.6202458	0	0	0	0
S130	T1	0	-218.7846308	0	0	0	0
S60	T2	0	140.9424717	0	0	0	0
S70	T2	0	137.7540088	0	0	0	0
S90	T2	0	136.975723	0	0	0	0
S100	T2	0	136.975723	0	0	0	0
S130	T2	0	136.4563354	0	0	0	0

Fig. 8 - Hog & Sag Displacements considered for piping during sea transportation

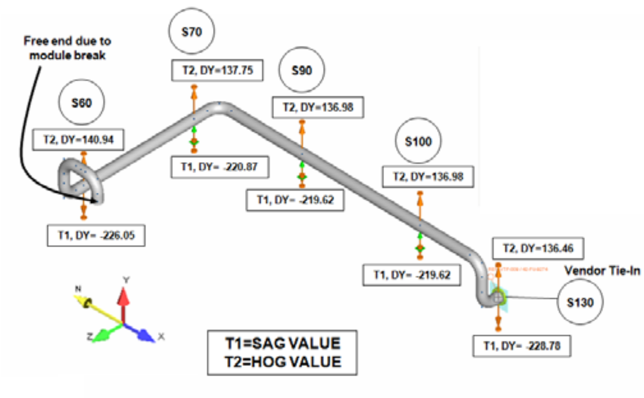


Fig. 9a - Hog & Sag displacement values applied to piping system during sea transportation

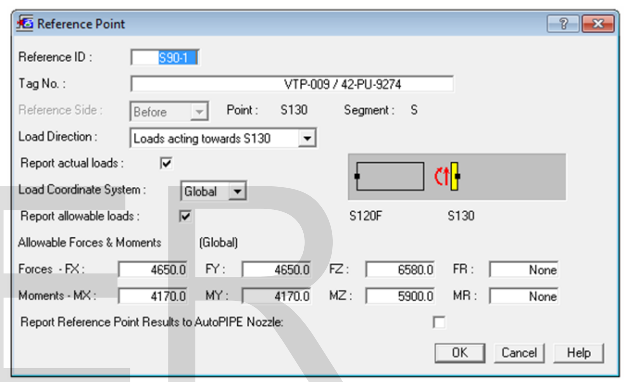


Fig. 9b - Allowable Loads and moments applied at vendor tie-in point during transportation

Refer Fig 10 for wind profile applied in Autopipe.

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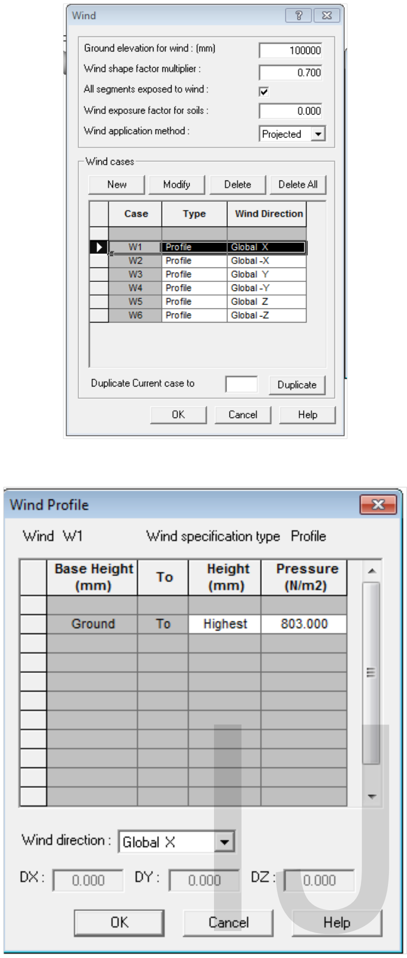
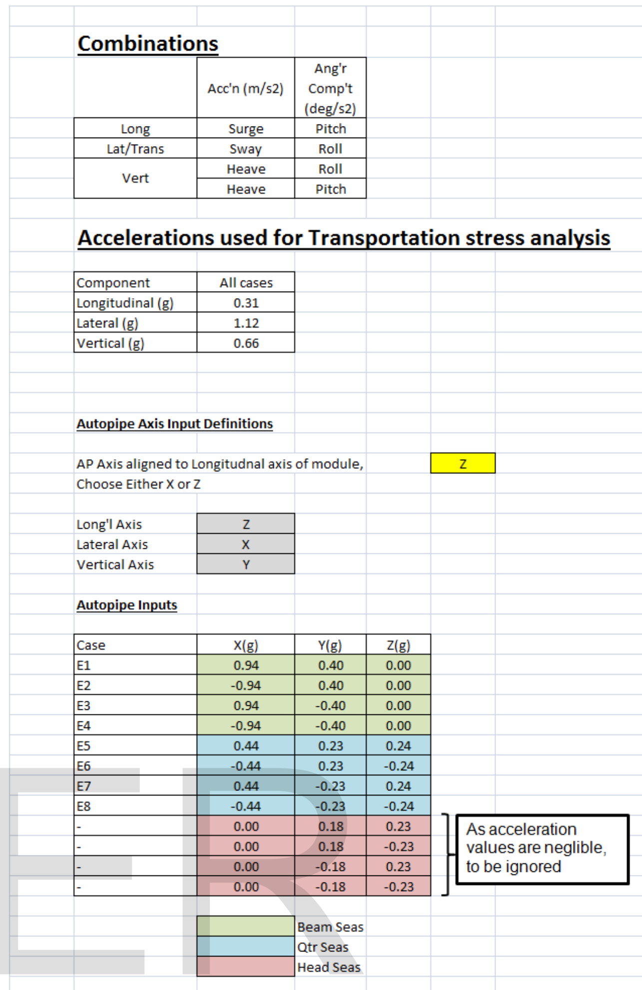


Fig. 10 - Wind Profile applied to piping during Transportation



Combinations

	Acc'n (m/s2)	Ang'r Comp't (deg/s2)
Long	Surge	Pitch
Lat/Trans	Sway	Roll
Vert	Heave	Roll
	Heave	Pitch

Accelerations used for Transportation stress analysis

Component	All cases
Longitudinal (g)	0.31
Lateral (g)	1.12
Vertical (g)	0.66

Autopipe Axis Input Definitions

AP Axis aligned to Longitudnal axis of module, Choose Either X or Z: Z

Long'l Axis	Z
Lateral Axis	X
Vertical Axis	Y

Autopipe Inputs

Case	X(g)	Y(g)	Z(g)
E1	0.94	0.40	0.00
E2	-0.94	0.40	0.00
E3	0.94	-0.40	0.00
E4	-0.94	-0.40	0.00
E5	0.44	0.23	0.24
E6	-0.44	0.23	-0.24
E7	0.44	-0.23	0.24
E8	-0.44	-0.23	-0.24
-	0.00	0.18	0.23
-	0.00	0.18	-0.23
-	0.00	-0.18	0.23
-	0.00	-0.18	-0.23

As acceleration values are neglible, to be ignored

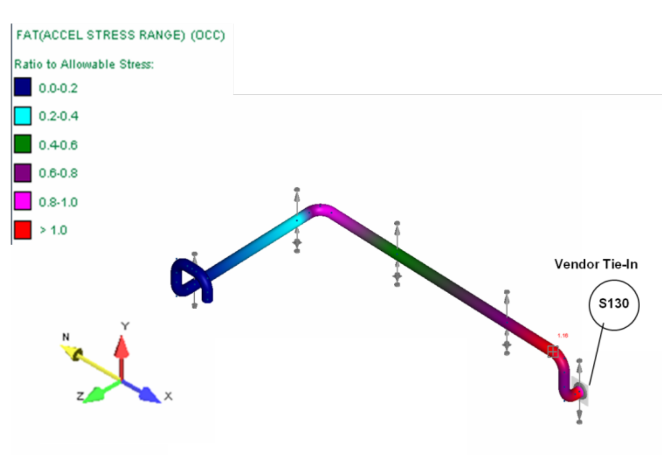
Beam Seas
Qtr Seas
Head Seas

Fig.11 - Sea Acceleration applied to piping during Transportation

The structural deflections are not considered in this case. Also, the sea acceleration values due to Head seas have been ignored as they are very low and will not have any major impact.

Refer Fig 11 for sea acceleration values applied in Autopipe.

The magnitude of stress generated in the piping system is very high during acceleration and exceeds the allowable value of 183.4 MPa [1] (as per ASME B31.3 2012) by 16%. In addition to this, the loads and moments at the vendor tie-in point are also high and these should be limited within the vendor allowable. Refer Fig 12.



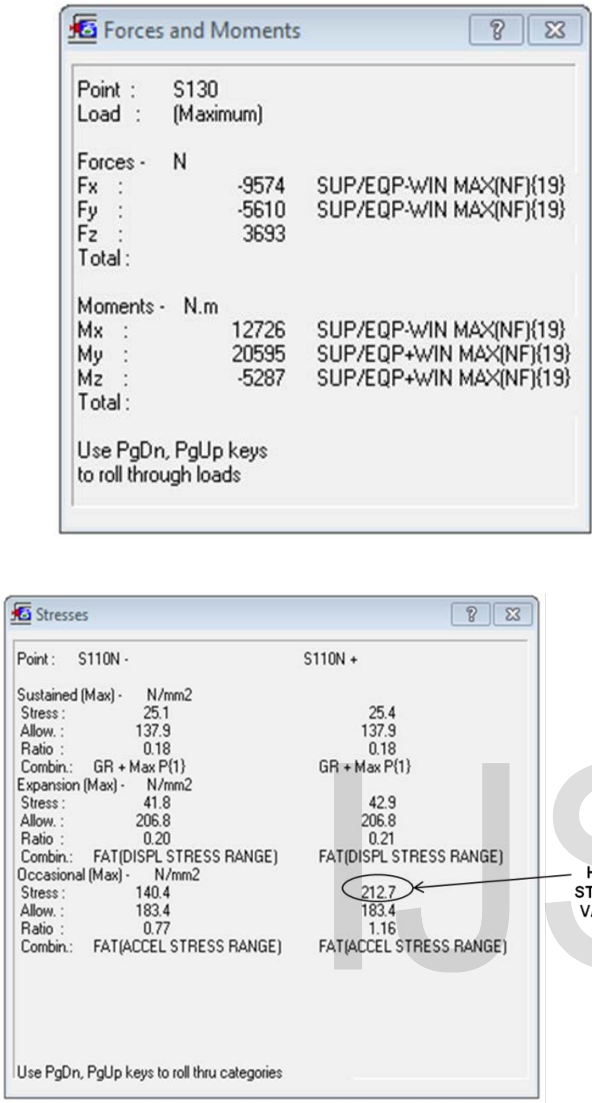


Fig. 12 - Failure of piping in stresses as well as allowable at vendor tie-in

In order to qualify the system, additional temporary restraints are required during the transportation stress analysis phase. The transportation analysis is carried out again and the piping system is found to be within the safe limit. Refer Fig 13.

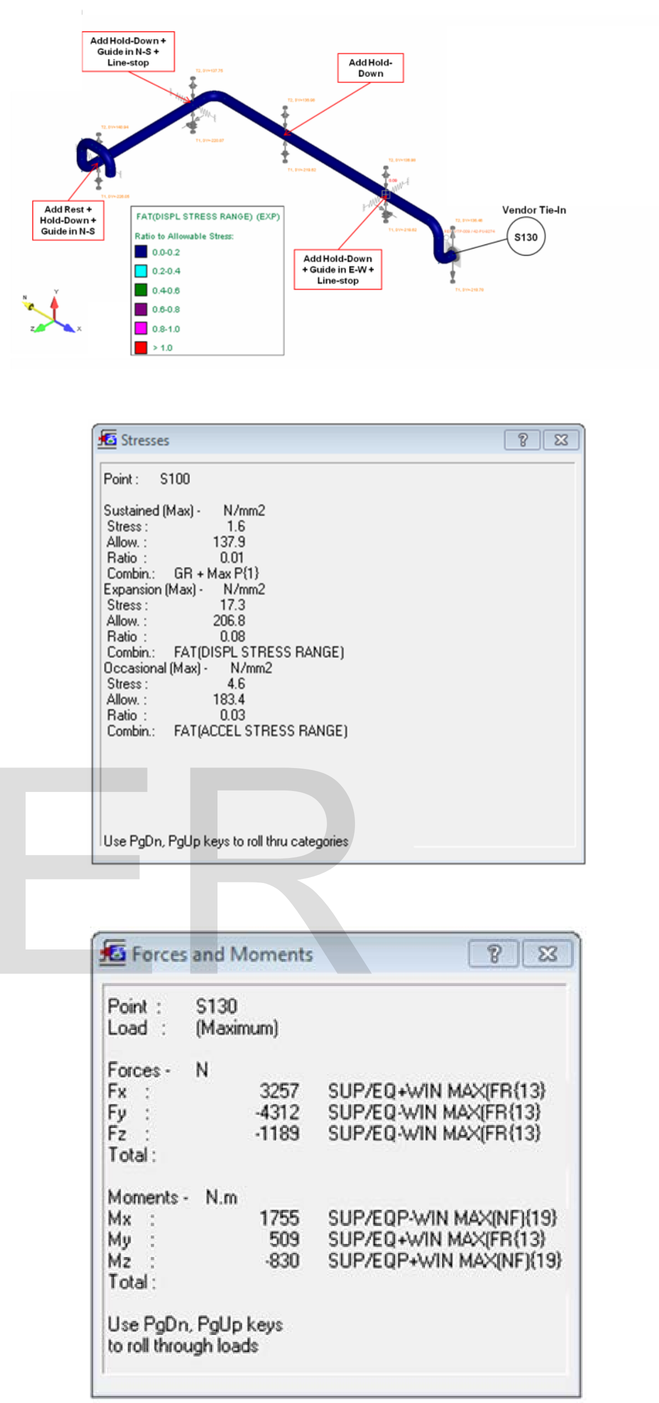


Fig. 13 - Piping system qualified by providing additional temporary supports during transportation

The additional temporary restraints must be removed post transportation, when the module is being installed at final location before start-up of the plant, to prevent the failure of system during normal operating condition.

3.4 Interpretation

It can be seen from the case study that the piping system was not safe during sea transportation and certain measures were required to ensure the safety of the system and connecting equipment. As it is the responsibility of the piping stress engineer to prevent instability of the piping system during sea transportation, therefore, carrying out proper transportation analysis will ensure the safety of the system.

4 ILLUSTRATIONS FOR PIPING DAMAGES WHILE TRANSPORTATION

The piping gets damaged in various ways during transportation. The misalignment of equipment nozzle, dislocation of pipes, damage to valves and flanges, deflected pipes, damage to structural steel due to clash with pipes etc. are few types of damages that are caused during sea transportation.

Refer Fig 14 for some of the ways in which the piping gets damaged during sea transportation due to lack of supports.

Fig. 14 - Damage to piping due to lack of proper transportation supports

5 CONCLUSION

Based on the case study, it can be concluded that carrying out transportation analysis for large bore piping not only safe guards the piping system but also enables engineers to determine the required shipping restraints. These restraints help in controlling the deflection of piping and to resist the effect of the accelerations and structure / equipment imposed displacements on the piping due to shipping. The analysis also helps in computing the significant shipping loads which can be used by structural group for steel design.

Transportation analysis also ensures that the pre-installed pipes are secured at the correct location and minimizes the misalignment between two modules post transportation. Transportation analysis helps to determine whether the connection between piping and equipment are safe and if not, then the disconnections can be recommended in order to avoid any damages to equipment or ships.

Temporary supports used during transportation must be designed for fatigue characteristics, adequate strength to resist the dynamic loading. Temporary Supports should be painted with bright fluorescent color coding for easy identification and removal at job-site.

Transportation analysis also helps in determining whether the engineered items such as spring hangers, struts, bellow etc. shall be in locked position or shipped loose during transportation.

The absence of transportation analysis does not guarantee the safety of the shipped module and generally incur extensive strapping of piping system. The extensive strapping results in wastage of time, cost and man-hours.

As industry moves towards cost-effective and schedule driven projects, carrying out transportation stress analysis ensures the safety of the modules during sea transportation.

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7 Units & Abbreviations

- COR - CENTRE OF ROTATION
- COG - CENTRE OF GRAVITY
- STD - STANDARD
- C - CELSIUS
- MPa - MEGA PASCAL
- ASME - AMERICAN SOCIETY OF MECHANICAL ENGINEERS
- Fig - FIGURE
- degree/s2 - DEGREE PER SQUARE SECONDS
- m - METER
- mm - MILLIMETER
- m/s^2 - METER PER SQUARE SECONDS
- g - ACCELERATION DUE TO GRAVITY
- N - NEWTON
- N/mm^2 - NEWTON PER SQUARE MILLIMETER
- N.m - NEWTON METER

8 References

[1] ASME B31.3 Process Piping Code.
[2] Interface standard for shipboard systems DOD-STD-1399 (NAVY) SECTION 301A.
[3] DNVGL-ST-N001GL Noble Denton Guidelines For Marine Transportation
[4] **Websites and Links**
   a. http://www.google.com
   b. http://mingaonline.uach.cl/scielo.php?pid=S0718-025X2006000100004&script=sci_arttext
   c. https://www.globalsecurity.org/military/library/policy/army/fm/10-67-1/CHAP4.HTML
   d. http://www.public.iastate.edu/~e_m.424/Palmgren-Miner.pdf
   e. https://en.wikipedia.org/wiki/Hogging_and_sagging
   f. https://en.wikipedia.org/wiki/Glossary_of_nautical_terms#H
[5] PD 5500, Annex C - Assessment of vessels subject to fatigue.