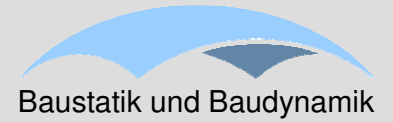


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Baustatik und Baudynamik

STRUCTURAL ANALYSIS OF A HEAVY-LIFT VESSEL

submitted by

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Master Thesis

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In co-operation with

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-Prakash.E.M

ABSTRACT

Dockwise is market leader in transport of extremely large and heavy cargoes. The world's largest heavy transport carrier **Blue Marlin** is able to carry ultra large and heavy floating production and drilling platforms up to 73,000tons. The Blue Marlin enables oil companies to build fully integrated units anywhere in the world and transport them to the final offshore destination, in order to limit hook up and commissioning at the offshore location.

Even though Blue Marlin is capable of transporting ultra heavy loads, the load-out of SPAR buoy weighing 20,000tons by skidding over the stern of the vessel poses difficulties to structure at the stern section mainly due to the engine room which is located on the stern and is quite a large section with out any bulkheads to carry the load.

The purpose of the thesis is to investigate the possibility of transporting a Future SPAR which weighs 35855tons. The structure of the vessel is investigated using FEA software FEMAP with Nx Nastran solver to study the feasibility of transporting "Future SPAR". An approximate model of the future SPAR is created in FEMAP environment and the model is used to load the vessel structure.

Several steps are linearly analyzed, based on the parameters such as position of SPAR on vessel deck, number of skid beams and method used for loading-out. By studying the results of the analysis the best possible method to load-out the SPAR has been recommended.

Declaration

I, Mr. Prakash E. Mohanasundaram, declare that this master's thesis is written independently and no sources have been used other than the stated references.

.....
Place/Date

.....
Signature

Master Thesis

Structural Analysis & Optimization of a Heavy-Lift Vessel

Dockwise is market leader in transport of extremely large and heavy cargoes. Dockwise serves its clients with a fleet of 22 semi-submersible vessels of different types and designs. The world's largest heavy transport carrier **Blue Marlin** is able to carry ultra large and heavy floating production and drilling platforms up to 73,000tons. The Blue Marlin enables oil companies to build fully integrated units anywhere in the world and transport them to the final off-shore destination, in order to limit hook up and commissioning at the offshore location.

Even though Blue Marlin is capable of transporting ultra heavy loads, the load-out of SPAR buoy weighing 20,000tons by skidding over the stern of the vessel poses difficulties to structure at the stern section which causes bending and buckling of the deck. The structure of the vessel has to be investigated to find out constraints affecting the integration of the structure during such load-outs and explore ways to improve and optimize it. And also to increase the load carrying capacity of the vessel's structure during stern skidded load-out of SPAR buoy's from 20,000tons to 40,000tons.



In particular, the following steps have to be performed:

- Review of existing structure of the vessel and study the process of the stern skidded load-out to find the parameters involved.
- Analysis of the vessel model using Finite Element Method based on the parameters collected using the commercial software package FEMAP with integrated solver NX Nastran.
- Investigation of the results obtained from the analysis to identify the constraints affecting the structure during loading process.
- Explore ways to improve and optimize the structure and depicting recommendations.

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CHAPTER 1

INTRODUCTION OF THE THESIS

1.1 Motivation



In the summer of 2001 Dockwise carried out the first single piece of Truss SPAR transport across the Atlantic from Technip fabrication yard in Pori, Finland to Gulf of Mexico using its heavy lift carrier vessel Might Servant 1. The weight of the SPAR transported was 21390 Tons.

The notion of this thesis came into existence when Dockwise shipping B.V head office in Breda, The Netherlands was contacted by Technip Offshore Finland to transport a SPAR from Pori in Finland to US Gulf with an expected departure date of mid April 2012. This time Technip came up with a proposal requesting Dockwise to evaluate the feasibility of transporting a SPAR weighing 35000Tons. The spar, if realized, will be the largest ever. The SPAR is termed by Dockwise as "Future SPAR".

Engineering Team at Dockwise revised the technical details of the SPAR received from Technip and came to a decision that the SPAR can not be transported by the vessel Mighty Servant 1 as its deadweight carrying capacity is 40,000 Tons. Transporting a SPAR of 35,000 Tons with all the other accessories, sea fastening supports and grillages would push the structure of Mighty Servant 1 to its limits. So the SPAR can only be transported by its Heavy lift carrier vessel MV Blue Marlin which has a capacity of carrying ultra heavy load of up to 73,000 tons.

1.2 Objective and Overview of Thesis

Even though Blue Marlin is capable of transporting ultra heavy loads, engineers at Dockwise are expecting some heavy loading on the structure at the stern section of the ship. Load-out of heavy cargoes over the stern of the vessel as it would be done with Future SPAR might induce heavy stresses on the structure, mainly because of two reasons:

1. The engine room which is located on the stern of the vessel and is quite a large section with out any bulkheads to carry the load.
2. The stern section is an overhang above the propeller which allows Blue Marlin to dock with keyside along the stern to load-out the cargoes. If translated, which also means that the water pressure which acts as a support under the vessel could be less in the stern section compared to the mid ship or even no water contact depending on the draft of the vessel. This exposes the structure of the vessel in stern section for heavy loading condition.

The vessel structure is investigated in the frame work of Finite Element Analysis using package FEMAP with Nx Nastran.

1.3 Methodology

The load-out conditions are re-created as a Finite Element model in FEMAP with Nx Nastran software package and the structure of the vessel is investigated to study the feasibility of transporting "Future SPAR" which weighs almost 40,000 tons and to find out the weak spots affecting the vessel's structure during load-out of the "Future SPAR" and explore ways to improve/optimize it.

The objective of the thesis can be listed as:

1. Based on the criteria and parameters of the SPAR and the vessel, the possible stowage positions of the SPAR on the vessel deck are investigated.
2. The most critical stowage position, in terms of structural loads is identified and possible load-out methods of the SPAR are studied to find out the most feasible load-out conditions.
3. The conditions are then further analyzed using Finite Element Method.

CHAPTER 2

SPAR



SPAR is an offshore floating structures used for deep sea oil drilling and production. It is a cylindrical hollow structure with inner structural members to form tanks which creates buoyancy to keep the weight of the topside and self weight of the SPAR floating in the high seas. It is designed in such a way to adapt to the ocean currents and provide damping for the whole structure with the topside to be stable in the sea during all weather conditions. As of now there are more than 15 SPAR's installed on the world's oceans, most of the SPAR's are built by Technip, a world leader in the offshore structures. SPAR will be moored to the sea bed for preventing the motion due to the ocean currents.

Fig 2.1 SPAR with production platform [3]

2.1 Spar types and description

There are three types of production spars built so far, they are classic, truss and cell spars. They differ in design due to the technological advances in the field. The classic SPAR is rather a cylindrical structure from the top to bottom. A truss SPAR has a cylindrical tank at the top and a truss in the middle section and a square tank at the bottom. The cell SPAR is a new generation of the SPAR's it is much cheaper and easier to build.

The basic parts of a typical spar are;

1. Hard tank
2. Middle section
3. Soft tank

The name hard tank means that the stiffness of the section is high as it contains internal structural members to make the tank into compartments to be able to withstand the hydrodynamic pressure imposed by the waves. The hard tank provides the sufficient buoyancy to support the weight of the topside and also the self weight of the SPAR. There are usually five to six levels of tanks inside separated by watertight decks. Each level is further divided in to four compartments. Usually only the bottom level of the compartments is used for ballasting of the SPAR, other compartments are empty spaces to provide the floatation to the SPAR structure.



Figure 2.2 Progressions of Spar (Technip Offshore) [4]

The midsection section below the hard tank is designed to give the deep draft necessary for the SPAR to prevent the swaying of the SPAR in ocean currents. The midsection of the a classic SPAR is just an extension of the outer cylindrical shell of the hard tank. There are no internal structures. The truss SPAR's as the name indicated contains a truss in the midsection, the truss SPAR reduced the weight of the SPAR and is also less expensive than a classic SPAR and has less drag and also reduces loads on the mooring lines.

The soft tank is designed for providing floatation for the SPAR during installation process where it is floatation horizontally. It also has compartments for the fixed ballast to keep the SPAR upended.

2.2 Spar Construction

SPAR's are always built horizontally on the land and transported in the same state to its final destination where it is upended while floating. The important factor for fabricating the SPAR horizontally is the usage of the standard fabrication yard equipment and shipyard techniques. Over 70% of the spars built till date has been constructed at the Mantiluoto, Finland yard owned by Technip Offshore.

The SPAR structure are divided in to subassemblies and fabricated in a shop equipped with automatic plate cutting and welding equipment. The subassemblies are joined to form half round ring sections of the spar. After construction, the spar is loaded out onto a heavy lift vessel for transportation using hydraulics and skid beams to move the hull.

CHAPTER 3

BLUE MARLIN

3.1 Definition of a Heavy-lift Vessel

A Heavy Lift Vessel is designed to carry extremely large and/or heavy items that cannot be transported in or on other vessels. Semi-submersible types are designed to transport very large floating objects, including damaged ships. Ro-Ro heavy lift vessels also exist.

Heavy lift vessels have extremely large cargo decks, unusual deck and pilothouse configurations to accommodate unusual types of cargo and very high-capacity on-deck cranes

Size or Length varies by vessel and type of cargo. There are different types of heavy-lift vessels built specific for a purpose. A large heavy lift vessel can measure 584.6ft (178.20m) in length and 137.8ft (42m) in width.

Heavy-lift carriers can transport high-value, complex cargoes such as: transformers, locomotives, rockets, crushers, semi-submersible rigs, jack-ups, oil platforms, bridge spans, TLPs (tension leg platforms) and SPAR buoys, etc.

Cargo is loaded by onboard cranes or shore-based cranes. Conventional loading is the over-the-top Lo-Lo (Load-on/Load-off). Some heavy lift vessels also have Ro-Ro capabilities

3.2 Semi submersible Heavy-lift vessel

[10] A semi-submersible is a watercraft that can put much of its bulk underwater. With a relatively small area above the water's surface, the semisubmersible is less affected by the waves than a normal ship, but must be trimmed continuously. Unlike a submarine, such a ship is never entirely underwater.

A semisubmersible heavy-lift ship, also known as a "flo/flo" (for float-on/float-off), has a long and low well deck between a forward pilot house and an after machinery space. In superficial appearance, it is somewhat similar to a dry bulk carrier or some forms of oil tanker. Its ballast tanks can be flooded to lower the well deck below the water's surface, allowing oil platforms, other vessels, or other floating cargo to be moved into position for loading. The tanks are then pumped out, and the well deck rises to shoulder the load. To balance the cargo, the various tanks can be pumped unevenly.

The flo/flo industry's largest customer base is the oil industry. Dockwise have transported many oil drilling rigs (the flo/flo ships can carry the rigs from their construction site to a drilling site at roughly three to four times the speed of a self-deploying rig). Rapid deployment of the rig to the drilling site can translate into major savings to the oil industry. They also transport other outsized cargo and yachts. [10]

3.3 Heavy-lift Vessel MV Blue Marlin



Fig. 3.1 MV Blue Marlin

The heavy transport vessel Blue Marlin is an open-deck vessel and able to carry fully integrated ultra heavy and large floating production and drilling platforms up to 73,000 tons. The Blue Marlin enables oil companies to build fully integrated units anywhere in the world and transport them to the final offshore destination, in order to limit hook up and commissioning at the offshore location. The vessel can be semi-submerged to load floating cargos like rigs even other ships and submarines.

The Blue Marlin has an open cargo deck of 63 meters at portside and 164.20 meters at starboard. By moving the portside buoyancy casing the cargo stowage possibilities can be increased

Principal characteristics of Blue Marlin

length o.a	224.50 m
length b.p.	206.50 m
breadth	63.00 m
depth	13.30 m
draft sailing	10.28 m
max draft submerged	28.40 m
gross tonnage	51,821
deadweight	76,410 tons
deck space	63 x 178.2 m
deck load	27.5 t/sq.m
Service Speed	12.0 Knots
Maximum Speed	13.3 Knots
Range	65 days

Table 3.1 Principal characteristics of Blue Marlin

Ballasting/deballasting: Four ballast pumps each of 3,300 cu.m./hr.

Propulsion: 12,640 kW MAN-B&W 8S50MC-C, driving one 4 bladed c.p. propeller, One 2,000 KW bow thruster. Three diesel generators of 4,581kVA / 6,600V each, driving two retractable Azimuth thrusters of 4,500 kW each.

Auxiliary engines: One diesel generator 450 V/60 Hz, 990 kW aft. One emergency generator of 450 V/60 Hz, 200 kW.

Anchors and chains: Anchors fwd (chain 107 mm) 2 pcs of 14.4 tons, Anchor aft (chain 95 mm) 1 pc of 11 tons

Accommodation: On board additional for the crew

Classification: DNV + 1A1, general cargo carrier, Eo, DK(+), PWDK.

CHAPTER 4

LOAD-OUT PROCEDURE OF SPAR

The SPAR is a very heavy offshore structure used in deep sea oil production. It is fabricated on land and is dry transported on a heavy-lift vessel such as Blue Marlin to its destination, usually other part of the globe for its utilization.

The process of transferring the SPAR from land on to a heavy-lift vessel for its final voyage is called Load-out. This section investigates and explains the procedure involved in transporting the SPAR from its position in the fabrication yard to the high seas where it is used for oil production.

4.1 Vessel Capabilities and limitations

The Vessel Blue Marlin was built as a submersible heavy lift carrier; it was acquired by Dockwise and modified. The original vessel is extended on its sides to increase its dead weight capacity. Figures 4.1 shows web frame of the original vessel and Fig 4.2 shows web frame of the modified vessel.

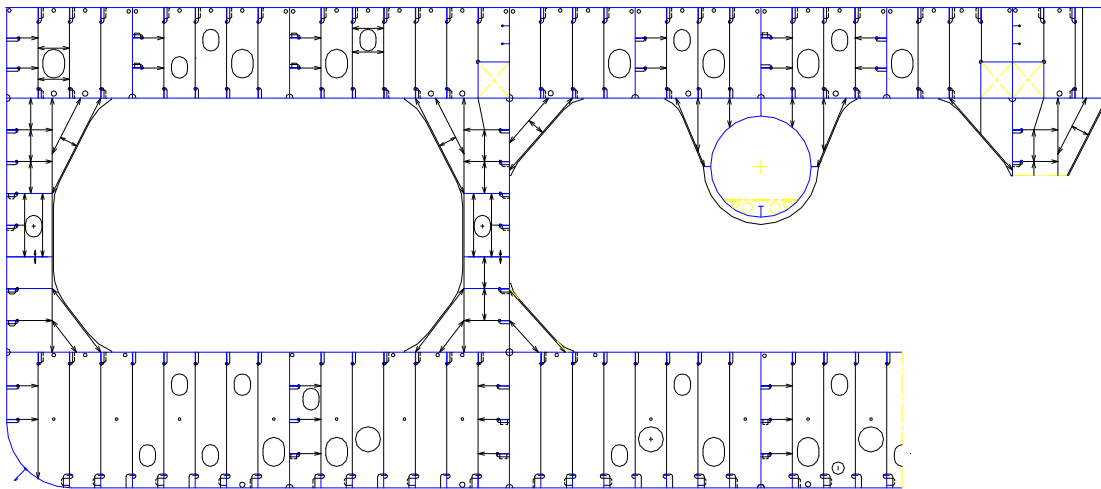


Fig. 4.1 Typical web frame of Blue Marlin - original vessel

What makes Blue Marlin capable of carrying ultra heavy loads? The answer lies in its structural design. The vessel is divided into a number of individual tanks allowing it to take on ballast water for adjusting its draft and stability. To separate the tanks from one another and to withstand the high pressure exerted by the fluid it carries, it has been strengthened with bulkheads both longitudinally and transversely. These are the structures which help carry heavy loads on Blue Marlin today.

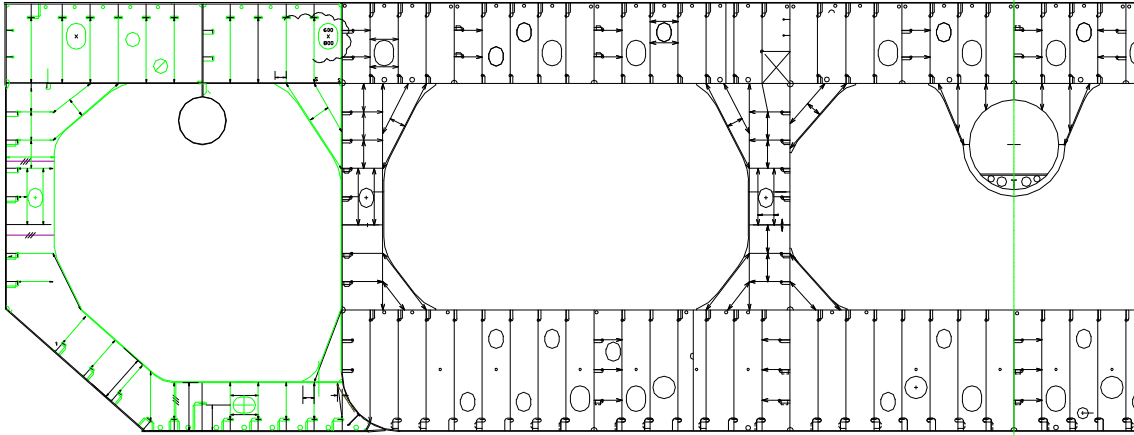


Fig 4.2 Typical web frame of Blue Marlin - modified vessel

On the deck of the Blue Marlin, there are two casing at the stern end of the deck. Casings are like a tower extending from the deck. The casing on the Star Board side is called Star Board casing (SB casing) and is for engines breathing during a submerging operation and it also has some tanks for taking in ballast water. The Star Board casing is fixed to the deck and cannot be removed. The casing on the port side is called port side casing and are just with tanks for ballast water for compensating the weight of the star board casing and provide stability for the vessel. The port side casing is not fixed and can be moved to another location on deck when needed.



Fig. 4.3 Blue Marlin in submerged condition

4.2 SPAR particulars

As discussed in chapter 2, the Future SPAR is a truss SPAR. It is fabricated in a yard near by a port so that it can be transported after its fabrication. Having discussed enough about the SPAR design and working principle in chapter 2, we will discuss the particulars of the Future SPAR which has been analyzed in this thesis for transportation on the vessel Blue Marlin.

The SPAR includes a hard tank with a square well connected through a truss with its soft tank and floatation tank. The spar general arrangement has been shown in fig 4.4 and a detailed drawing with dimensions is given in Appendix 1.

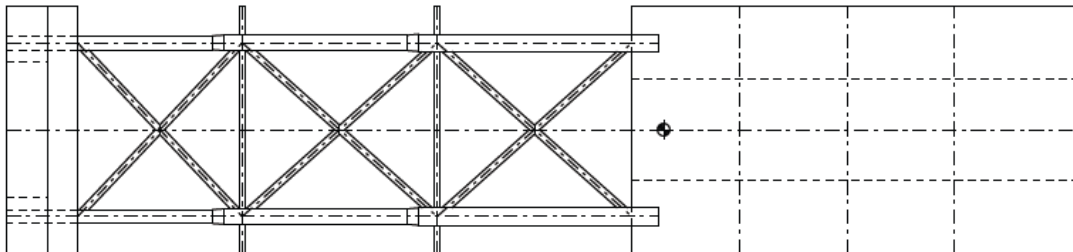


Fig 4.4 General Arrangement of Future SPAR

The following are the main particulars of the SPAR:

:SPAR weight properties

Weight	30174 Ton
Longitudinal center of gravity (from bottom soft tank)	119.14 Meer
Transverse center of gravity (from centerline)	0.00 Meter
Vertical center of gravity (from side hard tank)	22.25 Meter

Hard Tank properties

Length	81.38 Meter
Diameter	44.5 Meter
Inner well breadth/ height	18.29 Meter
strake height	15 %
Outer diameter	57.85 Meter

Soft Tank properties

Length	7.32 Meter
Breadth/ Height	44.50 Meter
Inner well breadth/ height	18.29 Meter
Centre well breadth dimensions	21.34*24.38Meter
Flotation tank dimensions (L*B*H)	5.49*44.50*13.11 Meter

Length overall	194.77 Meter
Total height (including cradles)	51.78 Meter
Cradle height (distance from deck to spar hull)	0.60 Meter
Free floating draft aft	10.6 Meter
Free floating draft mid	10.4 Meter
Free floating draft forward	10.1 Meter

SPAR weight including supports

Weight	34855 Ton
Longitudinal center of gravity (from bottom soft tank)	119.14 Meter
Transverse center of gravity (from centerline)	0.00 Meter
Vertical center of gravity (from side hard tank)	20.35 Meter
Free floating draft aft	12.8 Meter
Free floating draft mid	11.9 Meter
Free floating draft forward	11.0 Meter

The weight and CG of the spar has been derived by the designers, and a detailed breakdown has been given in the table below. It is assumed that the weight of the supports includes the supports of the hard tank and heave plates.

	Weight mt	LCG from soft tank keel m
Hard tank	14304	149.34
Heave plate at 140 ft	529	42.69
Heave plate at 256 ft	529	78.04
Truss	3292	63.39
Soft tank	2315	5.26
Outfitting	9205	127.53
Spar weight	30174	119.14
Supports	4681	119.14
Spar weight including supports	34855	119.14

Table 4.1 Weight of SPAR components

General procedure of SPAR fabrication is discussed in chapter 2, the same fabrication technique will be used in Future SPAR fabrication. The SPAR is built in a number of sections and is assembled under a crane on rails. The same rails are later used in the load out process of the SPAR on to the vessel.

4.2.1 Weight distribution of the SPAR.

The weight distribution of the whole SPAR with its supports and outfittings based on its support location are provided by the designers, and is listed below;

Support Location	Percentage distribution %	Weight (mt)
Hard Tank	68.22%	23776.8
Upper Heave Plate	11.00%	3834.1
Lower Heave Plate	20.78%	7244.2
Total	100.0%	34855.0

Table 4.2 Weight distribution of SPAR

4.3 Load-Out

Load-out as the name implies, means loading an object from its origin to a vehicle for transportation to its destination. The term load-out is often used in heavy-lift industry during its handling - heavy structure moved from the place where it is fabricated to a marine vessel (a ship or barge) for transportation to its final destination.

There are quite a lot of ways used to load-out cargoes on a normal scale. For example, forklifts, cranes, trolleys, conveyors etc. But when it comes to heavy-lift there are very few methods employed to do the task.

4.3.1 Types of Load-out Methods

The possible methods of Load-outs for such a large scale are:

1. Lifting
2. Ro-Ro using Modular trailers
3. Floating
4. Skidding method

4.3.1.1 Lifting

Method of loading-out heavy objects using gantry or cranes is called lifting. Gantry are equipments usually used to upend the object in the same position, it can move the lifted objects horizontally. So use of gantry for loading-out SPAR is not possible

[11] Cranes are distinguished from jacks and simple hoists in that they not only have the capability of lifting a load but also can move a load horizontally and set it down again. The operation is usually performed with a hook and line from above the object being moved. Cranes can be classified into several broad categories such as mobile cranes, tower cranes, derricks, bridge/gantry cranes, container cranes, barge cranes, etc. Tower cranes and derricks are referred to as *fixed* cranes.

Tower crane and mobile crane design is continually improving, which greatly increases their lifting capacity and have made them an invaluable tool in heavy rigging work operations. [11]

Lifting of the SPAR weighing 35000tons is not possible as there are no cranes available to lift more than 5000Tons.

4.3.1.2 Ro-Ro using Modular Trailers

Roll-on/roll-off (RORO or ro-ro) ships are vessels designed to carry wheeled cargo such as automobiles, trucks, semi-trailer trucks, trailers or railroad cars that are driven on and off the ship on their own wheels.



Fig 4.5 Roll-off operation of a heavy-lift on SPMT

In the heavy-lift scenario, the wheeled vehicles are replaced by Modular trailers which are capable of carrying ultra heavy loads. The modern modular trailers are called SPMT. The self-propelled modular transporter, or SPMT, is a flat bed high capacity transporter with 4 or 6 axle lines that can each accommodate a load of 30 tons. Each axle is mounted such that sharp turns, side way movements or even 'carousels' on the spot can be executed. Integrated computer control calculates each intended move to the right setting of any axle line. Hydraulic suspensions allow for very slow movements and the positioning of a load within millimeters of tolerance. The modular design allows combining individual SPMT's into large configurations that may consist of several clusters. Fig 4.5 shows Roll-off operation of a heavy structure on SPMT

Even though modular trailers can be configured to carry any amount of loads, they have a limitation. The cargo has to be jacked up to a height more than the height of the trailer to load the cargo on its top. In case of the SPAR, it is such a huge structure, it is too costly affair either to fabricate the SPAR at such heights or to jack up the SPAR to the required height after fabrication, so other methods of Load-outs have to be adopted.

4.3.1.3 Floating.

Since SPAR is a floating structure, it can be fabricated in a dry dock as like fabricating a seagoing vessel. Once fabricated the dry dock is flooded to float the SPAR to the ocean. The SPAR is then towed on to the semi-submerged vessel like Blue Marlin to load the SPAR on its deck and transport to its destination.

But fabricating a SPAR in a workshop is much easier and cost effective than building a dry dock. So the Floating of the SPAR for Load-out is ruled out.

4.3.1.4 Skidding Method

An alternative method for horizontal transport is skidding. The load is fitted with skid shoes that move in skid tracks with a fairly low resistance. Power is provided by hydraulics but may also involve the use of strand jack systems to pull the load along its way. Simple and non-invasive, skidding has proven to be a very economical method of transporting heavy loads over short distances.



Fig 4.6 Skidding of a SPAR

To load-out the SPAR from its fabrication yard to the vessel deck, skidding method is feasible and cost effective way to move such heavy loads. The SPAR is normally fabricated in a location near to a jetty or port for ease of loading-out to the heavy-lift vessel. The separately fabricated sections of SPAR are assembled in position on a skid rails placed under it. Rollers are placed in between the SPAR and skid beams to reduce the friction and to facilitate easy movement of load on the beams. The SPAR is pushed by means of hydraulics power on the Skid beams until it reaches its final stowage position on the deck of the vessel.

Skidding is the most feasible method to load-out the SPAR from its fabrication yard to the vessel Blue Marlin.

4.3.2 Types of Skidding method

The standard skidding method utilizes only 2 skidding beams to support the heavy load, as usually the center of gravity of the load will be in the center and the load can be equally distributed between the skid beams. The beams also serve as a spreader to distribute the load on the vessel structure.

The skidding can further be divided into 2 categories based on the loading condition

1. Standard skidding

The standard skidding is the usual way of doing skidding with out any additional equipment, the load is placed on skid beam, rollers are placed in between the heavy object (load) and the beams for reducing friction and hydraulic power is applied to push the load. The loads on the beams are in relation to the properties of the cargo moved. The loads are not same all along the skid tracks.

2. Skidding by Uniform loading using hydraulics

The distribution of the SPAR mass on the skidding beam can also be controlled and distributed evenly all along the skid beams by means of hydraulic smart skidding system. Hydraulic cylinders are placed all along the line in between the cargo supports and skid rollers as shown in fig 4.11. The hydraulic cylinders connected to a computer controls and maintains the load exerted on the skid beam below it, to be even all along the beam. As the methods implies, it involves more equipments and time consuming to do the same skidding operation and is comparatively costly.



Fig 4.7 Skidding by uniform loading using hydraulic cylinders

4.4 Stowage Position

The position of the cargo on the vessel is referred to as stowage position. Depending on the SPAR parameters the possible stowage position of the Future SPAR on the deck of the vessel is investigated.

The Hard tank of the SPAR is fabricated with strakes around it, which provide stability to SPAR from ocean currents and provides damping from wave loads. Since the most of the strakes are fabricated with the hard tank in the yard and transported together, a part of the strakes under the hard tank where transportation supports are located will be installed after the transportation. Removing other sections of the strakes for transportation purposes is also possible and investigated in this section.

The preferable stowage position for all kind of heavy lift transportation of such huge scale will be that the centre line (where the COG acts) of the cargo and vessel should be on the same plane. But in our case SPAR's COG cannot be positioned with vessel's COG as Blue Marlin has a fixed SB casing. The casing cannot be removed to accommodate the SPAR as air intake and exhaust of the engine runs through this casing.

As the SPAR has to be positioned away from the center, now the possible stowage positions of the SPAR on vessel deck mainly depends on the whether the strakes will be removed or not.

4.4.1 Possible Stowage Positions

Based on removal of strakes, two stowage positions are possible;

1. The SPAR 1.7 m off vessel centre towards the port side
2. The SPAR 8.3 m off vessel centre towards the port side

In both cases the hard tank and heave plates are ~0.3 m clear from the starboard casing. In order to load the spar, based on the given spar width, the vessel PS casing needs to be removed and will be placed in front of the SB casing. For both spar stowage positions the ballast capacity of the Blue Marlin is sufficient for stern load out.

4.4.1.1 SPAR 1.7m off the vessel centre

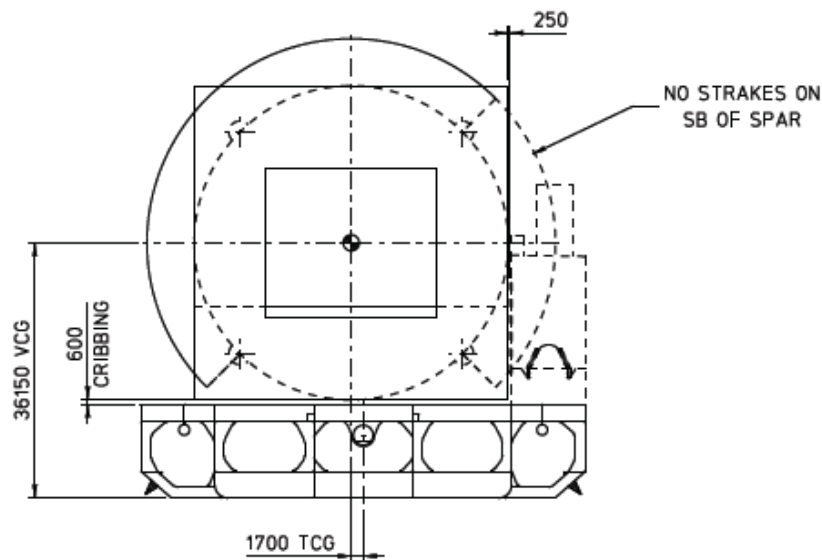


Fig.4.8 Stowage plan-1.7m off centre

The SPAR centre is offset from the centre line of the vessel by 1.7m on the port side as shown in the figure 4.8. The strakes on the star board side of the vessel have to be removed to prevent the intervention of the Star Board casing.

4.4.1.2 SPAR 8.3m off the vessel centre

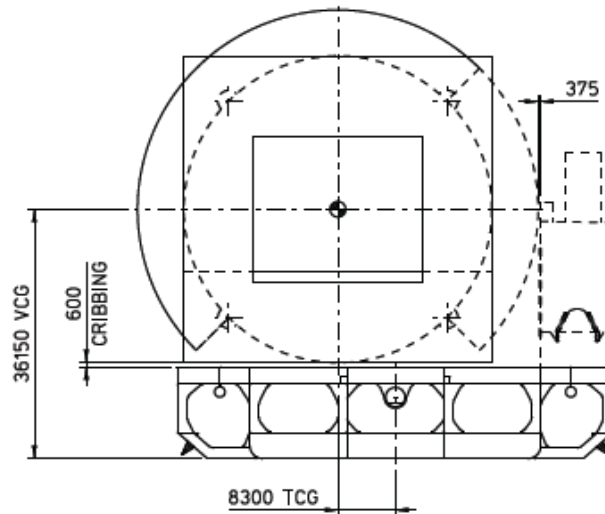


Fig 4.9 Stowage plan-8.3m off centre

The SPAR centre is offset from the centre line of the vessel by 8.3m on the port side as shown in the figure 4.9. This stowage position does not require any removal of strakes as the SPAR is offset enough on the vessel to accommodate it with the strakes attached. But most of the SPAR load is on the port side causing a lot of shear and bending stress on the vessel structure.

4.4.2 Selection of Stowage position for analysis

The ballast capacity of Blue Marlin is investigated and found that it is sufficient for the stern load out of the SPAR.

As per the weight distribution of the SPAR from chapter 4.2.1, it is clear that the weight of the hard tank with its supports and outfitings is the largest load acting of the vessel structure. And the step, hard tank just passed vessel stern is the most critical step due to the weakness present in the stern section of the vessel, i.e, engine room. In this step the moment of the spar weight that has been skidded onto the vessel is the largest.

The stowage position 8.3m offset to the vessel center is the most critical position as the moment of the SPAR weight on the vessel when the SPAR is stowed at 8.3m offset is higher than the 1.7m offset.

So we can say in any case, the loads exerted by the stowage position where the SPAR is 8.3m offset is the critical loading case. It is also desirable to transport the SPAR with as much strakes as possible to reduce the amount of work needed to fix the strakes when the SPAR is floating on the ocean.

The load-out of SPAR with 1.7m offset will be taken into consideration for analysis, if the results of the 8.3m offset position of the SPAR are not favorable.

As the SPAR stowage position of 8.3m offset from the vessel center is considered as the critical and desired load-out position, the same position is chosen for our analysis.

4.4.3 Number of skid beams

As the “Future SPAR” is extremely large in terms of size and mass compared to its predecessors, skidding with just 2 skid beams could lead to over loading the vessels structure. So the number of skid beams might have to be increased to distribute the loads to other parts of the vessel. Increasing the number of skid beams could also be a solution for making the load-out possible.

Number of skid beams used for load-out is also an influencing factor. But, can 3 beams do the job or 4? Has to be found out in the analysis

4.4.4 Location of skid beams

The skid beams bears and transfers all the weight of the SPAR to the vessel structure; so it has to be positioned on top bulkheads which are vertical partitions in a ship arranged transversely and longitudinally. The bulkheads are of greater structural importance, it holds all the sections of the vessel together.

Since the load-out is carried out over the stern of the vessel, the skid beams have to be placed longitudinally on the vessel deck from running from stern end towards the bow. Skid beams must be located on top of the longitudinal bulkheads as much as possible to avoid loading of the vessel on other section.

The bulkheads for supporting the load on vessel are chosen according to the stowage position of the SPAR. The location of the skid beam on bulkheads based on the stowage position of 8.3m offset of the SPAR is shown in the fig. 4.10

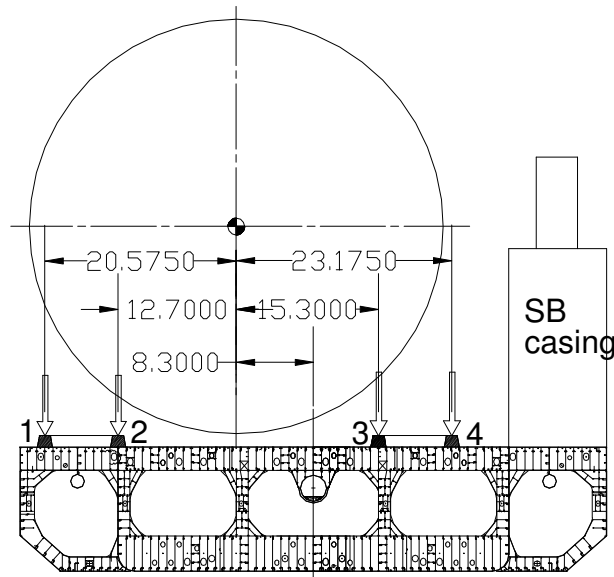


Fig 4.10 shows the locations of the skid beams

The location of the skid beams number 2 and 3 are very obvious, above the longitudinal bulkheads under the SPAR. Skid beam number 2 is located on the second longitudinal bulkhead from the center on the port side of the vessel, which is also a side wall structure of the vessel before its modified. Skid beam number 3 is located on the first longitudinal bulkheads from the center on the starboard side of the vessel.

The location of skid beam number 1 is on the side wall structure of the vessel, which is also a strong member of the structure similar to a bulkhead except that it has no stiffeners on the outside wall of the vessel.

The specified location of 20.5750m from the center of SPAR is chosen based on the length of skid beams, at this location the Skid beam is well within the supports of the stiffeners on the side wall and also the length of the skid beam at this location is the maximum, which is 163.2m.

As the next bulkhead on the star board side is on the line of the star board casing, it is not possible to support the SPAR on that location, so a different location is chosen based on strongest members on the vessel. The location shows in the fig 4.10 for skid beam number 4 is chosen as the material used in that section is thicker, so it can carry more loads.

The same system of numbering of skid beams have been adopted throughout this thesis for identifying the skid beams.

4.4.5 Supporting the SPAR for load-out

As the locations of the skid beams have been investigated in the previous section, it is very clear that the supports under the SPAR should be conforming to the dimensions in relation to the SPAR centre and skid beams.

The length of the SPAR is more than the length of the vessel deck, we can only support the hard tank and the truss section on the vessel deck, soft tank will be hanging during the transportation. Through past experiences in similar transportations projects, it is decided to leave the SPAR hanging as the stiffness of the truss will be able to hold the soft tank mass within the allowable deflection. So the idea of supporting the soft tank on vessel deck is not possible and is omitted.

But during previously executed projects, the soft tank will be temporarily supported during load-out until the SPAR reaches its final stowage position. The soft tank will be supported on the skid beams on the same plane of the hard tank and truss supports, but the supports under the soft tank are not fixed or temporarily fixed. When the SPAR reaches its final stowage position on the vessel deck, the supports under the soft tank will be released and the draft of the vessel will be decreased so that the soft tank lifts-off the supports and will be hanging over the vessel stern.

The temporary supports for the soft tank is to prevent the deformation of the SPAR due to the deflection of the over hang during load-out and also to avoid the irregularities in the loading condition on the supports under the hard tank and truss due to the deflection, as the SPAR is a very stiff structure.

The same method will be followed in all the analysis done in this thesis, SPAR's soft tank will be supported during the load-out process.

4.5 Selection of steps to be analyzed

As discussed in the above sections, the factors affecting the load-out of the Future SPAR can be summarized as:

1. Types of skidding method
2. Number of skid beams
3. Stowage position

By investigating the stowage position in the chapter 4.4, it is decided that 8.3m offset of the SPAR on the vessel deck is considered to be the critical position.

Now the factors influencing can be narrowed to number of skid beams and types of skidding methods.

With the space on the vessel deck, we can rule out the use of 5 skid beams for load-out. So the 2, 3 and 4 skid beams are the possible option concerning the number of skid beams for load-outs.

As discussed in chapter 4.4.2, the step that the complete hard tank just passed vessel stern has been found to be the most critical step regarding vessel longitudinal strength which can be seen in attachment 3.

The critical load step together with the influencing factors; number of skid beams and types of skidding method, the following combination of 9 steps have been chosen for analysis.

1. Hard tank on the vessel with 4 skid beams by uniform loading using hydraulics
2. Hard tank on the vessel with 3 skid beams by uniform loading using hydraulics
3. Hard tank on the vessel with 2 skid beams by uniform loading using hydraulics
4. Hard tank on the vessel with 4 skid beams by SPAR model loading
5. Hard tank on the vessel with 3 skid beams by SPAR model loading
6. Hard tank on the vessel with 2 skid beams by SPAR model loading
7. Entire SPAR on vessel with 4 skid beams by SPAR model loading
8. Entire SPAR on vessel with 3 skid beams by SPAR model loading
9. Entire SPAR on vessel with 2 skid beams by SPAR model loading

The 2 skid beam load-out is also analyzed to make sure whether the load out is possible in such a case and to compare the results.

The above 9 steps are recreated in the FEMAP environment and analyzed to find the optimal method to load-out the "Future SPAR"

CHAPTER 5

FEMAP with Nx NASTRAN

[13] Femap is an advanced engineering finite element analysis environment. It is both CAD and solver neutral, and has become the world's most popular engineering analysis environment for Nastran users. It is widely used by the world's leading engineering organizations and consultants to model complex products, systems and processes, including satellites, aircraft, defense, automotive vehicles, electronics, heavy construction equipment, lift cranes, marine vessels and process equipment.

Femap is CAD independent and both leverages the Siemens Parasolid® software modeling kernel that allows direct access to Parasolid data for surface and solid modeling in addition to providing advanced geometric tools necessary to access non-Parasolid geometry.

From advanced beam modeling, mid-surface extraction and hex meshing, to robust CAD import and idealization, Femap gives unparalleled model control and flexibility with a broad range of loads, materials, analysis types and visualization options.

In many cases this may be all that you need. It includes linear statics, normal modes, buckling, model checkout, spot weld, steady-state and transient heat transfer, basic nonlinear, design sensitivity and unlimited problem size capabilities.

5.1 Features of FEMAP

1. Depth of analysis functionality

The high level of analysis functionality exposed by Femap and supported by the user interface provides great value to full-time analysts and occasional-use multi-disciplinary engineers alike and cannot be matched by other solution offerings in the industry. This combined with the level of advanced analysis solutions offered by NX Nastran makes the Femap with NX Nastran combination able to solve more complex engineering problems in a straightforward manner. Nastran is traditionally a very capable solver for dynamic response analysis, and additional dynamics solutions that are supported by Femap with NX Nastran, but not by competitive offerings include random response, response spectrum, material and geometric nonlinearity with time-dependent loading and rigid and deformable body contact.

Other types of advanced analysis options offered by NX Nastran, include implicit integration nonlinearity, advanced thermal analysis solutions and 3D computational fluid dynamics.

2. Post-processing versatility

Post solution, Femap offers more results processing tools to enable quick and efficient understanding of the behavior of the system under analysis. Additional tools including time animations, streamlines, cutting planes, free-body diagrams, grid point force balance, bar and beam visualization and shear and bending moment diagrams, and user defined reports are provided by Femap. Furthermore, Femap offers versatile results processing functionality that allow the result combinations to be made after the analysis has completed, and data mapping to create input loading for results quantities for subsequent analysis.

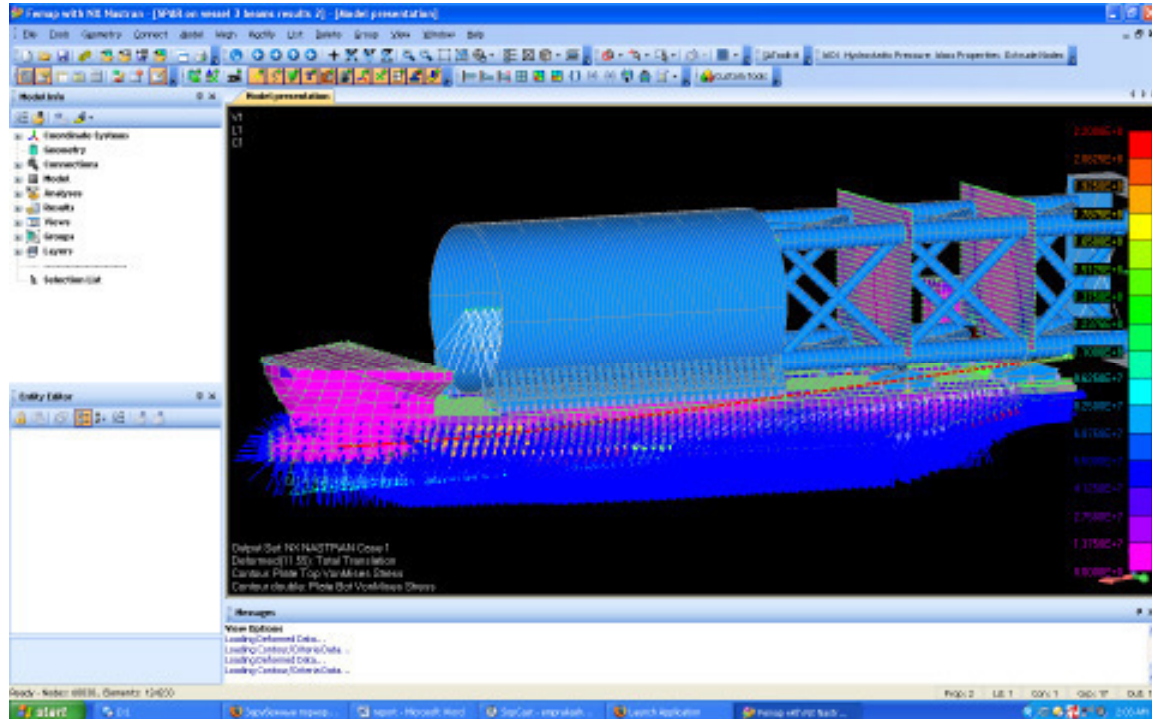


Fig 5.3 FEMAP environment

3. Versatile modeling and visualization tools

Femap includes an impressive array of versatile modeling and visualization tools to aid FE model creation and verification prior to the analysis. Additional capabilities include the following:

- Loads and boundary conditions can be applied either directly to the geometry model, or to the FE entities created after meshing.
- Time and temperature dependent loads can be applied for transient dynamic and heat transfer analyses.
- Application of loads based on equations, functions.
- Weldment modeling.
- Visualization using model transparency.

4. Supports a broad range of engineering disciplines

From simple linear static analysis right through to robust advanced solutions based computational fluid dynamics, engineers and analysts use Femap to virtually simulate a complete range of product behavior. The advanced analysis capabilities available with Femap with NX Nastran employ the Nastran and TMG solvers and provide proven industrial strength solutions of known and trusted quality. These advanced solutions enjoy an excellent reputation, to solve the most demanding real world engineering problems by large engineering companies for many years.

5. Scalability of solutions

Femap offers scalable solutions and can be used to simulate everything from simple solid components to entire spacecraft assemblies, within the same user interface. Femap with NX Nastran can be tailored to specific customer needs, and can expand to meet future demands without the need for additional product procurement or retraining.

6. Easy to deploy

With a native Windows environment, Femap offers comprehensive analysis functionality that is easy to use and quick to learn. This brings about a reduced training overhead and allows engineers to maintain maximum productivity even when Femap is used on an occasional basis.

7. Low total cost of ownership

The depth and true scalability of functionality offered by Femap provides exceptional value. Femap with NX Nastran offers a complete range of powerful analysis options at competitive prices.

8. Solver neutral support

Femap can be used with a large variety of solvers, allowing access to many types of advanced analysis solutions. There is no limitation with access to alternative solvers for advanced or alternative analysis solutions.

9. CAD independent

Femap offers neutral CAD support that allows the analyst or engineer access to any kind of CAD data.

Femap leverages the Parasolid® modeling kernel that allows direct access to Parasolid data for surface and solid modeling, and provides robust advanced geometric tools necessary to access non-Parasolid geometry. In addition, Femap is fully associative with Solid Edge® software.

10. Powerful customization tools

Femap offers a comprehensive set of customization tools including a fully featured application programming interface and a facility to record, edit and play user-defined macros. The new Program File capability is hosted in its own Femap window. User-defined macros can be recorded, edited, debugged and played back all within the Femap interface. Macros to automate repetitive modeling tasks for example, can be created in an easy and straightforward manner, and once created, can be added to any Femap toolbar, providing powerful automation tools that are easy to use and deploy. In addition to the macro-driven Program Files, a full-featured BASIC development environment in a separate window is available. Directly from Femap's user interface, you can now access the OLE/COM object-oriented FEMAP Application Programming Interface (API) that provides direct access to all Femap objects and functionality. The BASIC engine is fully OLE/COM compliant and can interface with Femap as well as any OLE/COM compliant program such as Word or Excel. You can create custom programs that transfer model information to Word or Excel to create customized reports. [13]

5.2 Element Description

5.2.1 Line Elements

[14] All line elements structurally connect two nodes. The different types represent different structural conditions.

1. Rod Element

Description: Uniaxial element with tension, compression and torsional stiffness. It does not have any bending or shear capability.

Application: Typically used to model truss, or other "pin-ended" members

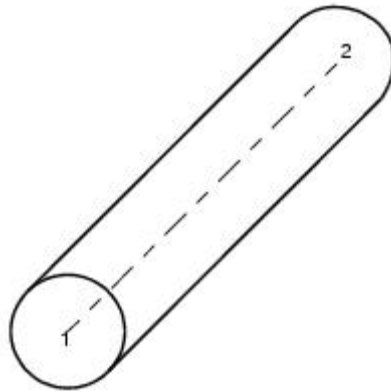


Fig 5.4 Rod Element

Shape: Line, connecting two nodes.

Element Coordinate System: The element X axis goes from the first node to the second.

Properties: Area (of cross-section), Torsional Constant, Coefficient for Torsional Stress, Nonstructural Mass/Length.

2. Beam Element

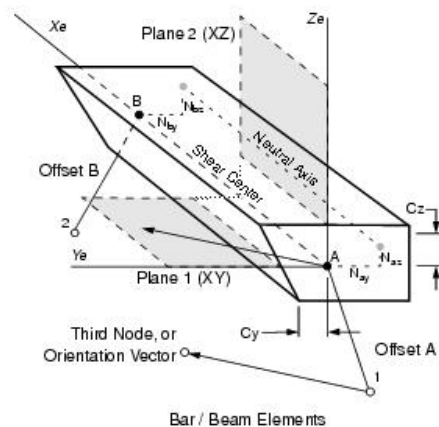


Fig 5.5 Beam Element

Description: Uniaxial element with tension, compression, torsion, and bending capabilities. This element can be tapered. You can specify different properties at each end of the beam.

Application: Used to model beam/frame structures.

Shape: Line, connecting 2 or 3 nodes, A orientation node can be specified to orient the element Y axis.

Element Coordinate System: The element X axis goes from the first node to the second. The element Y axis is perpendicular to the element X axis. It points from the first node toward the orientation (or third) node. If you use an orientation vector, the Y axis points from the first node in the direction of the orientation vector. The element Z axis is determined from the cross product of the element X and Y axes.

Properties: Area, Moments of Inertia (I_1 , I_2 , I_{12}), Torsional Constant, Shear Areas (Y , Z), Nonstructural Mass/Length, Warping Constant, Stress Recovery Locations, Neutral Axis Offsets (N_{ay} , N_{az} , N_{by} and N_{bz}). All required input properties for this element can be automatically calculated for standard or arbitrary shapes by using the FEMAP beam cross section generator (accessed under *Model, Property, Shape*). The Shear Areas calculated by the beam property section generator and the input to FEMAP are the effective areas for shearing, not a shear factor. If you are inputting values directly, and has a shear factor, simply multiple it by the actual area to obtain the shear area. If the beam is tapered, you can specify different properties at each end of the element.

3. Spring Element

Description: A combined stiffness (spring) and damper element. It can be either axial or torsional. The DOF spring is an alternative formulation.

Application: Used to represent any purely axial, or purely torsional, structural member.

Shape: Line, connecting two nodes.

Element Coordinate System: The element X axis goes from the first node toward the second.

Properties: Stiffness, Damping

If formulation is 1.. CBUSH then Stiffness and Damping values can be defined for individual degrees of freedom, Structural Damping, Spring/Damper Location, Orientation Csys, Stress/Strain recovery coefficients. For Frequency or nonlinear analysis function dependence can be define for stiffness and damping values.

5.2.2 Plane Element

The plane elements are used to represent membrane, shell, and plate structures. They all follow the same shape and numbering conventions. The simplest formulations of these elements are just a three-noded triangle and a four-noded quadrilateral. In addition, six-noded "parabolic" triangles and eight-noded "parabolic" quadrilaterals are also available.

In most cases, loads on plane elements will be applied to face 1. In this case positive pressure acts in the same direction as the face normal (as determined by the right-hand rule). Conversely, if loads are applied to face 2, their positive direction will be opposite to the face normal. Therefore a positive pressure on face 2 is equivalent to a negative pressure on face 1. If you need to apply edge loads, they can be applied to faces 3 through 6 as shown. Their positive direction is inward, toward the element center.

Whenever possible, you should try to use elements which closely resemble equilateral triangles or squares. These shapes will usually result in the best analysis accuracy. Consult your analysis program documentation for specific shape limitations of that program.

Plate/Shell Element

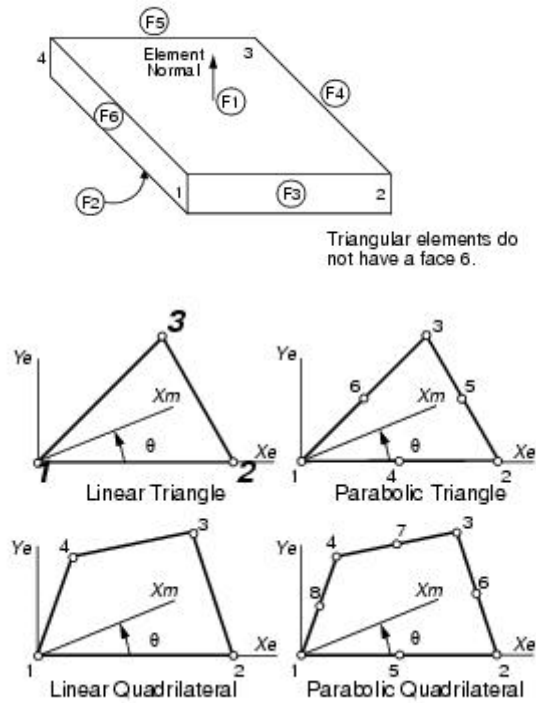
Description: A combined planar shell element. This element typically resists membrane (in-plane), shear, and bending forces. Some analysis programs also include transverse (through the thickness of the element) capabilities.

Application: Any structure which is comprised of thin plates/shells.

Shape: Planar, three-noded triangle, four-noded quadrilateral, six-noded triangle, eight-noded quadrilateral. Some shapes are not available for all analysis programs.

Element Coordinate System: Refer to the figure 4.6. The material angle can be used to rotate the element X axis.

Properties: Thickness (average, or varying at each corner), Nonstructural mass/area, Bending Stiffness parameter (Nastran only), Transverse shear/Membrane thickness (Nastran only), Bending, Shear and Membrane-Bending Coupling Materials (Nastran only), Fiber distances for stress recovery.



Triangular elements do not have a face 6.

Fig 5.6 Plate Element

Additional Notes: Many analysis programs do not support tapered plate elements. For those that do, specify a different thickness for each corner of the plate. You can always specify a single thickness for all corners simply by entering the average thickness. Plate Offsets (Nastran Only) can be defined to offset the plate a particular distance from its nodes. Only one offset may be specified, and it will be in the plate's positive or negative normal direction.

5.2.3 Volume Elements

These elements are all used to model three-dimensional solid structures. They can provide very detailed results, but usually require additional modeling and analysis time and effort.

Solid Element

Description: A three-dimensional solid element.

Application: Modeling of any three-dimensional structure.

Shape: Four-noded tetrahedron, six-noded wedge, eight-noded brick (hexahedron), ten-noded tetrahedron, fifteen-noded wedge, and twenty-noded brick. Some shapes are not available for all analysis programs.

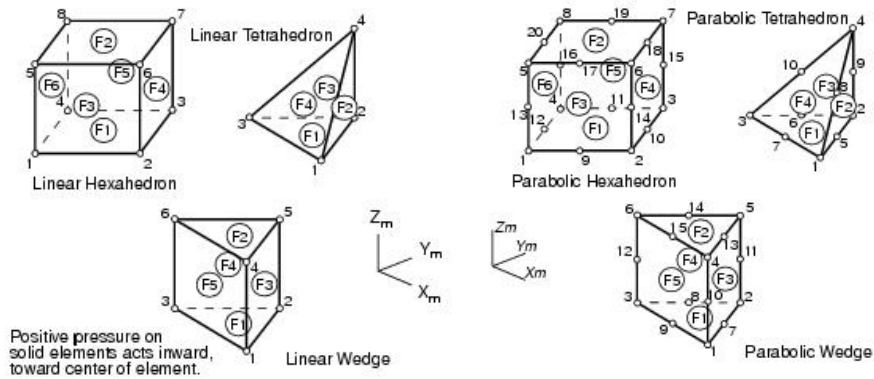


Fig 5.7 Solid Element

Element Coordinate System: Can be aligned based on the node locations or aligned to a coordinate system. Check your analysis program documentation for supported options.

Properties: Material axes, integration order (not all programs).

Additional Notes: If you want to apply pressure loads to solid elements, you must specify a face number. The previous and following figures show the face numbers (F1 through F6, in the circles) for each element shape. Positive pressure is always directed inward, toward the center of the element.

5.2.4 Other Elements

1. Mass Element

Description: A generalized three-dimensional mass and/or inertia element located at a node. The center of mass can be offset from the node. An even more general form is the mass matrix element.

Application: Representing parts of a structure which contain mass, but which do not add any stiffness.

Shape: Point, connected to one node.

Element Coordinate System: Aligned with a coordinate system that you specify. Some analysis programs require that you define masses relative to global rectangular coordinates or the nodal degrees of freedom.

Properties: Mass (or MassX, MassY, and MassZ for some programs), Inertias (I_{xx}, I_{yy}, I_{zz}, I_{xy}, I_{yz}, I_{xz}), Offsets.

2. Rigid Element

Description: Represents a rigid connection between a master node and one or more other nodes. FEMAP has no limit on the number of additional nodes, or the degrees of freedom which may be connected on these additional nodes. Weighting factors for these connections may also be defined. Some analysis programs require that the rigid element connects all six degrees of freedom. Other programs let you limit the connection to selected degrees of freedom. In addition, support for the rigid element weighting factors in analysis programs is limited.

Application: Modeling connections which are very stiff relative to the remainder of the structure.

Shape: One master node, connected to one, to nineteen, additional nodes. If element formulation for Nastran is set to 1..RSPLINE then the element will have at least two independent nodes and at least 1 dependent node.

Element Coordinate System: None, depends on nodal degrees of freedom.

Properties: None. [14]

CHAPTER 6

FINITE ELEMENT MODEL

In this chapter, the FE model of the vessel Blue Marlin and SPAR are discussed. It elaborates on steps involved in creation of the model and the necessity of doing so.

6.1 Blue Marlin Model

A standard FE model of Blue Marlin is available with Dockwise engineering department. So the need for creating the FE model of the vessel is exempted. This section explains the construction details of the Blue Marlin model.

6.1.1 Coordinate system and units

FEMAP is a full three-dimensional modeling program. All coordinates are always specified with three coordinates, relative to one of the global or user-defined coordinate systems. The FEMAP work plane is only used for graphical selections and to orient geometry created by certain geometry creation commands.

Rectangular coordinate system is used in the FE model of the Blue Marlin and throughout this thesis. In Rectangular system the coordinate is located by the relative distance from the origin in X, Y and Z axis as show in the fig. 6.1

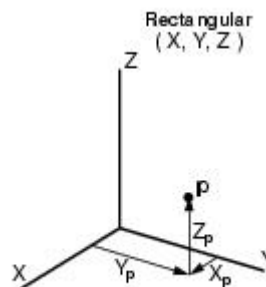


Fig 6.1 Rectangular coordinate system

The origin (0,0,0) of the Blue Marlin model is located on intersection of the aft perpendicular and the bottom line of the vessel model. The length of the vessel runs through the X axis, stern on the origin and the aft facing the positive direction of the X-axis. The port side of the vessel is located in the positive of the Y-axis and star board side on the negative of the Y-axis.

The deck of the vessel is located in the positive z-axis of the coordinate system and the keel on the negative z-axis. Fig 6.2 shows the FE model of the Blue Marlin and its coordinate system axes.

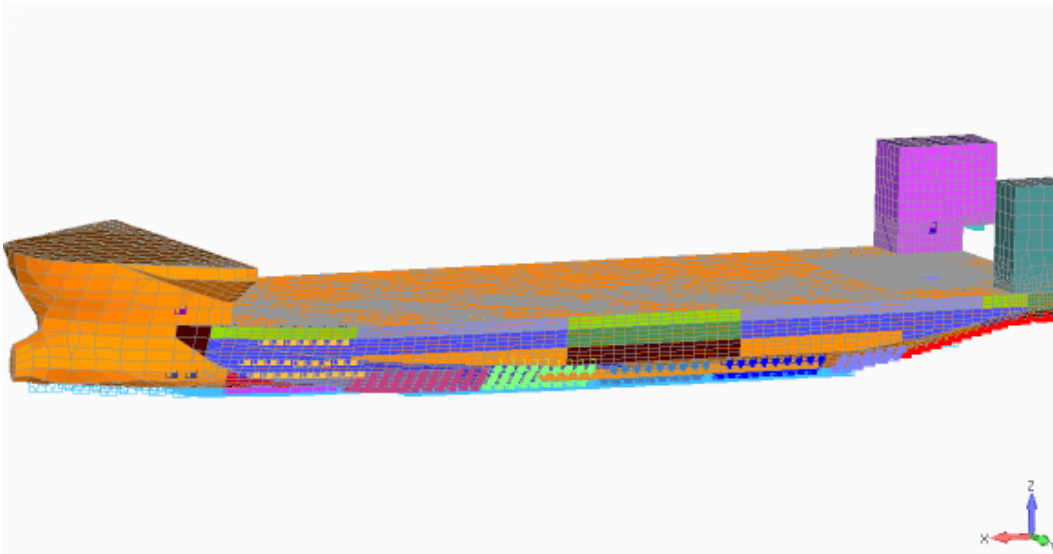


Fig 6.2 FE model of Blue Marlin and coordinate system axes

The units used in the FE model of the Blue Marlin and the entire analysis are Metric (metres).

6.1.2 FE Model details and properties

The vessel structure is a complex combination of steel of different cross sections and properties. It has a total of 306 properties with a combination of 4 element types and 13 materials. A summary of the whole model can be seen in the table below

Total No. of Nodes	55466
Total No. of Elements	119486
Total No. of Properties	306
Total No. of Materials	13
Elements types used	Plate, Beam, Spring, Mass

Table 6.1 Summary of FE model of the vessel

As the vessel model was already available; details about the most important components of the vessels structure are presented. As the greatest longitudinal bending stresses will occur over the midship region, the plate thickness of most of the members of the structure in this section will be thicker compared to other sections. So, Let us have a detailed look in to the design details of important aspects of the vessel structure at midship section and its corresponding FE model.

6.1.2.1 Keel

[9] At the centre line of the bottom structure is located the keel, which is often said to form the backbone of the ship. This contributes substantially to the longitudinal strength and effectively distributes local loading caused when docking the ship. The commonest form of keel is that known as the 'flat plate' keel, and this is fitted in the majority of ocean-going and other vessels. A form of keel found on smaller vessels is the bar keel. [9]

Blue Marlin has a flat plate keel which is fabricated using a plate thickness of 0.21m & 0.20m. The flat plate keel of Blue Marlin in the FE model is shown in the Fig.6.3. The FE mesh of keel in the model is created using plate/shell elements.

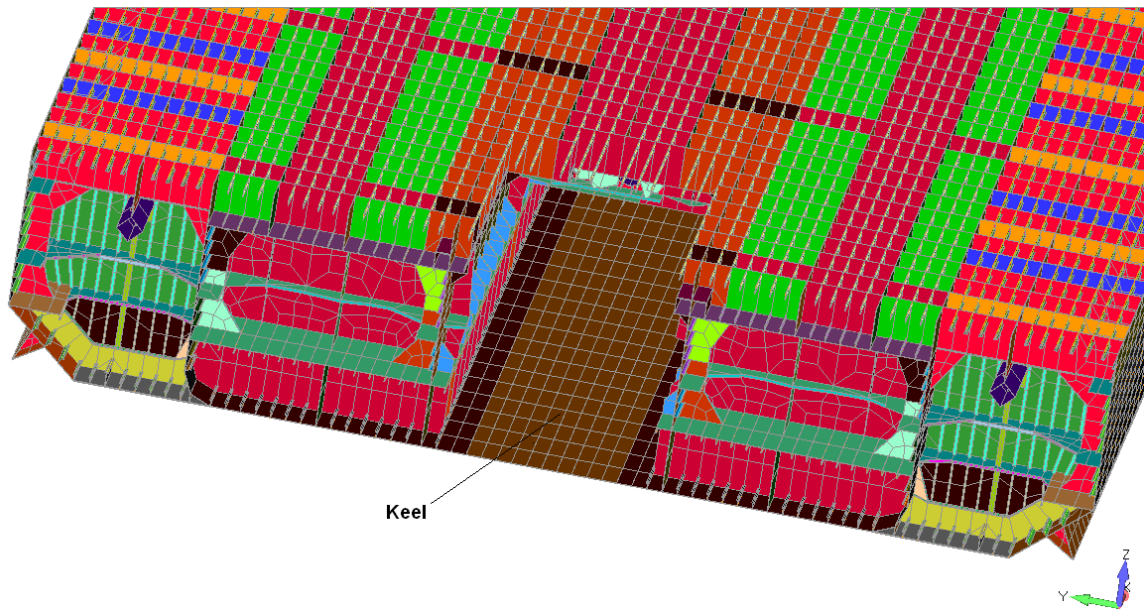


Fig. 6.3 FE model showing mesh of the Keel of Blue Marlin.

Properties of Keel is depicted in the table below

Description	Element type	Cross section	Dimension	Density
Keel, flat plate	Shell / Plate (QUAD4)	Plate	Thickness 0.021m/0.020m	7850.kg/m ³

Table 6.2 Properties of FE model of keel

6.1.2.2 Bottom Structure

Blue Marlin has a double hull bottom structure. An inner bottom (or tank top) provided at a minimum height above the bottom shell, and maintained watertight to the bilges. This provides a considerable margin of safety, since in the event of bottom shell damage only the double bottom space may be flooded. The space is not wasted but utilized to carry oil fuel and fresh water required for the ship, as well as providing ballast capacity. Water ballast bottom tanks are commonly provided right forward and aft for trimming purposes.

[9] Double bottoms may be framed longitudinally or transversely, but where the ship's length exceeds 120m it is considered desirable to adopt longitudinal framing. The explanation of this is that on longer ships tests and experience have shown that there is a tendency for the inner bottom and bottom shell to buckle if welded transverse framing is adopted. [9]

As Blue Marlin is longer than 200m, it has a longitudinally framed double hull bottom structure. The extended section of the vessel is a single hull bottom structure. The bottom structure is a combination of number of different cross sections of girders and frames as shows in the fig 6.4.

The FE model of the vessel bottom structure at midship section consists of the following cross sections and properties

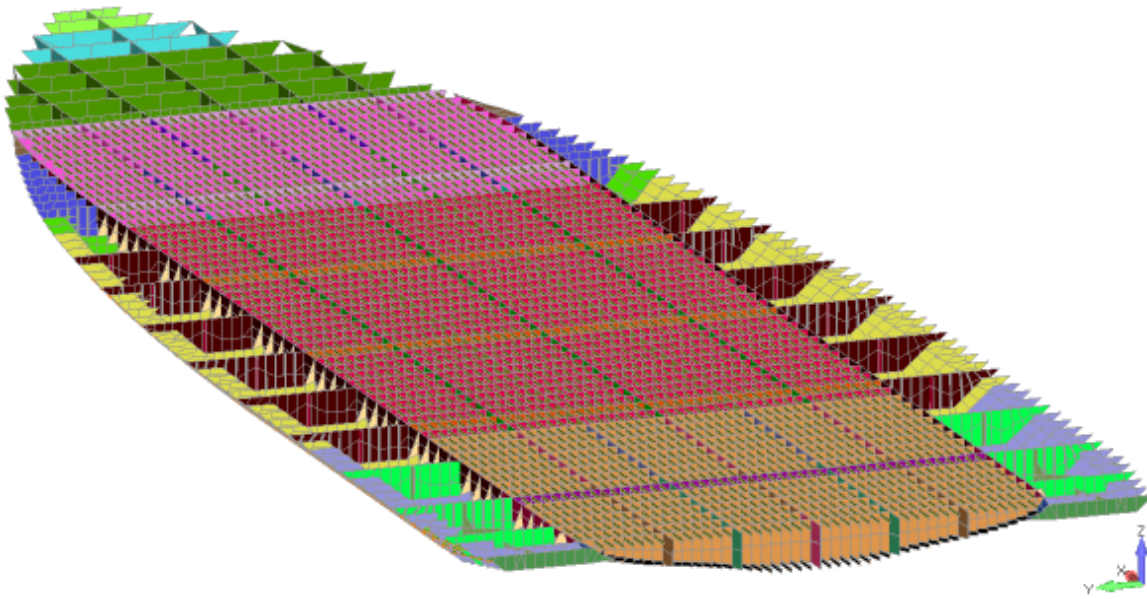


Fig 6.4 FE model of Double hull bottom structure of Blue Marlin

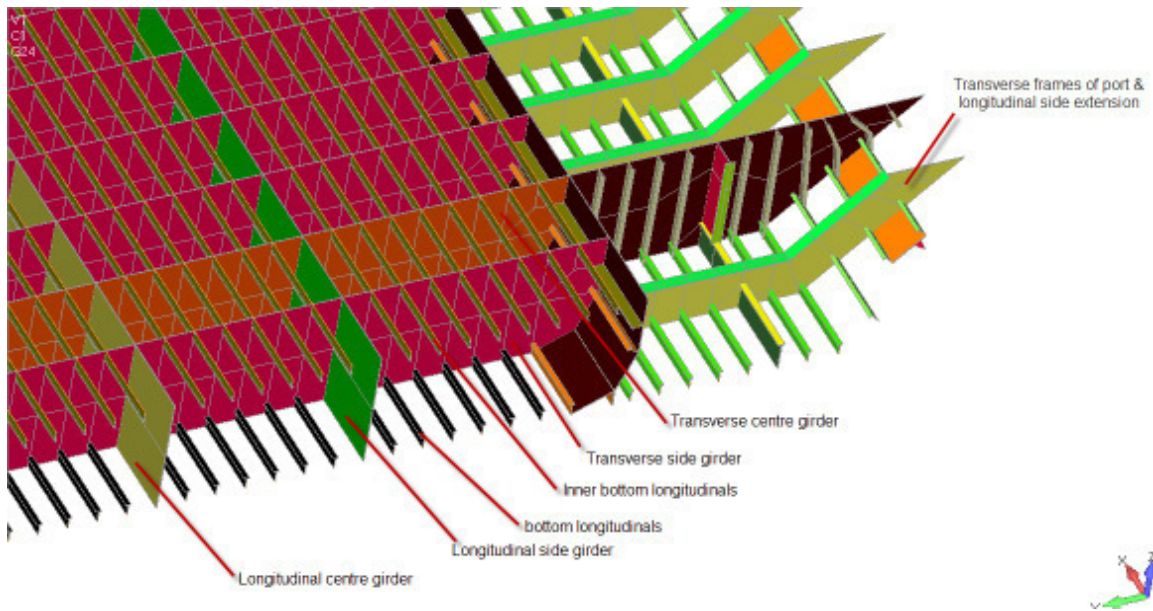


Fig 6.5 FE model details of bottom structure

Description	Element type	Cross section	Dimension	Material Density
Longitudinal centre girder	Shell / Plate (QUAD4)	Plate	Thickness 0.022m	12575.5kg/m ³
Longitudinal side girder	Shell / Plate (QUAD4)	Plate	Thickness 0.018m	12575.5kg/m ³
Transverse centre girder	Shell / Plate (QUAD4)	Plate	Thickness 0.017m	12575.5kg/m ³
Transverse side girder	Shell / Plate (QUAD4)	Plate	Thickness 0.015m	12575.5kg/m ³

Transverse frames of port & starboard side extension	Shell / Plate (QUAD4)	Plate	Thickness 0.022m	12575.5kg/m ³
Inner bottom longitudinals	Beam	Offset bulb plate	H*T (0.32*0.012)m	7850kg/m ³
bottom longitudinals	Beam	Tee Bar	H*T (0.35*0.012)m W*T(0.15*0.014)m	7850kg/m ³

Table 6.3 Properties of FE model of bottom structure

6.1.2.3 Bulkheads

Vertical partitions in a ship arranged transversely or longitudinally are referred to as 'bulkheads'. Those bulkheads which are of greatest importance are the main hull transverse and longitudinal bulkheads dividing the ship into a number of watertight compartments.

These are the muscles of the vessel which help resist the transverse and longitudinal stress induced in the vessel structure. Much of this structure, particularly the pillars and to some extent the transverse strength bulkheads, is responsible for carrying the vertical loading experienced by the ship. When a huge cargo is loaded on the vessel deck, it is important that the support of the cargo must be placed above the bulkhead sections.

The bulkheads are fabricated using different properties at different sections of the vessel; the following table shows properties of transverse and longitudinal bulkheads at midship section.

Description	Element type	Cross section	Dimension	Material Density
Transverse bulkhead	Shell / Plate (QUAD4)	Plate	Thickness 0.015m	12575.5kg/m ³
Longitudinal bulkhead	Shell / Plate (QUAD4)	Plate	Thickness 0.022m	12575.5kg/m ³

Table 6.4 Properties of FE model of bulkhead

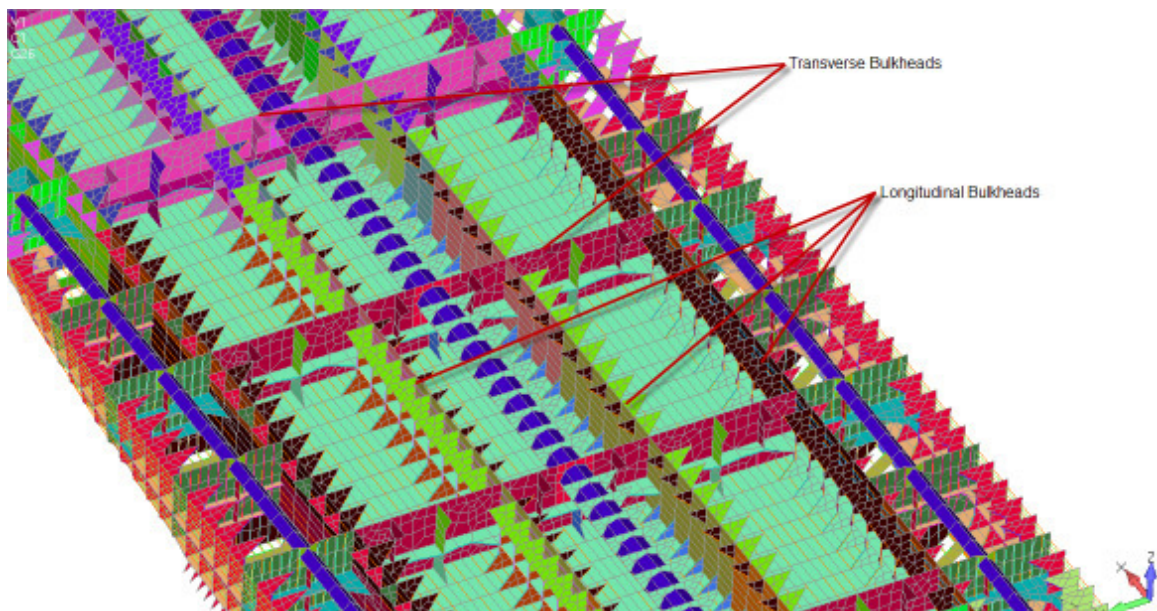


Fig 6.6 FE model details of bulkheads

6.1.2.4 Stiffeners

All the longitudinal and transverse surfaces of the vessel structure are fitted with stiffeners longitudinally at least on one of its surfaces to provide strength to the structure. It prevents buckling of plates in loading. The side shell of the vessel also longitudinally framed with stiffeners. These stiffeners are the nerves of the vessel which helps in distributing the load.

Often profile bulb sections are used for stiffeners. But angle bar and flat bar are used for stiffening side shell of the vessel and deck. All the stiffeners in FE model of the vessel are created with beam elements of appropriate cross section.

The following table shows properties of some of the stiffeners used in Blue Marlin FE model

Description	Element type	Cross section	Dimension	Material Density
Stiffeners on bottom deck	Beam	profile bulb	H*T (0.26*0.011)m	7850kg/m ³
Stiffeners on vertical bulkheads	Beam	profile bulb	H*T (0.28*0.011)m	7850kg/m ³
Stiffeners along the side shell	Beam	Angle Bar	H*T (0.35*0.012)m W*T(0.10*0.017)m	7850kg/m ³
Stiffeners under top deck	Beam	Flat Bar	H*T (0.43*0.026)m	7850kg/m ³

Table 6.4 Properties of FE model of stiffeners

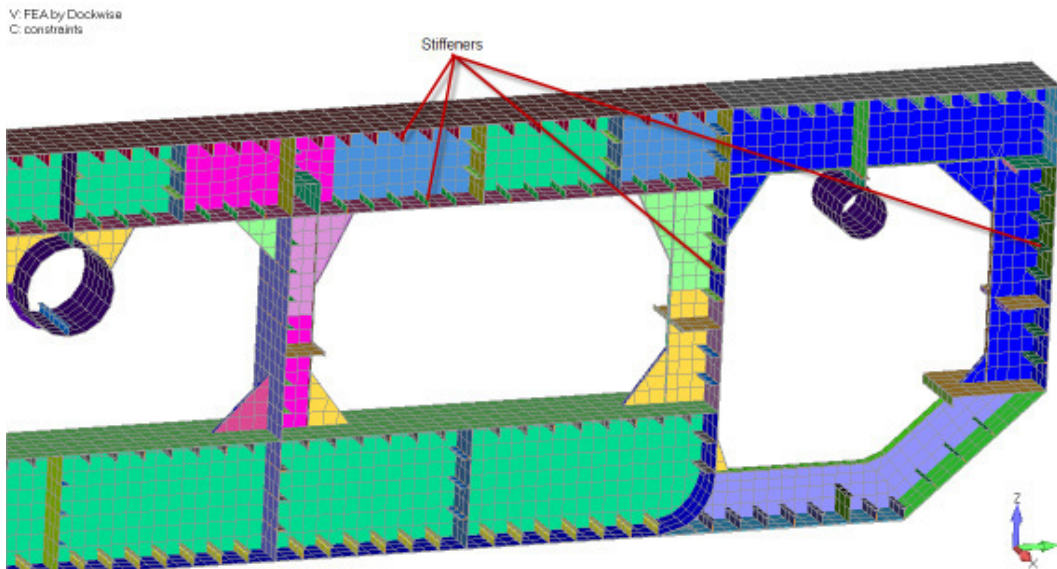


Fig 6.6 FE model of typical Blue Marlin web frame with stiffeners

6.1.2.5 Deck

Similar to the double hull bottom structure of Blue Marlin, the deck is also a double deck to give the vessel the agility it needed to carry ultra heavy cargos. The deck is strongest structure in the vessel. It is a combination of longitudinal and transverse plate panels as shown in the fig.6.7. Unlike other cargo ships Blue Marlin has a fixed horizontal deck, which helps in carrying huge structures such as offshore oil & gas platforms on its deck. Longitudinal stiffeners run under top deck plate and above bottom deck plate to reinforce the deck structure further.

The following table shows properties of some of the elements used in modeling deck of the Blue Marlin FE model.

Description	Element type	Cross section	Dimension	Material Density
Longitudinal centre girder	Shell / Plate (QUAD4)	Plate	Thickness 0.026m	12575.5kg/m ³
Longitudinal side girder	Shell / Plate (QUAD4)	Plate	Thickness 0.018m	12575.5kg/m ³
Transverse girder	Shell / Plate (QUAD4)	Plate	Thickness 0.018m	12575.5kg/m ³
Inner deck longitudinal stiffeners	Beam	Offset bulb plate	H*T (0.32*0.012)m	7850kg/m ³
Top deck longitudinal stiffeners	Beam	Flat Bar	H*T (0.26*0.011)m	7850kg/m ³

Table 6.5 Properties of FE model of deck

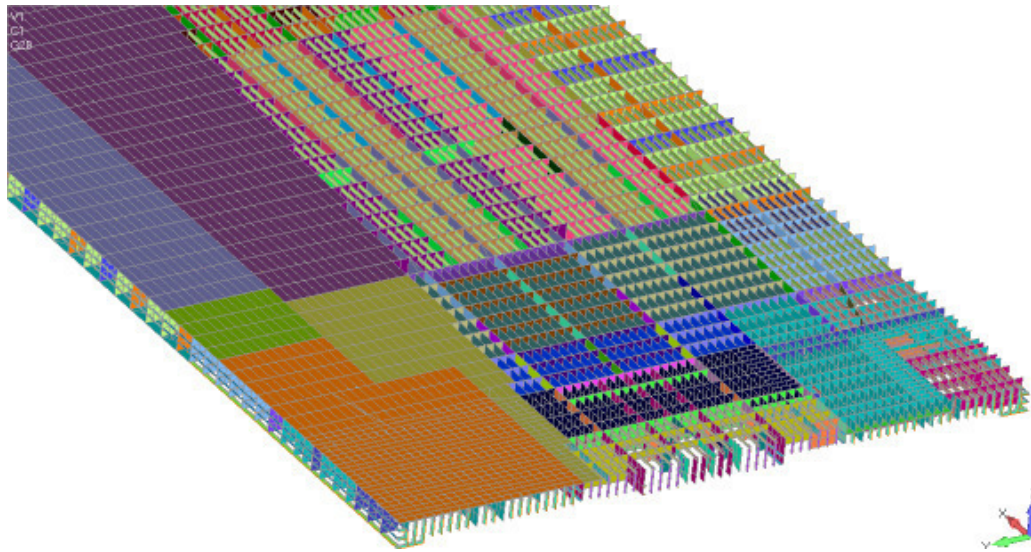


Fig 6.7 FE model of the vessel deck

6.1.2.6 Bow & superstructure

The bow is the front part of the vessel before the deck, the hull in front of the bow is designed in such a way to reduce drag during sailing. Bow section of the vessel Blue Marlin is not modeled to actual design. As the cargo will only be loaded on top of the deck, analysis of the bow section is not necessary and is of little importance in the model. Since the bottom of the bow section has ballast tanks, just the outline of the bow section and its divisions are modeled to utilize the ballast tank space in the model.

The whole bow section is modeled using few properties; the following table shows the properties of the bow section model.

Description	Element type	Cross section	Dimension	Material Density
Front section	Shell / Plate (QUAD4)	Plate	Thickness 0.03m	35778.68kg/m ³
Middle section	Shell / Plate (QUAD4)	Plate	Thickness 0.03m	3758kg/m ³
Back section	Shell / Plate (QUAD4)	Plate	Thickness 0.03m	9955.4kg/m ³
Hull Side shell	Shell / Plate (QUAD4)	Plate	Thickness 0.03m	7850kg/m ³
stiffeners	Beam	T-section	H*T 0.8x0.02 +0.2x0.04 m	7850kg/m ³

Table 6.6 Properties of FE model of bow section

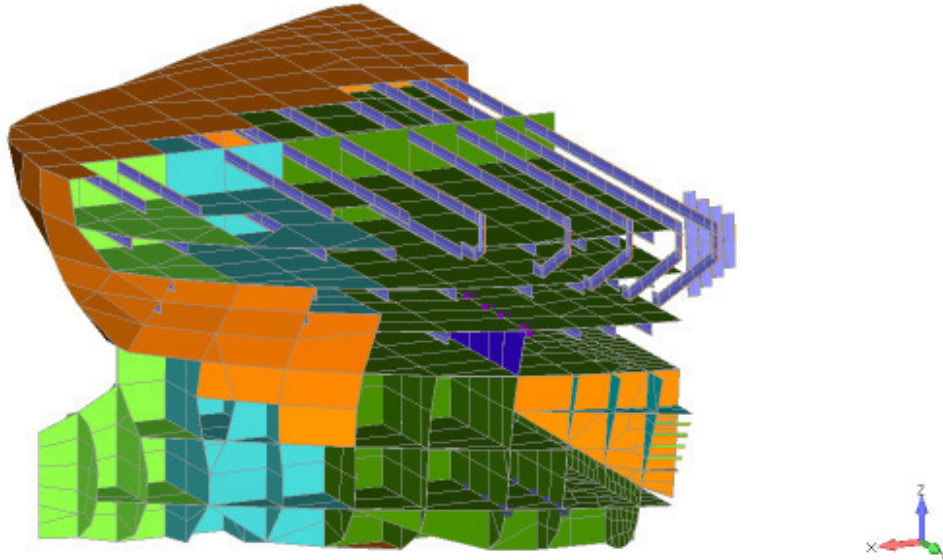


Fig 6.8 FE model of the bow section

Superstructure is the tower on top of the bow which houses control tower; crew accommodation, stores and other necessary spaces. Only the mass of the structure matters when calculating the ballast necessary for the vessel, so the weight of the superstructure is incorporated in the model using mass elements

6.1.2.7 Stern

Blue Marlin has a transom stern, which offers a greater deck area aft and can also provide improved flow around the stern. The stern of the Blue Marlin is the most complicated section of the vessel; it should incorporate a number of features, engine room, shape of the stern for propeller and rudder, provision for the drive shaft to connect the engine to the propeller, ballast tanks, provision for piping of the engine and the vessel etc.

Due to the presence of the engine in the stern section, the engine room section along the centre line of the vessel, to accommodate the engine is a big space with out any bulkheads or supports. This makes the structure on the stern section of the vessel vulnerable to heavy loads. Special Care should be taken when supporting the heavy cargoes on top of the stern section. The considerable complication of the stern section makes it a hassle to model it. It is modeled using 61 properties with 2 different element types. The most important properties used in the FE model of the stern of the vessel Blue Marlin is illustrated in the table below.

Description	Element type	Cross section	Dimension	Material Density
Front section	Shell / Plate (QUAD4)	Plate	Thickness 0.015m	13568.1kg/m ³
Mid section	Shell / Plate (QUAD4)	Plate	Thickness 0.012m	20581.2kg/m ³
Back section	Shell / Plate (QUAD4)	Plate	Thickness 0.02m	16217.9kg/m ³
Hull Side shell	Shell / Plate (QUAD4)	Plate	Thickness 0.035m	7850kg/m ³
stiffeners	Beam	Flat bulb	H*T 0.3x0.011m	7850kg/m ³
stiffeners	Beam	Flat bulb	H*T 0.2x0.02m	7850kg/m ³

Table 6.7 Properties of FE model of stern section

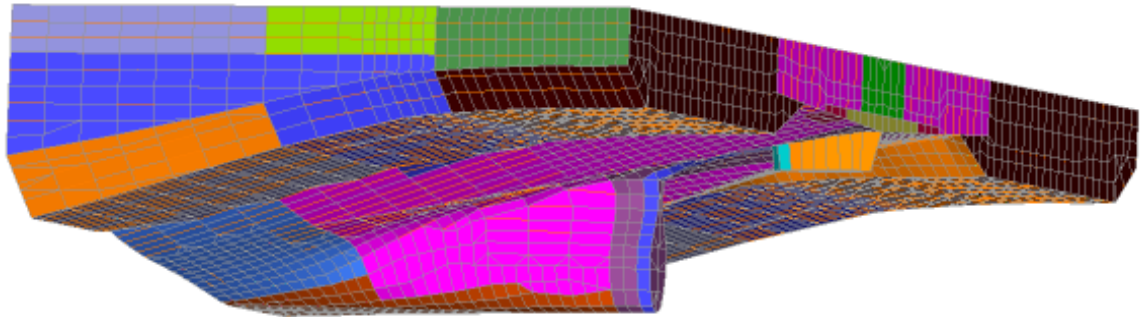


Fig 6.9 FE model of stern section showing the profile of the stern

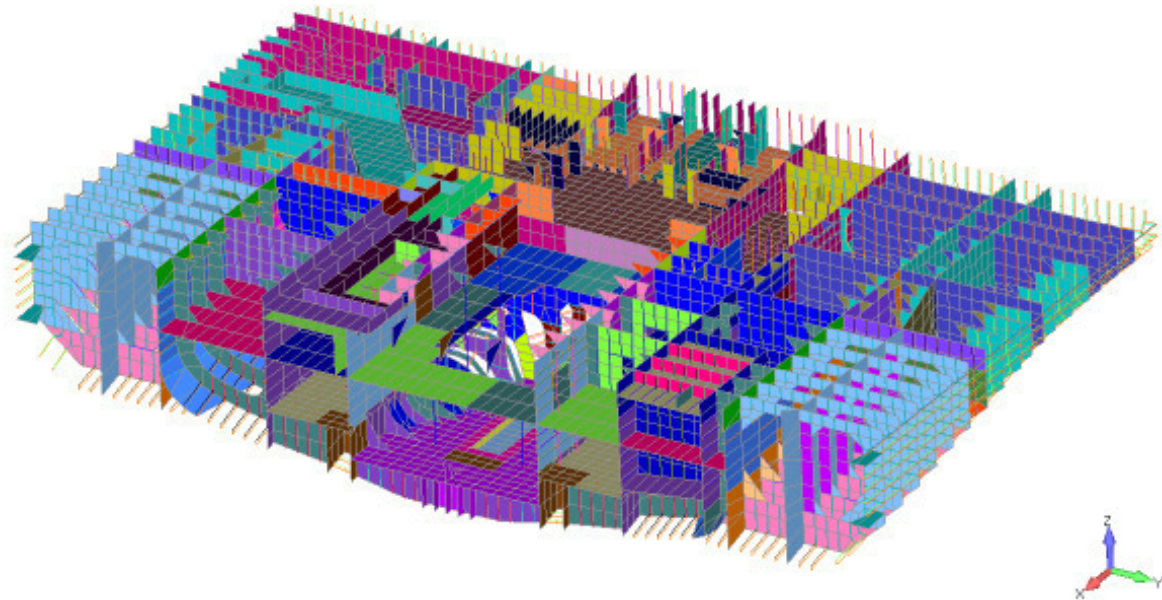


Fig 6.10 FE model of stern section without deck showing the engine room section

6.1.2.8 Floatation

Vessels floatation is provided by spring elements in the FE model. The bottom hull of the vessel's FE model is constrained on its nodes using spring elements, which prevents the model from dropping off to infinity. The spring elements are restricted to axial only deformation, as the vessel during floatation experience only axial movements not torsional. The stiffness used in the spring elements represents the stiffness of the buoyancy of the vessel. This stiffness provides upward force due to buoyancy of the vessel. This upward force in addition to the water pressure influences the draft of a floating vessel. Fig.6.8 shows the spring elements used in the model.

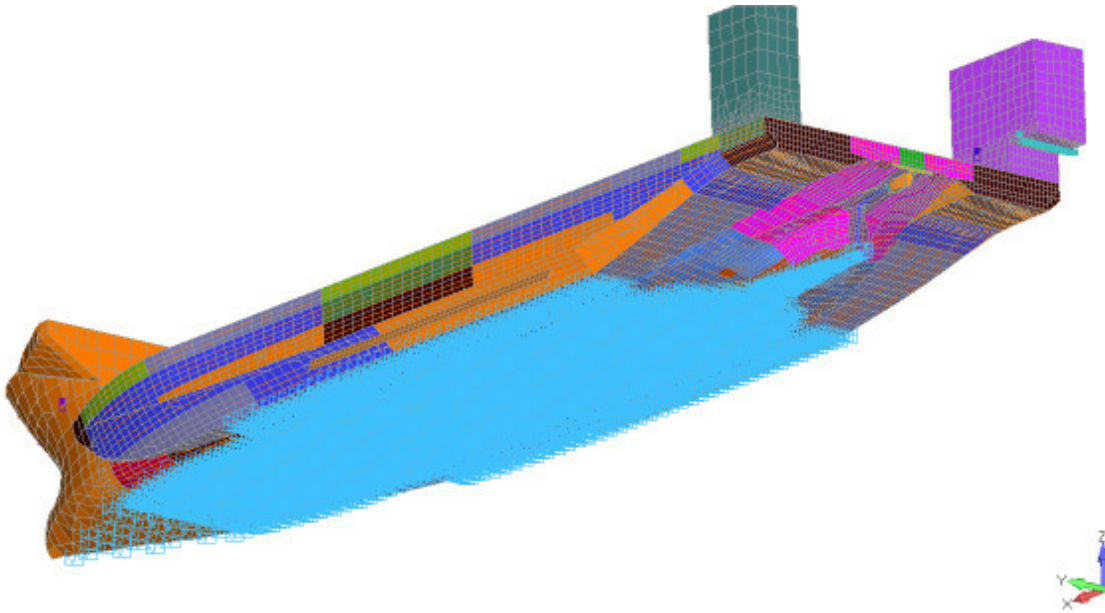


Fig 6.11 Spring elements under the vessel model.

Properties of the spring element

Description	Element type	stiffness	Deformation
Floataction on the vessel model	Spring	21995.86	Axial

Table 6.8 Properties of spring element under the vessel model

The stiffness of the springs created under the vessel model is to simulate the buoyancy of the vessel in the model; it represents the stiffness of the buoyancy. This is the additional upward force at a given displacement downward.

6.1.2.9 Draft and water pressure

The height of the vessel immersed in water measured from the midship section is called draft of a vessel. All vessels have a free floating draft which is the height of vessel under water with out any additional ballast or load on deck. The ideal sailing draft for Blue Marlin is 10.28 which is a design parameter of the vessel. The buoyancy as explained in the last section plays an important role in the draft of the vessel.

The pressure of water acting on the vessel's hull when the vessel is not sailing is called hydrostatic pressure. Since the main motive of this thesis is to analyze the load-out of heavy SPAR when the vessel is docked to the keyside, means the vessel is in static condition, we only take into account the hydrostatic pressure not the hydrodynamic pressure.

The hydrostatic pressure acting on the vessel hull at a point can be found out. The pressure at a certain point depends on the draft of the vessel. The pressure will be less on the sides of the hull near to the water surface and high on the hull bottom. The hydrostatic pressure acting on a unit area is calculated and applied on the element face as a pressure.

There are quite a lot of software's available in the market to calculate such marine properties of the vessel. Dockwise engineers make use of one such software and calculated the hydrostatic pressure of Blue Marlin for different drafts. To make it much easier they've incorporated the hydrostatic pressure data in an API tool to generate the water pressure on the hull of the vessel according to its draft.

If the draft of the vessel is entered in the tool, the API automatically calculates the pressure on each element face and creates a load set for hydrostatic pressure and applies it to all the elements inside the draft line. The effect of waves in sea water can also be set in the model using the API tool. Fig 6.12 shows the API tool for implanting draft and hydrostatic pressure. When the draft of the vessel is entered in the tool, it automatically calculates and applies the water pressure below the draft line.

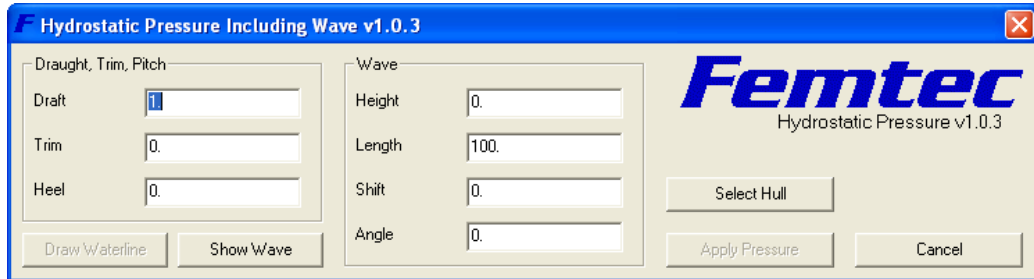


Fig 6.12 API tool for implementing draft and hydrostatic pressure in the model

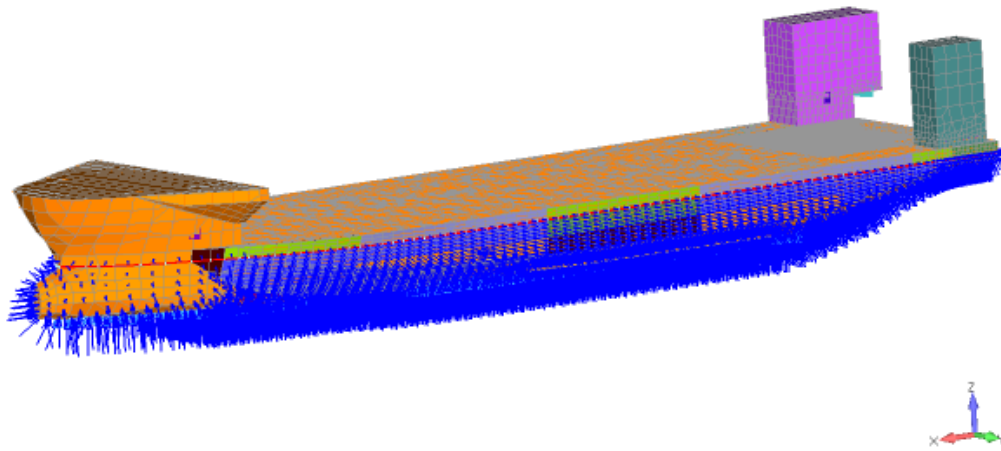


Fig 6.13 hydrostatic pressure applied to the FE model

A closer look at the applied pressure reveals the amount of pressure applied corresponding to the depth of water. Bigger the arrow size, higher the pressure. As you can see from the fig 6.14 the pressure is much higher at the hull bottom than on the sides.

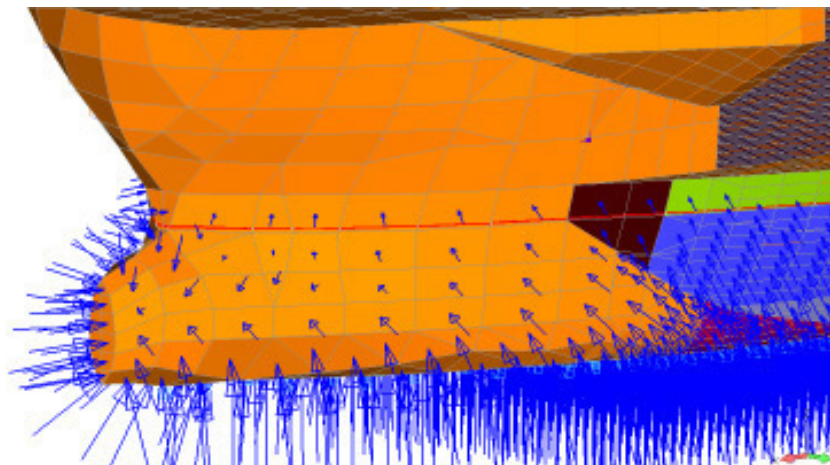


Fig 6.14 Closer look at the hydrostatic pressure applied

6.1.2.10 Water Ballast

Blue Marlin has 84 water ballast tanks, which helps the vessel in maintaining the draft and stability on the high seas. Other than the water ballast tanks, there are other tanks to store fresh water, fuel, oil for lubrication of its engines and other equipments onboard.

All the tanks and spaces used to store equipments are also part of the ballast tanks. Even the crew members are also part of the ballast. When doing a ballast calculation of the vessel all the above masses are taken into account. All the ballast tanks spaces are shown in the drawing in the Appendix number 2.

The ballast masses are represented in the model by placing mass elements to the nodes in appropriate location in the model. Other than water ballast tanks all the other masses are all permanently included in the FE model of the Blue Marlin. All the masses are represented by Mass elements. The water mass for ballasting the vessel can be added to the mass elements in the model according to the ballast calculation created. To do it more easily, an API tool is created. Each ballast tanks section in the model is added with mass elements on its surfaces to add the mass of the ballast water. These elements are grouped under the name of the ballast tank in the API tool. Using the tool, the ballast water masses can be updated on the model quickly and efficiently. The entered mass for a tank will be equally distributed among all the mass elements present in that particular tank section. Fig 6.15 shows the API tool used for adding ballast masses to the model. The mass elements in the FE model can be seen in the fig 6.16



Fig. 6.15 API tool for updating the mass elements in the model

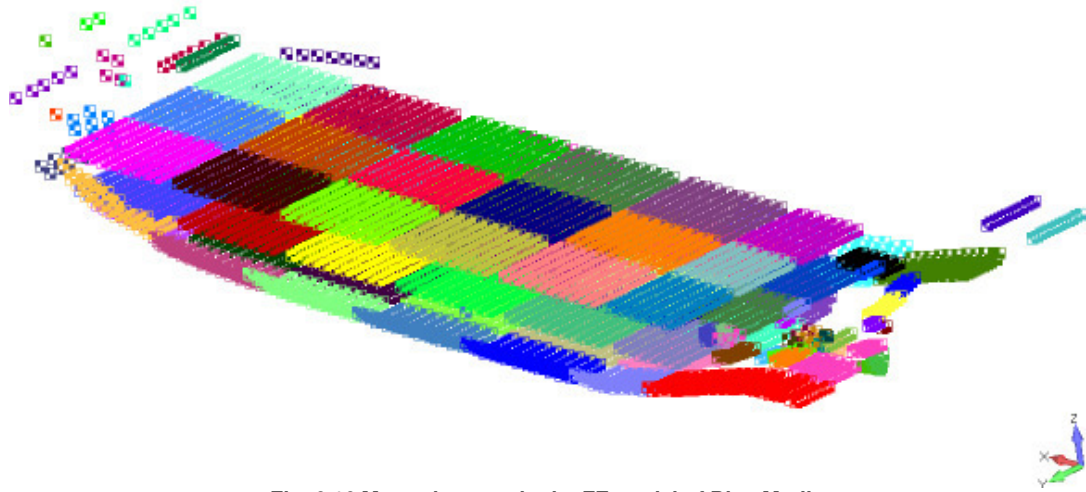


Fig. 6.16 Mass elements in the FE model of Blue Marlin

The following table shows the summary of all the mass elements in the model

Description	Element type	Total no of ballast spaces	constant ballast masses	Variable Water ballast masses
Ballast water	Mass	121	37	84

Table 6.9 Properties of Mass element in vessel model

6.1.2.11 Skid Beams

The number of skid beam and its location is already investigated in chapter 4.3 and 4.4. Based on the dimensions in the above chapter, skid beams are created on vessel model above the deck. The location of skid beams are identified and is modeled and meshed based on the nodes already available on the vessel deck. The properties of the skid beams, like, thickness, height and width are acquired from the experiences of previous projects. Fig.6.17 shows the modeled skid beams on the vessel deck.

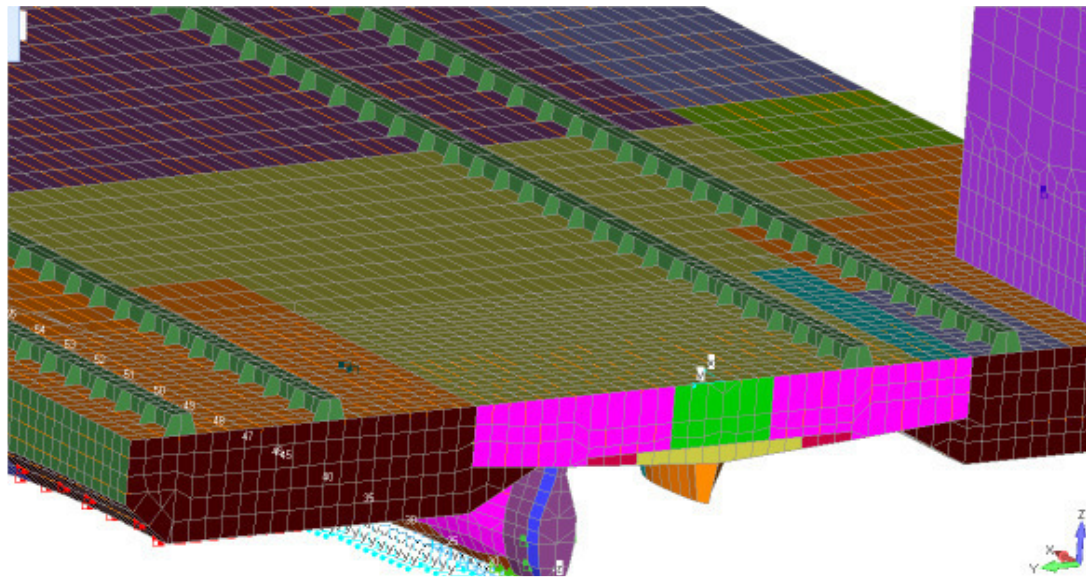


Fig 6.17 Skid beams on vessel model

The skid beams are created using the following properties;

Description	Element type	Cross section	Dimension	Material Density
Skid beams	Shell / Plate (QUAD4)	Plate	Thickness 0.025m	7850kg/m ³

6.1.3 Discrepancies in the model

As the most important constituents of the Blue Marlin structural FE model have been detailed above, the model is not 100% identical to the physical vessel. There are some discrepancies exist between the physical vessel structural details and the FE model.

The FE model does not include the following details which are present in the physical vessel:

1. Manholes
2. Holes for piping
3. Air/drain holes
4. Holes in the bottom and deck structural frames to interconnect the sections to form the ballast tanks and
5. Collars in the web frame are not chamfered
6. The bow section of the vessel is not modeled to exact details. As the structure of the vessel under the deck is the one carrying the load and the bow section has nothing to do with the load bearing, the details of the bow section are neglected and just an outline of the section is modeled.

The difference between the physical vessel and FE model can be visualized in the fig 6.18 and 6.19 as it shows the typical web frame of the Physical vessel and FE model.

The mesh of the whole FE model of the vessel is modeled in a coarse manner. The resulting output from the analysis of the model should be viewed as a representation of the stress of the whole model rather than the particular region. When the stresses are higher in a particular area, the model has to be compared with the vessel design drawings and modified to incorporate the discrepancies in that particular region and further refinement of mesh in that region should be done and analyzed again.

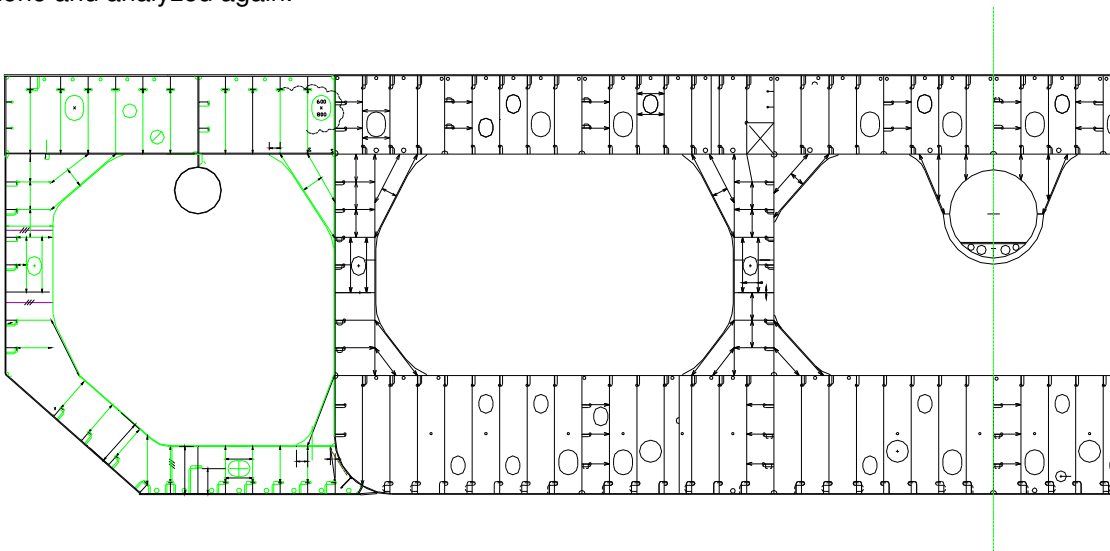


Fig 6.18 Typical web frame details of the physical vessel

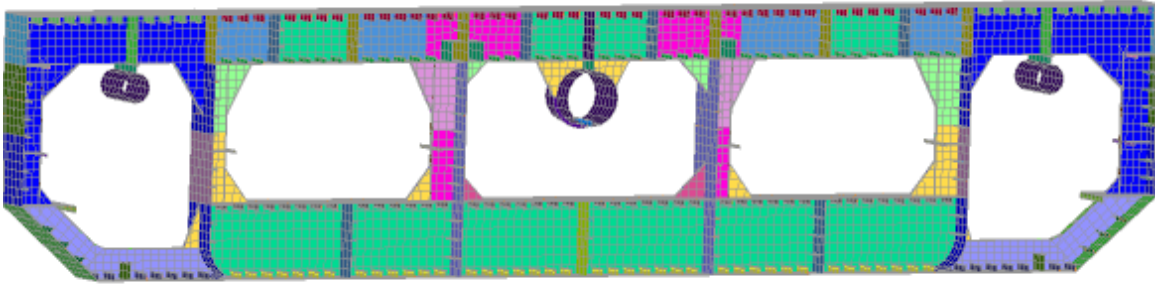


Fig 6.19 Typical web frame details of the FE model

The FE model of the vessel Blue Marlin has the following characteristics values, compared with the actual designed values as shown in the table below

Description	Design	FE Model
Mass of the vessel	34,302.41 Tons	34629.538 Tons
Longitudinal Centre of gravity from aft perpendicular	102.819m	101.8264m

Table 6.10 Comparison of FE model with the actual vessel.

The mass of vessel includes the weight of light ship, port casing, starboard casing, crew and effects, provisions, stores, fuel oil, lubricating oil, fresh water. The weight of these components doesn't change much for every project performed, there for it is fixed value. These component masses are permanently included in the FE model of the vessel as mass elements.

From the table above, it is clear that there are some percentage of difference in the weight of the model and the actual vessel. But the difference in the mass between the actual vessel and FE model is about 300tons, this difference is mainly due to the discrepancies present in the model as explained above. But for a model of such a huge scale where the masses are calculated in thousands, the difference of 300 tons is very less and it can be neglected.

The difference in centre of gravity of the model to the actual vessel is about 1 m, and is due to the above mentioned discrepancies and the differences in the design to the FE model.

It is very clear from the table above that the FE model of the vessel is almost as accurate to the actual design and can be safely utilized for the analysis.

6.2 SPAR Model

Unlike the Blue Marlin Model, which was readily available with Dockwise, the SPAR model was modeled from scratch. The design data of the SPAR provided by the client is discussed in section 4.2. With that information in hand, the SPAR is modeled in FEMAP.

Almost all the section of the SPAR resembles standard geometry like cylinder, tube and box; it is decided to model the SPAR entirely using beam elements except for the heave plates, to keep the model simple. Modeling the SPAR entirely using beam elements is due to the fact that it improves analysis execution speed compared to plate and solid elements and also the absence of the complete design details of the SPAR.

The data provided by clients about the SPAR is just an approximation to study the feasibility of the transport, so design details of the SPAR is not a concern, what matters most in our analysis is stiffness of the whole structure. To get the desired stiffness, it is very important to model the SPAR with same centre of gravity as per the clients design.

6.2.1 Coordinate system and units

As like the Blue Marlin model, the SPAR was also modeled in rectangular coordinate system. The origin (0,0,0) of the Spar model is located on the centre line of the SPAR at the Hard tank end. The centre line of the SPAR starting from the origin runs in the x-axis, to match the centre line of the vessel. The truss section with heave plates is followed by the hard tank and the SPAR ends with the soft tank keel.

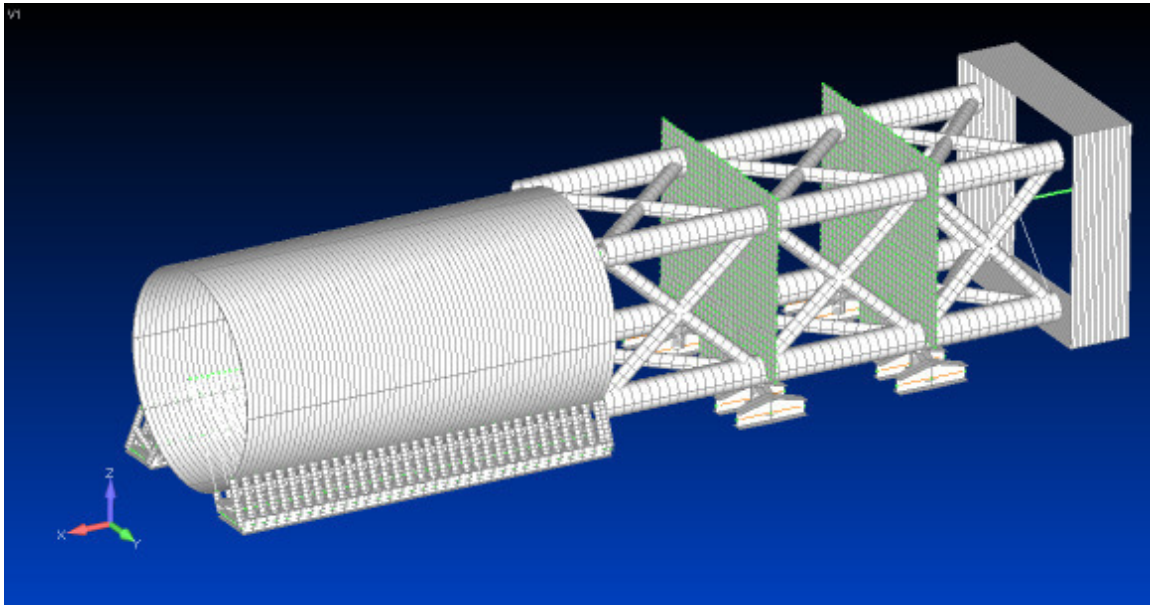


Fig 6.20 FE model of SPAR and coordinate system axes

The units used in the FE model of the SPAR and the entire analysis are Metric (Metres).

6.2.2 Material specification

As the complete design data about the SPAR, the material specifications and details of the dimension of the interior sections are not known, we are not following any standards in model of the SPAR created. The important parameter in the SPAR model is the density of the material used and the stiffness of the whole SPAR.

So to keep our model simple, we assume that the all the SPAR sections are hollow structure, the masses due to the internal structural details are added to the outline elements of the section by adjusting the density of the material specified in analysis. For example the mass of the internal details of the hard tank and the outfitting mass are added to the beam elements of cylindrical shape by altering the density of the material.

6.2.3 Model details and properties

As the FE model of SPAR is modeled using beam elements and the mass of additional structural elements are added to it by adjusting the density, so every component of the SPAR has to be fine tunes to achieve the desired mass by altering the density of the material.

The SPAR model has a total of 13 properties with a combination of 2 element types. A summary of the whole model can be seen in the table below

Total No. of Nodes	5253
Total No. of Elements	4819
Total No. of Properties	13
Total No. of Materials	13
Elements types used	Plate, Beam

Table 6.11 Comparison of FE model with the actual vessel

Now, we will have a detailed look in to the modeling details of each section of the SPAR.

6.2.3.1 Hard Tank

The Hard tank is the most important structure in the SPAR; it provides the buoyancy to float on the high seas and also withstand the loads of topside and also waves on its walls. The hard tank constitutes for more than 60% of the SPAR mass.

The total mass of the hard tank alone is 14304tons without the supports and outfittings. A line of 81.3m is created and meshed with beam elements with circular tube shape using the following properties for the achieving the required weight. Fig 6.21 shows the FE model of the hard tank section of the SPAR.

Description	Element type	Cross section	Dimension	Material Density
Hard tank	Beam	Circular tube	Radius: 22.2505m Thickness: 0.020m	62889kg/m ³

Table 6.12 Properties of FE model of hard tank

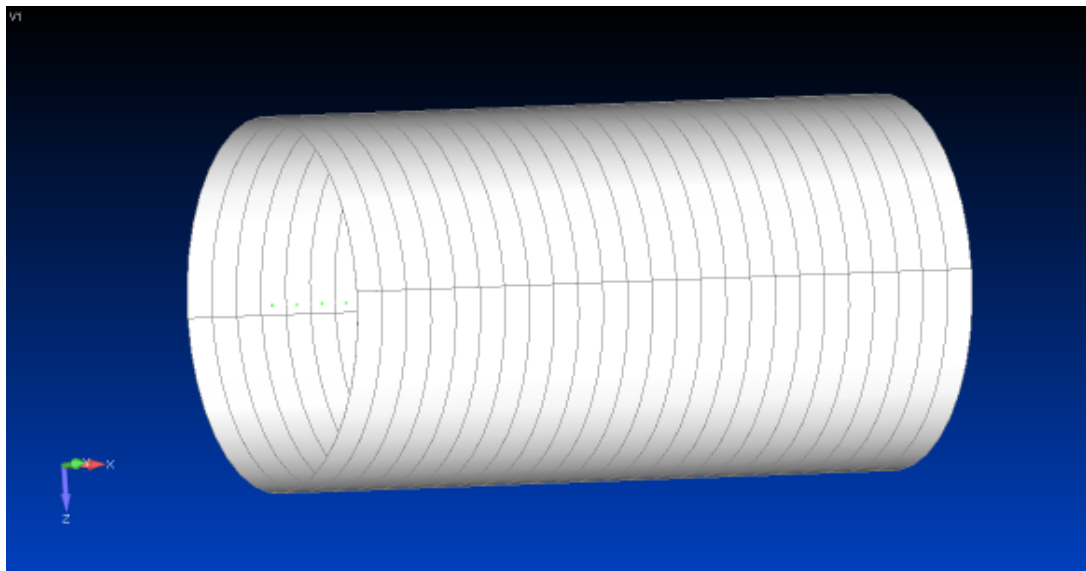


Fig. 6.21 FE model of Hard tank section of the SPAR

6.2.3.2 Soft Tank

The soft tank is used for ballasting the SPAR to maintain its draught and also to provide floatation during horizontal position before upending.

The soft tank's mass is 2315 tons. All the time during transportation, the soft tank are suspended on the stern of the vessel, so it doesn't has supports underneath it. There will be some additional masses in the soft tanks for guiding the risers in the center well.

Similar to Hard tank the soft tank is created by utilizing line geometry of length 12.8m and meshed using the beam element of following properties for achieving the required weight. Fig. 6.22 shows the FE model of the Soft Tank section of the SPAR.

Description	Element type	Cross section	Dimension	Material Density
Soft tank	Beam	Rectangular tube	Height * Width: 44.501m*44.501m Thickness: 0.020m	50820.93kg/m ³

Table 6.13 Properties of FE model of soft tank

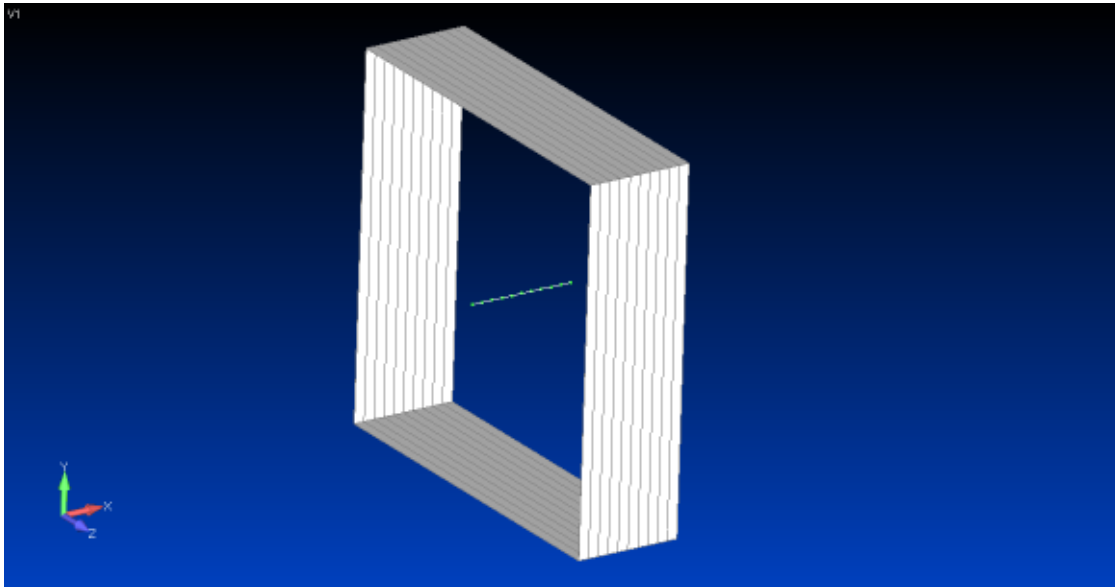


Fig. 6.22 FE model of Soft tank section of the SPAR

6.2.3.3 Heave plates

Heave plates are placed in between the truss structure of the SPAR to provide stiffness and also for damping the SPAR vertical motion while floating. The Future SPAR has 2 heave plates in between the truss structures.

The heave plates are modeled using plate elements with the following properties for achieving the required mass. Fig. 6.23 shows the FE model of the heave plate. The weight of the heave plate is 529tons and it has a cutoff section on both sides at the bottom for proving space for the supports.

Description	Element type	Cross section	Dimension	Material Density
Heave plate	Shell / Plate (QUAD4)	Plate	Height * Width: 44.501m*44.501m Thickness: 0.025m	11877.21 kg/m ³

Table 6.14 Properties of FE model of Heave plates

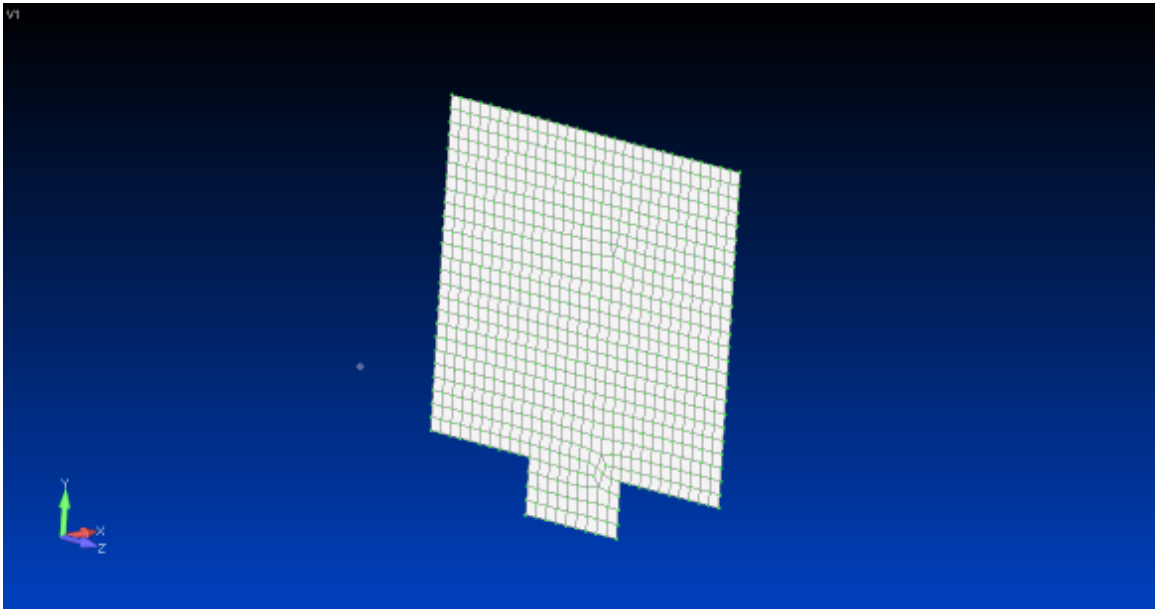


Fig. 6.23 FE model of Heave plate section of the SPAR

6.2.3.4 Truss

The truss section of the SPAR extends from the hard tank and connects the soft tank. It gives the SPAR the deep draught it requires for withstanding the heavy ocean currents.

The truss section of the SPAR is similar to a normal truss used for construction. The truss is fabricated with circular tubes, large tube for 4 legs and smaller tubes for the cross members. The weight of the truss is 3293 tons and is also modeled by beam elements with circular tube shape using the following properties for achieving the required mass. Fig 6.24 shows the FE model of the truss section of the SPAR

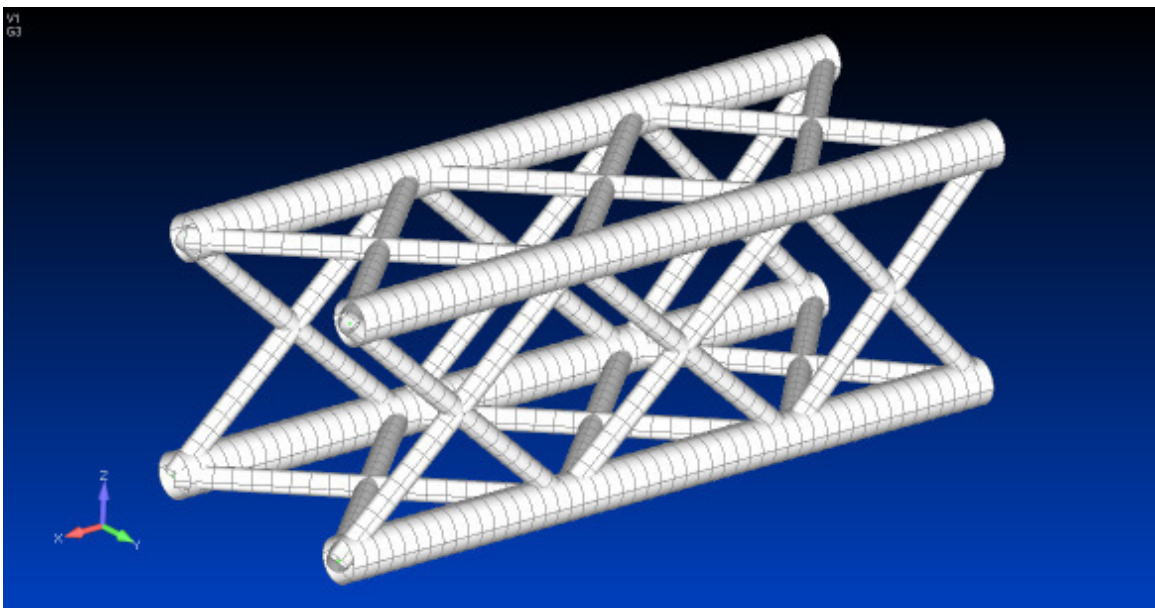


Fig 6.24 FE model of the truss section of the SPAR

Description	Element type	Cross section	Dimension	Material Density
Truss legs	Beam	Circular tube	Radius: 3m Thickness: 0.015m	13245.9kg/m ³
Cross members	Beam	Circular tube	Radius: 1.5m Thickness: 0.015m	11521.84kg/m ³

Table 6.15 Properties of FE model of Truss section

The connection between the hard tank and the four truss legs are made by rigid elements, so that the loads on the hard tank at the end node will be directly transferred to the truss legs and vice versa. This step is very critical for obtaining the desired stiffness of the SPAR, as there are no interior components designed in the hard tank model which in reality will make the hard tank stiffer and hold the truss legs in position. Fig 6.25 shows the line diagram of the hard tank and truss with rigid element. The rigid element connection between the truss legs and the end node of the hard tank is visible in the Fig. 6.25

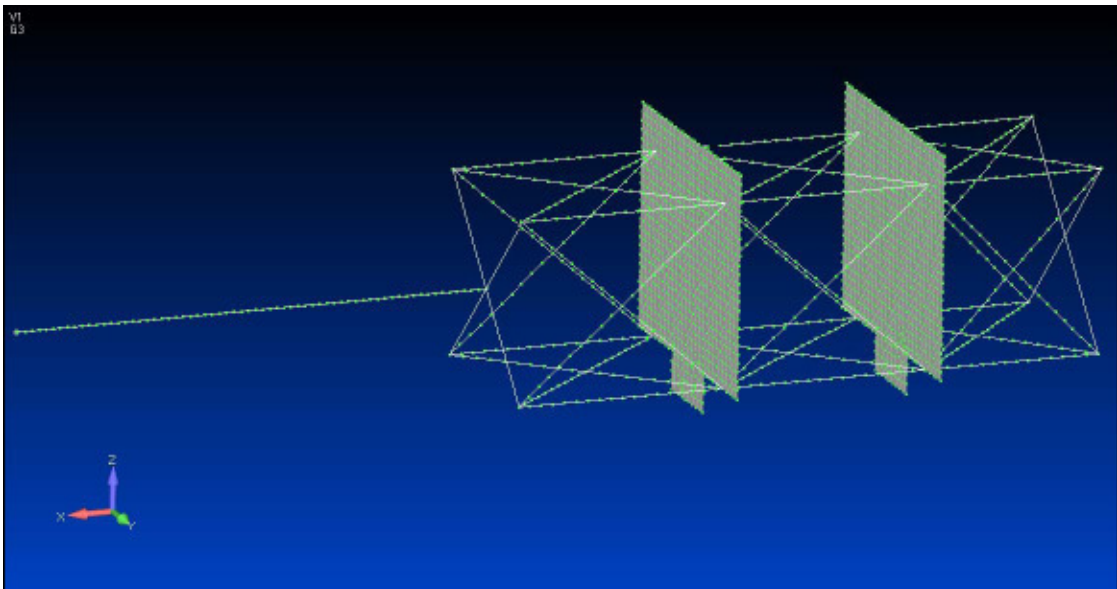


Fig 6.25 Line only FE model assembly of hard tank and truss

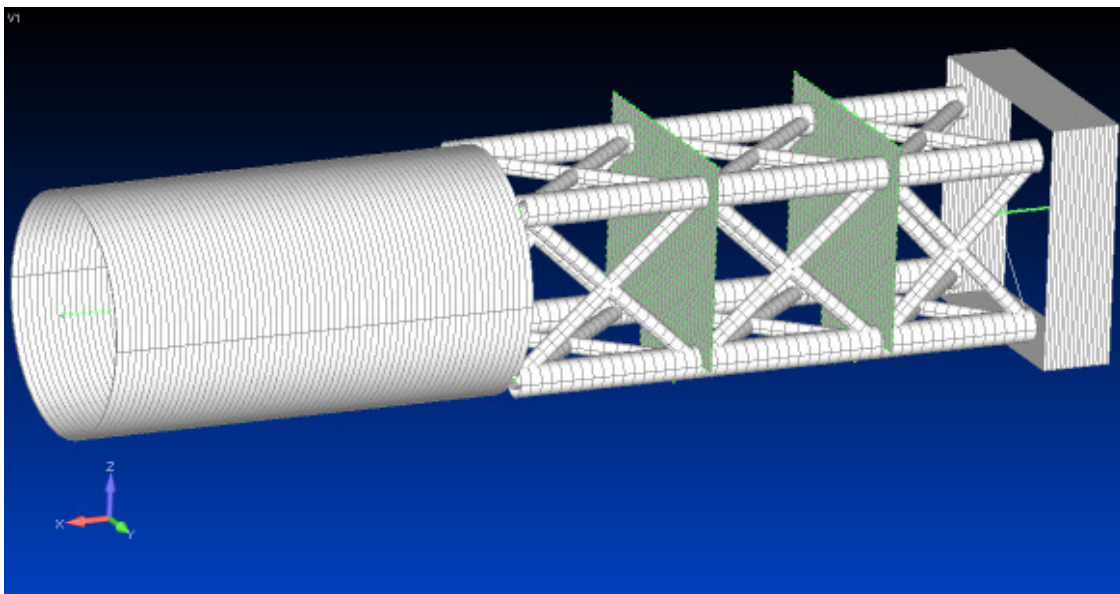


Fig 6.26 FE model of the SPAR without supports and outfittings

At this step the weight of the SPAR is 20970 tons, which is the sum of masses of hard tank, soft tank, truss and 2 heave plates. The weight in the model is checked and verified to make sure that the weights match with the design. Fig 6.26 shows the 3D view of the hard tank and truss connected with rigid element.

6.2.3.5 Supports

Now the main sections of the SPAR are modeled and assembled, its time to create the supports. As there are no constraints regarding the supports from the client's side, support design depends on the results of this analysis. Based on the conclusion of this thesis, Dockwise can recommend the clients number of skid beams configuration needed and also the dimension of the supports in relation to the center of the SPAR. For now, the supports are modeled appropriately based on the information from previous projects.

As the hard tank and truss section can be accommodated on the vessel deck area, it is necessary to support both hard tank and truss section. Since the Hard tank constitutes for more than 60% of the weight in the SPAR, it is the critical part whose loads have to be distributed on the vessel properly. So the Hard tank has to be supported throughout its length. As the truss weigh only 3293 tons, compared to the hard tank's weight it is very less. So it doesn't have to be supported throughout its length. The location where the heave plates are fixed in the truss are the strongest points, so it has been decided to support the truss at 4 points under its heave plates on the truss legs, as it was done earlier in previous projects.

The supports for soft tank as discussed in chapter 4.4.5 are not modeled. The soft tank will be temporarily supported from the start of the load-out operation until the SPAR reaches its final stowage position, until then it will be supported on the beams on the keyside not on the vessel deck. So the necessary supporting condition for the soft tank can be applied using the constraints in the model, the location and design of the supports for soft tank is of no significance.

The weight of the supports recommended by the clients in their design is 4681 tons, and we don't have any data regarding how much of the support weight is under the hard tank and how much is under the truss. The weight of the SPAR specified by clients is just an estimation based on their past experiences. So without that information it is not possible to model the support individually for each section, without knowing the weights of each support legs. When the supports are modeled after the SPAR assembly, the mass of the supports in total can be tuned exactly to match the specified weight.

As discussed in the topic 4.5, one of the factors affecting the load-out is the number of skid beams required, the supports design will also change according to the number of skid beams. So we need to design 3 support configurations for the SPAR as listed below:

1. for 4 skid beams load-out
2. for 3 skid beams load-out
3. for 2 skid beams load-out

As the locations of the skid beams are already known from the chapter 4.2.4, the supports are modeled as per the dimension in relation to the centre of the SPAR. The interior connections between the supports and hard tank nodes are meshed with rigid elements to connect the nodes on the hard tank with the supports and also simulate the stiffness due to the interior structural details of the SPAR. Fig 6.27 shows the modeled hard tank supports and the rigid element connection with the hard tank.

The supports under the truss are also modeled using the same skid beam location but with a different cross section of the beam element. From the past projects information, tapered beams were used as it tends to distribute the loads more gradually and also withstand SPAR's self weight. The length of each support under truss is taken as 15m, by mere approximation on studying the previous projects. The supports for the truss legs can be seen in the fig 6.28.

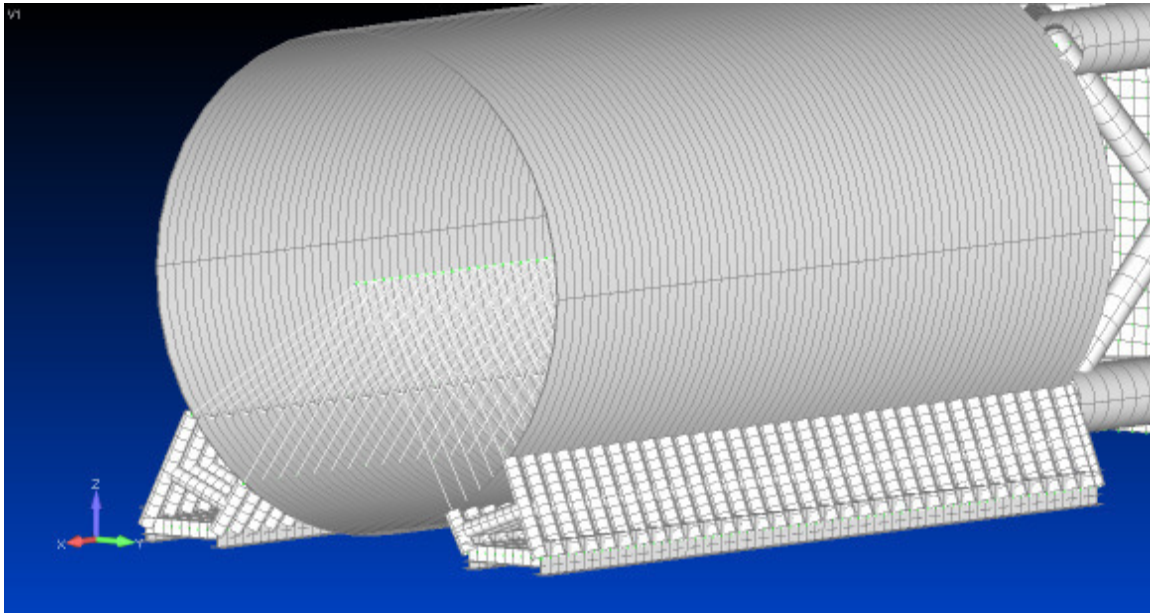


Fig 6.27 FE model of the hard tank supports

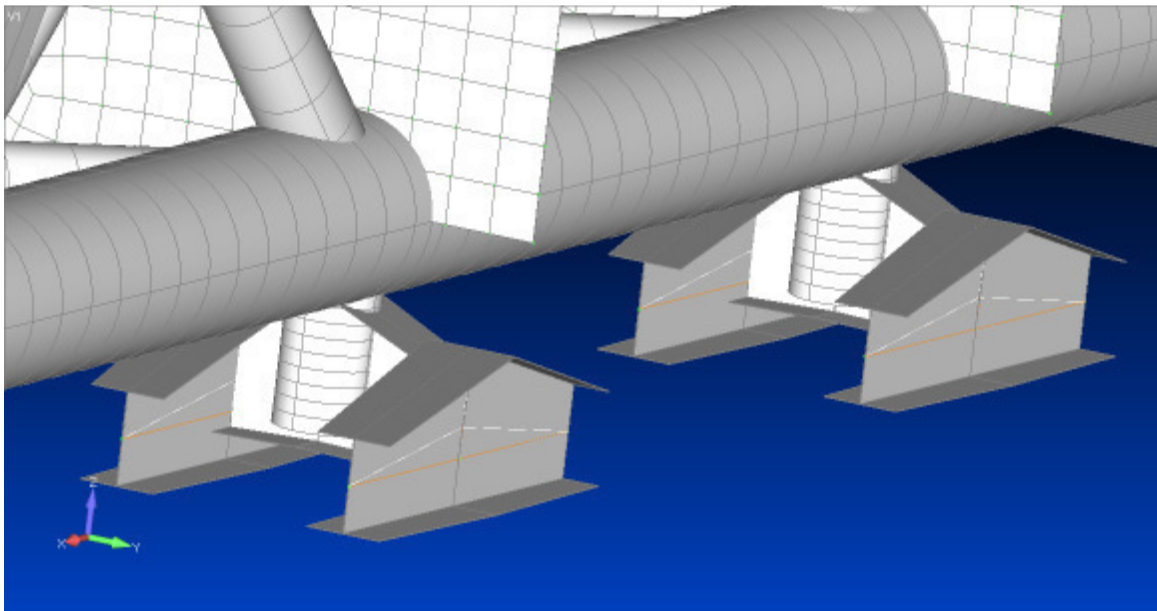


Fig 6.28 FE model of truss supports

After the supports are modeled, the densities of the different properties used are tuned to achieve the specified weight. Now the SPAR with its supports weighs 25651 tons. Fig. 6.29 shows the SPAR with supports for 4 skid beams load-out.

The same procedure is followed to model the support of the SPAR for 3 and 2 skid beams load-out. The 4th skid beam has been removed and the supports on the starboard side of the SPAR have been modified as shown in the Fig. 6.30 for the SPAR with 3 skid beams load-out. The 1st and 4th skid beam is removed and the supports are modified as shown in the fig 6.31 for SPAR with 2 skid beams load-out.

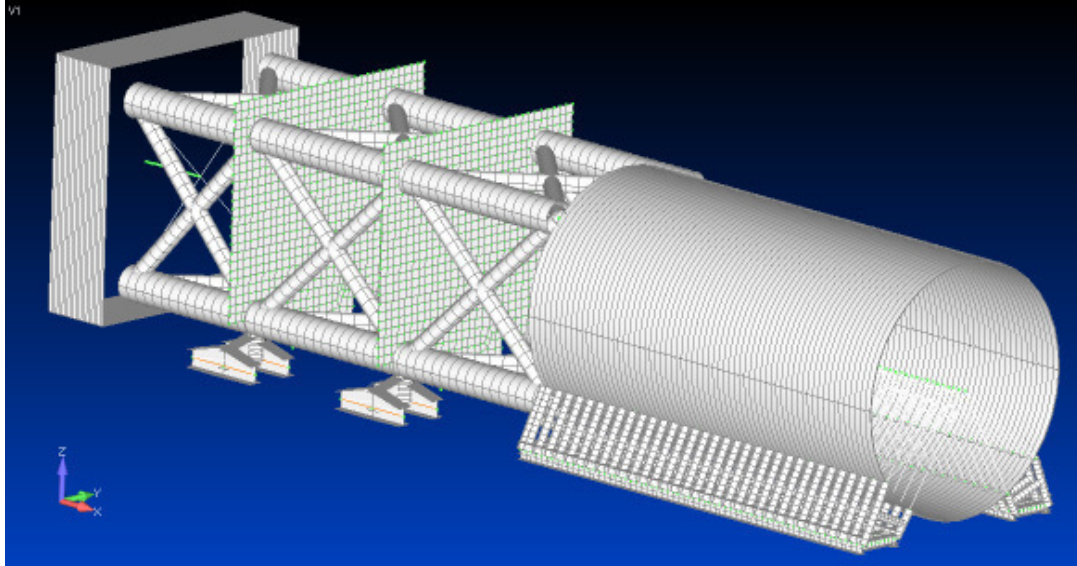


Fig 6.29 FE model of SPAR with supports for 4 skid beam load-out

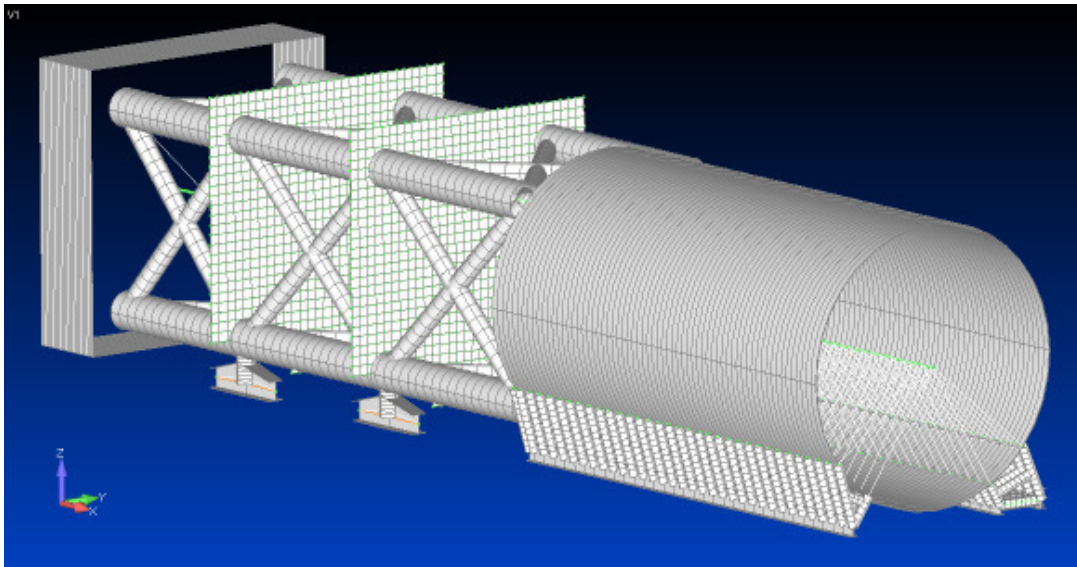


Fig 6.30 FE model of SPAR with supports for 3 skid beam load-out

The following table shows a summary of all the properties used in the SPAR supports modeling

Description	Element type	Cross section	Dimension	Material Density
Pipe section of the support	Beam	Circular tube	Radius: 0.75m Thickness: 0.022m	11328.6kg/m ³
End support beams	Beam	I beam	H*W: 3*1.5*1.5m T: 0.02*0.02*0.025m	11354.3kg/m ³
Beam connecting the end supports	Beam	I beam	H*W*W: 1.5*1.5*1.5m T: 0.015*0.015*0.025m	8951kg/m ³
Support beam under heave plate	Beam	Circular tube	Radius: 1.5m Thickness: 0.025m	11521.8kg/m ³
Tapered beams for truss supports	Beam	Tapered I beam	End A: 5*3*3*0.02*0.02*0.025 End B: 3*2.5*2.5*0.02*0.02*0.025	61521.8kg/m ³

Table 6.16 Properties of FE model of SPAR supports

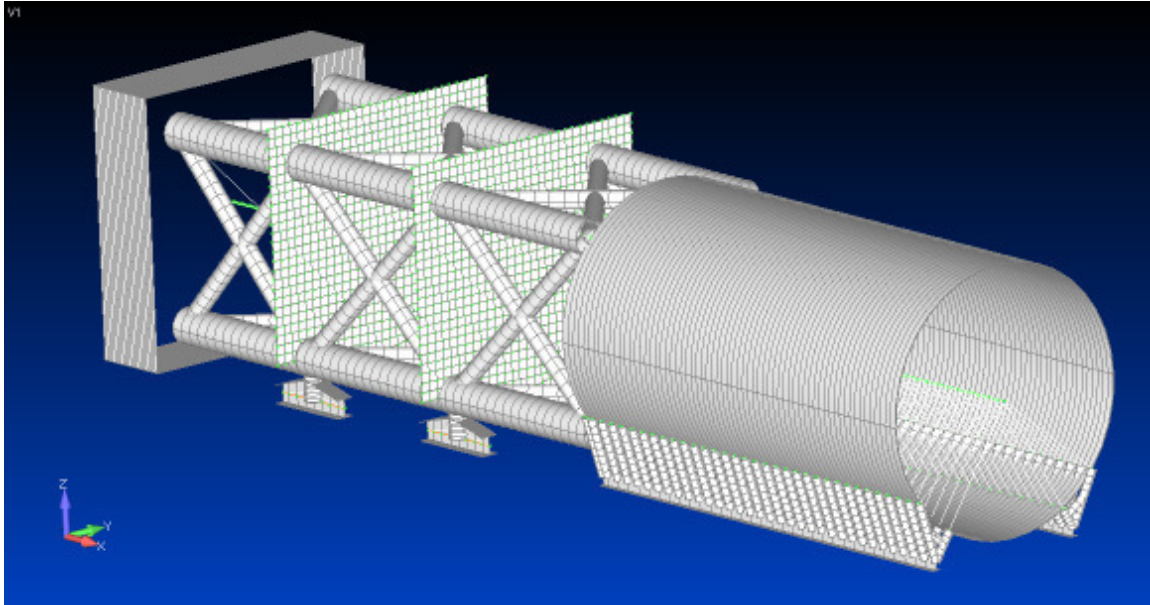


Fig 6.31 FE model of SPAR with supports for 2 skid beam load-out

6.2.3.6 Outfittings

Except the hard tank, soft tank, truss, supports, all the other objects which are fixed to the SPAR structure, for example pipe works, strakes, and additional steel fabrication works on the hard tank side etc., which doesn't influence the stiffness of the SPAR are termed as outfittings.

As the outfittings are objects scattered along all the sections of the SPAR and we don't have any detail information about the outfittings, it is of no importance to model it in a specific location in the SPAR model. So we utilize the mass of the outfittings, which is 9205 tons, to tune the COG specified. By spreading the outfittings mass on hard tank, truss and soft tank and tuning its densities we can achieve the required COG.

The weight of the outfittings is distributed in hard tank, truss and soft tank by modifying, i.e increasing the densities of its materials. And finally when the required total mass of the SPAR is attained, the COG can be moved by replacing the mass in one section to the other, such that the required location of COG, i.e 119.14, from the soft tank keel (end of soft tank) is achieved.

The final properties of the FE model of the SPAR including all the weights and after tuning the COG are summarized as follows:

Description	Element type	Cross section	Dimension	Material Density
Hard tank	Beam	Circular tube	Radius: 22.2505m Thickness: 0.020m	91583.57kg/m ³
Soft tank	Beam	Rectangular tube	Height * Width: 44.501m*44.501m Thickness: 0.020m	65315.8kg/m ³
Heave plate	Shell / Plate (QUAD4)	Plate	Height * Width: 44.501m*44.501m Thickness: 0.025m	11877.21kg/m ³
Truss legs	Beam	Circular tube	Radius: 3m Thickness: 0.015m	19798kg/m ³

Cross members	Beam	Circular tube	Radius: 1.5m Thickness: 0.015m	19657.4 kg/m ³
Pipe section of the support	Beam	Circular tube	Radius: 0.75m Thickness: 0.022m	11328.6 kg/m ³
End support beams	Beam	I beam	H*W: 3*1.5*1.5m T: 0.02*0.02*0.025m	11354.3 kg/m ³
Beam connecting the end supports	Beam	I beam	H*W*W: 1.5*1.5*1.5m T: 0.015*0.015*0.025m	8951 kg/m ³
Support beam under heave plate	Beam	Circular tube	Radius: 1.5m Thickness: 0.025m	11521.8 kg/m ³
Tapered beams for truss supports	Beam	Tapered I beam	End A: 5*3*3*0.02*0.02*0.025 End B: 3*2.5*2.5*0.02*0.02*0.025	61521.8 kg/m ³

Table 6.17 Properties of FE model of SPAR with outfittings for 4 skid beam load-out

The FE model of the SPAR has the following characteristics values, compared with the design values given in chapter 4.2 as shown in the table below

Description	Design	FE Model
Mass of the SPAR	34855 Tons	34855 Tons
Longitudinal Centre of gravity from soft tank keel	119.14m	119.14m

Table 6.18 Comparison of FE model of SPAR with the design.

The SPAR model is accurate to the design specification provided by the clients. The SPAR model can be safely utilized for the analysis.

CHAPTER 7

ANALYSIS & RESULTS

The process of load-out is discussed in chapter 4. The reason and factors for choosing skidding method for load-out of the Future SPAR has been discussed in detail. The skidding method is a very slow process; the average movement of the SPAR on the deck will be about 75mm per minute or even less which in turn depends on stroke of the hydraulic cylinders pushing the SPAR.

Since the skidding method is very slow, the load on the vessel structure can be considered as a static and linear loading as there are no sudden or harmonic changes in the loading pattern. The term "linear" means that the computed response--displacement or stress, for example, is linearly related to the applied force. The term "static" means that the forces do not vary with time--or, that the time variation is insignificant and can therefore be safely ignored.

So in this analysis, it has been assumed that the loading is static and the most critical load steps on the vessel structure are recreated in FEMAP environment and analyzed by linear static analysis.

7.1 Allowable stress level

[15] The most suitable strength or stiffness criterion for any structural element or component is normally some maximum stress or deformation which must not be exceeded. In the case of stresses the value is generally known as the maximum allowable working stress. Because of uncertainties of loading conditions, design procedures, production methods, etc., designers generally introduce a *factor of safety* into their designs, defined as follows:

Factor of safety = maximum stress / allowable working stress

However, in view of the fact that plastic deformations are not accepted this definition can be modified to: **Factor of safety = yield stress / allowable working stress**

According to the factors taken from allowable stresses in ship construction engineering guidelines, recommended safety factor is 1.43. [15]

i.e., Allowable stress = Yield stress/1.43

Yield stress for the material used in ship construction = 235Mpa

Allowable stress ($\sigma_{\text{allowable}}$) = 235/1.43 = 164.3Mpa

7.2 Uniform loading by hydraulics

Since the hard tank constitutes the most of the mass of the SPAR, the vessel deck will experience the critical load at any given area. When compared with loads induced by hard tank mass, the truss and soft tank loads are very small. So the hydraulic cylinders are used only under the hard tank for leveling out the peak loads exerted by the very stiff hard tank structure and equally distribute the critical load of the hard tank.

When the SPAR is loaded-out using hydraulic cylinders under the hard tank, the loads on skid beam surface are equal at any given point. So to analyze the uniform loading scenario the actual SPAR model is not used, instead the loads on each skid beam are calculated manually and the resulting loads are equally applied on the skid beam surface as nodal loads. The loads on skid beam vary according to the number of skid beam and its relative position from the Centre of gravity of the SPAR. So the loads are calculated separately for each steps analyzed in the uniform loading case.

7.2.1 Method of load application

Once the load on each skid beam is calculated manually as explained in the next section, to make sure that the loads are equally distributed along the length of the skid beam, following steps were utilized.

1. A line is drawn above the skid beams for the length of the hard tank which is 81.382m.
2. The calculated total load on each skid beam is applied to the line as a force per unit length (which is criteria in uniform loading)
3. The nodes on the centre line of the skid beams are associated with the line.
4. The load on the line, i.e., force per unit length is expanded and transferred to the nodes associated with the line.
5. Once the loads are transferred to the nodes, the line is detached from the nodes.

By this method the loads are equally distributed on the nodes in regard to its distances. Fig. 7.1 shows the loads applied on the skid beam by the above mentioned steps.

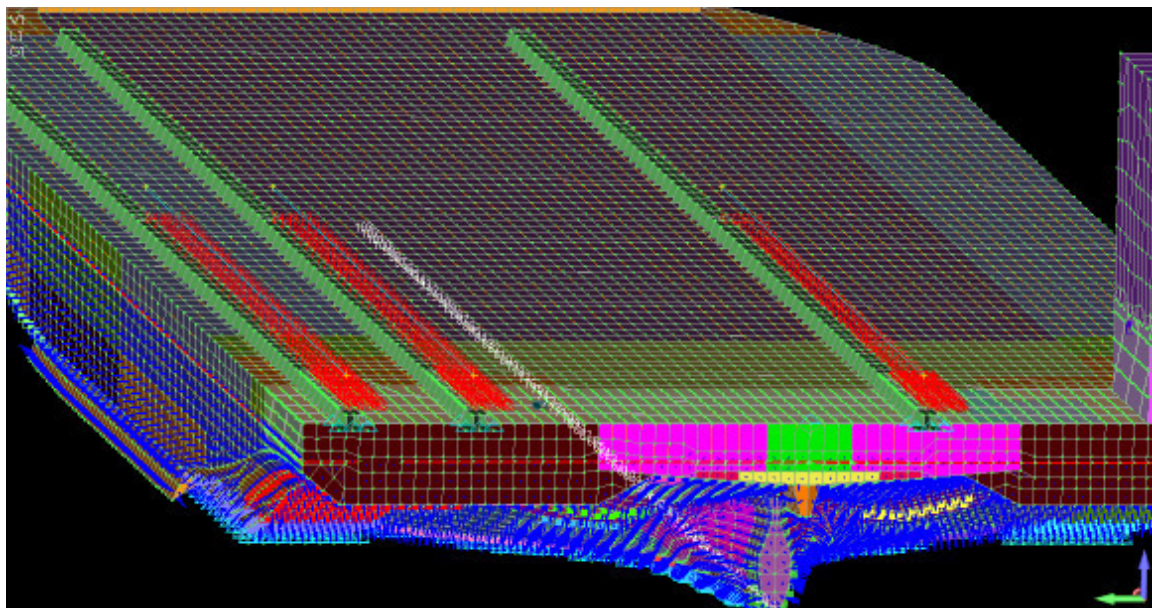


Fig 7.1 uniform loading on skid beams

7.2.2 Boundary conditions in Uniform loading

Every node in FEMAP has six degrees of freedom; the constraints are applied to the model by restricting the degrees of freedom of the necessary nodes corresponding to the real life scenario.

The following constraints were utilized in general for all the uniform loading steps:

1. Constraint in the vessel bow section.

The vessel's Y-axis is fixed to arrest the movement of the vessel in Y direction, as the vessel will not move in transverse direction during load-out; mooring lines are attached to prevent the vessel from moving. The X axis is not constrained as the vessel is free to deflect longitudinally when the loads are applied on the deck. The Z-axis is not constrained as the vessel will be floating on the water and is free to move up and down depending on the load on deck, ballast and tide conditions. The model is free to rotate in all 3 axes, since the vessel during load-out experience various rotational movements. Fig. 7.2 shows the constraint in the bow section of the vessel model. The constraint is applied as a nodal constraint.

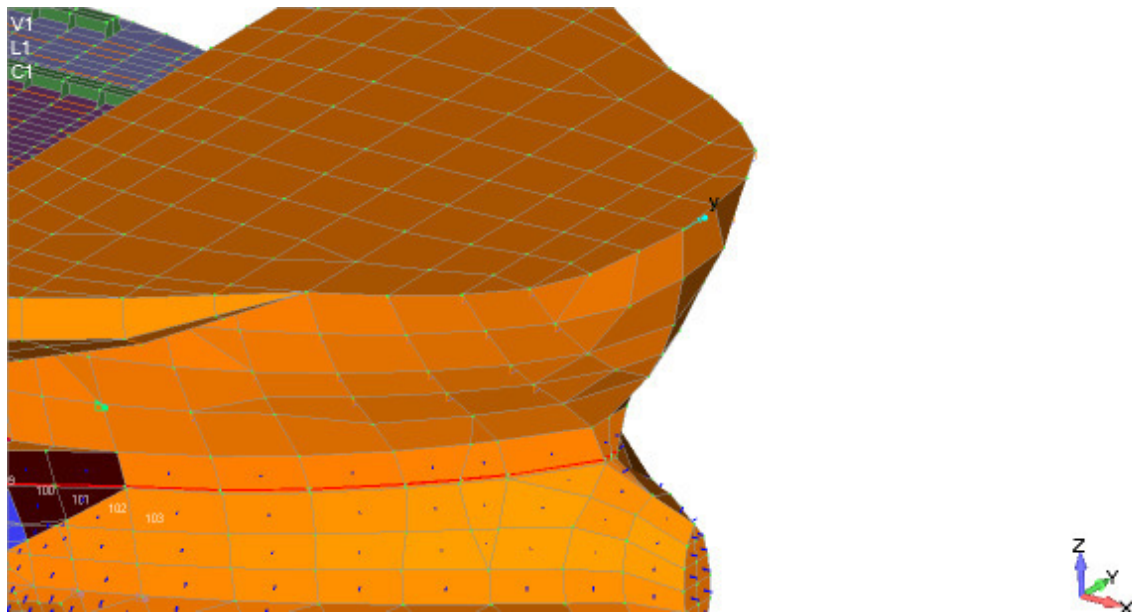


Fig 7.2 Constraint in bow section of the vessel

2. Constraint in the vessel stern section

Unlike the bow, stern section of the vessel is fixed in Y and X-axis as the vessel is docked along the stern with the keyside and moored. It can't move or deflect in X-axis due to the keyside. All the other DOF are free as the model has to move up and down in the Z-axis and the rotations should be free to simulate the floating condition of the vessel, where the vessel while floating in water will experience various rotational movement due to waves and also if not properly stabilised. Fig. 7.3 shows the Constrains in the stern section of the vessel.

The model is constrained only at 2 nodes as explained because two nodes are located on the center line of the vessel and the model is free is rotate around the X- axis. Constraining other nodes may lead to restriction of the rotation movement of whole vessel model which might results in not providing the actual floatation scenario to the model.

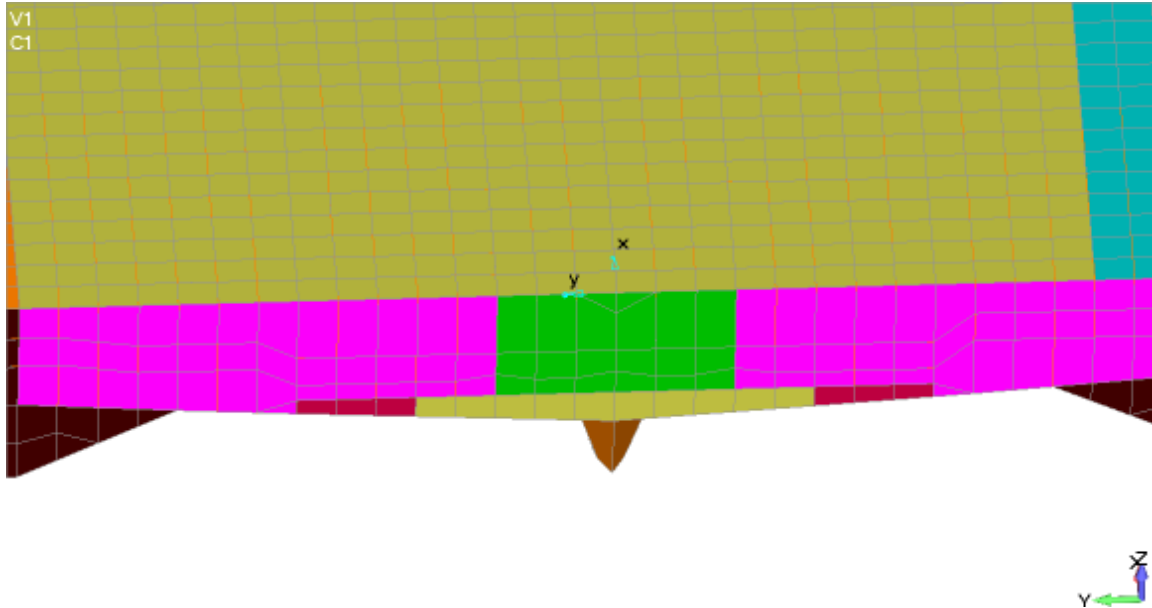


Fig 7.3 Constraints in stern section of vessel

3. Constraints on the spring elements

The spring elements as explained in chapter 6.1.3.6 are used to make the model stable when not precisely balanced. The spring elements are created between two node groups, nodes on the bottom hull of the vessel and one on the space below the vessel. The hanging node below the vessel is fixed in all 3-axes, as the spring element can take only axial loads, to stabilize the lower node the additional X and Y axis constraints are needed. Fig. 7.4 shows the constraints of the spring elements

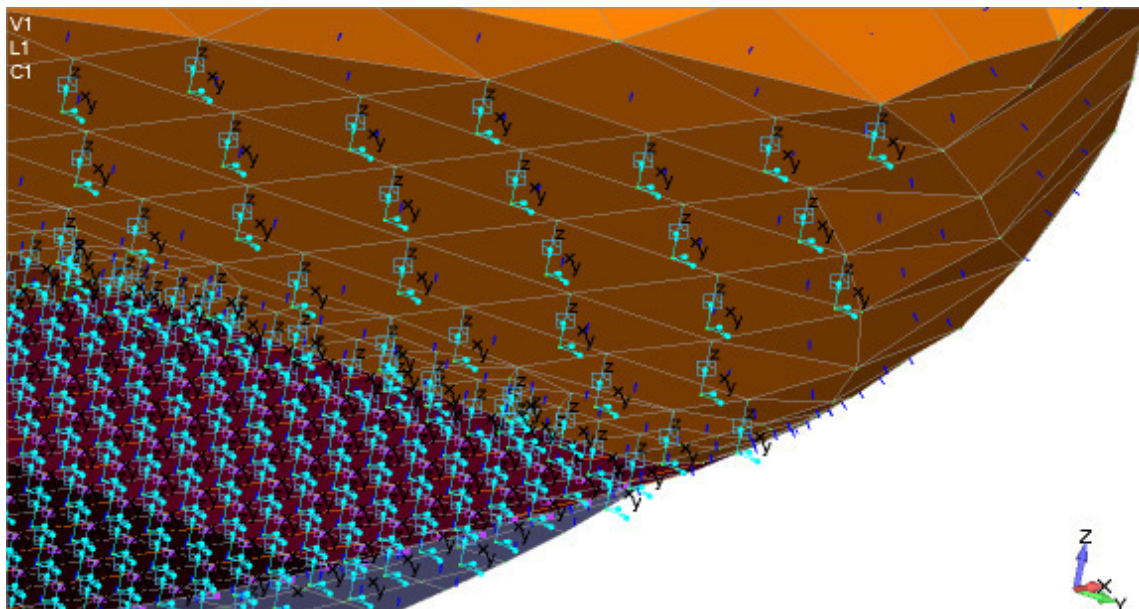


Fig. 7.4 Constraints in the spring elements

7.2.3 Draft

During the calculation of the draft and ballast condition using the software as explained in chapter 6.1.2.9, it is found that the vessel draft has to be 11m.

Only when the draft is increased to 11.0 m the aft part of the vessel generates sufficient buoyancy to reduce the shear force down to 99.9% of the allowable limit during the load-out of the SPAR hard tank. The minimum draft required for load-out of the SPAR is set at 10.95m for the load-out operation of the hard tank.

The draft is updated in the model using the API tool. When the draft is entered the water line is drawn on the model to show the level of the draft and the water pressures are applied on the element faces which are inside the draft level. The water level line serves as a reference in the model to visualize the trim and rolling movement of the vessel model. The draft and the hydrostatic pressures applied can be seen in the Fig. 7.5

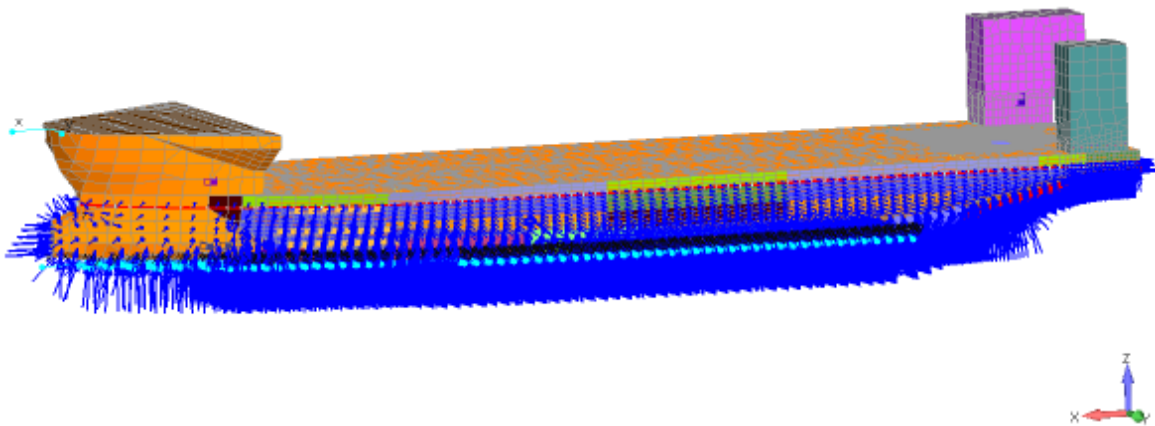


Fig. 7.5 Draft level and hydrostatic pressure for the step hard tank on the vessel.

7.2.4 Ballast condition

As discussed in chapter 6.1.2.10, the mass of ballast water required to maintain the draft and stability of the vessel during load-out are incorporated as mass elements in the model.

The amount of water necessary for ballast is calculated based on number of parameters like load on deck and its COG, draft, bending moment in the vessel and stability. It is calculated using software called GHS, the calculated ballast is updated in the vessel model using the API tool available. A complete ballast calculation as created from the software GHS for the step hard tank on the vessel has been attached in appendix 3. The detail of ballast mass needed in each ballast tank for the load step hard tank on the vessel is given in the table below.

Tank Description	Name	Capacity in kg	% filled	Mass in kg
1 upper S	WBT1U.S	839760	100	839760
1 upper P	WBT1U.P	851280	100	851280
1 upper C	WBT1U.C	624050	100	624050
2 upper S	WBT2U.S	839340	100	839340
2 upper P	WBT2U.P	861430	100	861430
2 upper C	WBT2U.C	839210	100	839210
3 upper S	WBT3U.S	861430	100	861430
3 upper P	WBT3U.P	850380	100	850380
3 upper C	WBT3U.C	861290	0	0

4 upper S	WBT4U.S	850840	25	212710
4 upper P	WBT4U.P		0	0
4 upper C	WBT4U.C	839210	0	0
5 upper S	WBT5U.S	862475	0	0
5 upper P	WBT5U.P	849650	0	0
5 upper C	WBT5U.C	861910	0	0
6 upper S	WBT6U.S	585330	0	0
6 upper P	WBT6U.P	607420	0	0
6 upper C	WBT6U.C	585240	0	0
1 middle S	WBT1M.S	2444290	100	2444290
1 middle P	WBT1M.P	2444290	100	2444290
1 middle C	WBT1M.C	846690	100	846690
2 middle S	WBT2M.S	2467700	100	2467700
2 middle P	WBT2M.P	2487600	100	2487600
3 middle S	WBT3M.S		0	0
3 middle P	WBT3M.P	2467700	0	0
3 middle C	WBT3M.C		0	0
4 middle S	WBT4M.S	2466490	79.6	1963326
4 middle P	WBT4M.P	2487610	100	2487610
4 middle C	WBT4M.C	2321520	100	2321520
5 middle S	WBT5M.S	2487600	0	0
5 middle P	WBT5M.P	2467700	0	0
5 middle C	WBT5M.C	2332400	0	0
6 middle S	WBT6M.S	1711630	0	0
6 middle P	WBT6M.P	1732380	0	0
6 middle C	WBT6M.C	1588440	0	0
1 lower S	WBT1L.S	1214410	100	1214410
1 lower P	WBT1L.P	1214410	100	1214410
1 lower C	WBT1L.C	1116960	100	1116960
2 lower S	WBT2L.S	1302220	100	1302220
2 lower P	WBT2L.P	1307690	100	1307690
2 lower C	WBT2L.C	1325950	100	1325950
3 lower S	WBT3L.S	1309480	100	1309480
3 lower P	WBT3L.P	1304220	100	1304220
3 lower C	WBT3L.C	1327370	100	1327370
4 lower S	WBT4L.S	1303230	90.4	1178119.9
4 lower P	WBT4L.P	1310214	88.8	1163470
4 lower C	WBT4L.C	1325897	75.8	1005029.9
5 lower S	WBT5L.S	1309430	0	0
5 lower P	WBT5L.P	1309430	0	0
5 lower C	WBT5L.C	1328750	0	0
6 lower S	WBT6L.S	782700	0	0
6 lower P	WBT6L.P	788170	0	0
6 lower C	WBT6L.C	789920	0	0
water bal oflow	WBTOVERF.S			0
fwd lower WB P	WBTF.L.P		0	0
fwd lower WB S	WBTF.L.S	1592033	54.1	861289.85
fwd upper WB S	WBTFU.S		0	0

fwd upper WB P	WBTFU.P		0	0
aft WB P	WBTA.P		0	0
poop aft WB S	WBTPA.S		0	0
poop fwd WB S	WBTPF.S		0	0
engine RM TOP S	WBTERTOP.S		0	0
engine RM TOP P	WBTERTOP.P		0	0
aft ballast S	WBALWL.S		0	0
aft peak C	WBAPC.S		0	0
lower peak C	WBTLOWPEAK.C		0	0
high peak C	WBTHIGHPEAK.C	2995970	0	0
WB overf fwd	WBTOVERFWD.C		0	0
aft poop lower WB P	WBAPL.P		0	0
aft poop upper WB P	WBAPU.P		0	0
1 outer wing P	WBT10.P	1291440	100	1291440
1 outer wing S	WBT10.S	1291470	100	1291470
2 outer wing P	WBT20.P	2708360	100	2708360
2 outer wing S	WBT20.S	2708360	100	2708360
3 outer wing P	WBT30.P	3168290	0	0
3 outer wing S	WBT30.S	3168290	100	3168290
4 outer wing P	WBT40.P	3262750	0	0
4 outer wing S	WBT40.S	3262750	100	3262750
5 outer wing P	WBT50.P	3276980	0	0
5 outer wing S	WBT50.S	3276980	3.5	114694.3
6 outer wing P	WBT60.P	2126910	0	0
6 outer wing S	WBT60.S	2126900	0	0
7 outer wing P	WBT70.P	2596050	0	0
7 outer wing S	WBT70.S	1859960	0	0
		Total ballast mass		54418600

Table 7.1 Ballast condition for step hard tank on the vessel.

Some of the masses which are permanent in the vessel like, fuel, lubricating oil, fresh water, weight of the crew, weight of the materials in stores etc., regardless of the load on deck are permanently incorporated in the model. But, if needed the permanent masses can also be edited using the API tool.

The ballast condition above is the used for all the analysis step of hard tank on vessel by uniform loading, namely, hard tank on vessel with 4 skid beams, hard tank on vessel with 3 skid beams and hard tank on vessel with 2 skid beams.

In all the cases of the uniform loading, weight distribution of the hard tank taken in to account for analysis is 25122 tons, which is much higher than the weight distribution of the hard tank provided by the designers. The weight of the 4 skid beams, which is 327 tons, is already taken in to account with the SPAR weight. Since the weight of the skid beams are not that much high compared to the vessel and SPAR weight, the difference of weight arising in the number of skid beams in every other step can neglected.

7.2.5 Load calculation for the uniform loading cases.

When the load-out is done by uniform loading using hydraulics, the loads on the each side of the supports will be equal on both skid beams. Since the peak loads will be equally distributed, loads on each skid beam can be calculated using analytical method and can be used in the model.

Hard tank on vessel with 4 skid beams:

The following calculation shows the method of load calculation for the step hard tank on vessel with 4 skid beams:

The support locations for 4 skid beams on the vessel deck and its dimension in relative to the SPAR centre is shown in the fig 7.6.

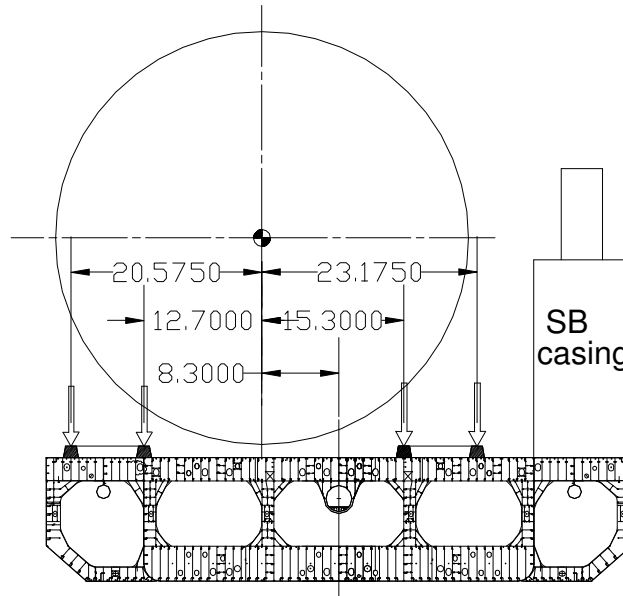


Fig. 7.6 Location of supports for 4 skid beams load-out

The loads on each skid beam are calculated as follows:

Total length of each skid beam on the vessel = 163.2 m

Weight of skid beams from the model = 327 tons

length of hard tank on the skid beams (length of skid beam where load acts) = 81.382 m

weight of hard tank on vessel with outfitting used for ballast calculation = 25122 tons

Assuming that the skid beams are also included in the above weight of hard tank for ballast calculation,

Total load on vessel = weight of hard tank - weight of skid beams
= 25122 - 327 = 24795 tons

Since the skid beam is already modeled with the vessel, the load of hard tank is taken as above for calculation purposes.

From the Fig 7.6 the following are calculated

Distances in Port side:

Distance between 2 skid beams = 20.575 - 12.7 = 7.875 m

Centre of 2 skid beams where the load acts in case of uniform loading = 7.875/2 = 3.9375 m

Distance between SPAR center and the point of load acting = 12.7 + 3.9375 = 16.6375 m

Distances in Starboard side:

Distance between 2 skid beams = 23.175 - 15.3 = 7.875 m

Centre of 2 skid beams where the load acts in case of uniform loading = $7.875/2 = 3.9375$ m
 Distance between SPAR center and the point of load acting = $15.3 + 3.9375 = 19.2375$ m

Total distance between point of load acting on both sides = $16.6375 + 19.2375 = 35.8750$ m

Load on port side:

Total load on both skid beams = $(24795 \times 19.2375) / 35.8750 = 13295.9947$ tons
 Load on each skid beam = $13295.9947 / 2 = 6647.99738$ tons
 Load per unit length on each skid beam = $6647.99738 / 81.382 = 81.688$ ton/m

Load on starboard side:

Total load on both skid beams = $(24795 \times 16.6375) / 35.8750 = 11499.0052$ tons
 Load on each skid beam = $11499.0052 / 2 = 5749.50261$ tons
 Load per unit length on each skid beam = $5749.50261 / 81.382 = 70.648$ ton /m

	Port side (2 skid beams)	Starboard side (2 skid beams)
Total load	13295.994 tons	11499.0052 tons
Total load on each skid beam	6647.997 tons	5749.50261 tons
Load per unit length on each skid beam	81.688 tons/m	70.648 tons/m

Table 7.2 Load calculation for the uniform loading with 4 skid beams load-out

The load per unit length on each skid beam in port side is 81.688 ton/m or 8.0136×10^5 N/m

The load per unit length on each skid beam in starboard side is 70.648 ton/m or 6.930×10^5 N/m

Hard tank on vessel with 3 skid beams:

The support locations for 3 skid beams on the vessel deck and its dimensions in relative to the SPAR centre is shown in the fig 7.7

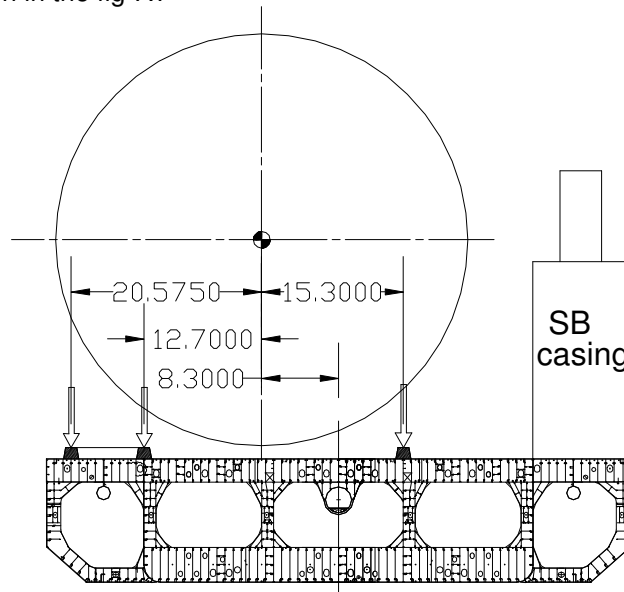


Fig. 7.7 Location of supports for 3 skid beams load-out

Based on fig 7.7, the loads on each skid beams are calculated as in the previous loading case and the results are displayed in the table below.

The weight of 3 skid beams from the model = 247 tons.

Total weight of hard tank on vessel with outfitting in the ballast calculation = 25122 tons

Assuming that the skid beams are also included in the above weight of hard tank for ballast calculation,

Total load on vessel = weight of hard tank - weight of skid beams = 25122 - 247 = 24875 tons.

	Port side (2 skid beams)	Starboard side (1 skid beam)
Total load	11916.634 tons	12958.365 tons
Total load on each skid beam	5958.317 tons	12958.365 tons
Load per unit length on each skid beam	73.214 tons/m	159.228 tons/m

Table 7.3 Load calculation for the uniform loading with 3 skid beams load-out

The load per unit length on each skid beam on port side is 73.214 tons/m or 7.182×10^5 N/m
 The load per unit length on each skid beam on starboard side is 159.228 tons/m or 1.562×10^6 N/m

Hard tank on vessel with 2 skid beams:

The support locations for 2 skid beams and its dimension relative to the SPAR centre is shown in the fig 7.8 It is very obvious that the skid beams are supported on the longitudinal bulkheads.

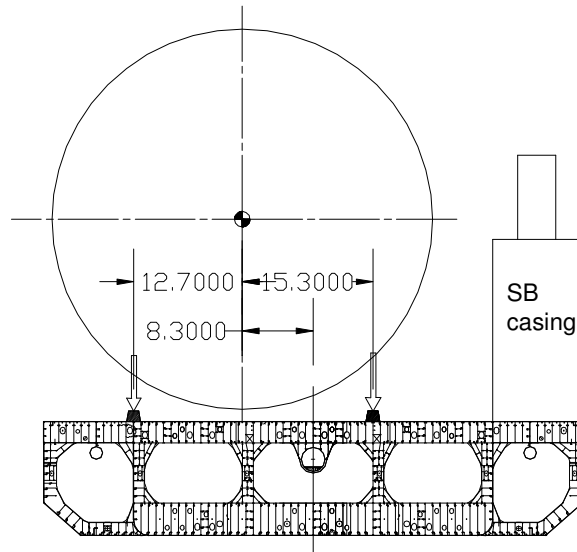


Fig. 7.8 Location of supports for 2 skid beams load-out

Based on fig 7.8, the loads on each skid beams are calculated as in the previous loading case and the results are displayed in the table below.

The weight of 2 skid beams from the model = 169 tons.

Total weight of hard tank on vessel with outfitting in the ballast calculation = 25122 tons

Assuming that the skid beams are also included in the above weight of hard tank for ballast calculation,

Total load on vessel = weight of hard tank - weight of skid beams = 25122 - 169 = 24953 tons.

	Port side (1 skid beam)	Starboard side (1 skid beam)
Total load	13635.032 tons	11317.967 tons
Total load on each skid beam	13635.032 tons	11317.967 tons
Load per unit length on each skid beam	167.543 tons/m	139.072 tons/m

Table 7.4 Load calculation for the uniform loading with 2 skid beams load-out

The load per unit length on each skid beam on port side is 167.54 tons/m or 1.64×10^6 N/m
The load per unit length on each skid beam on starboard side is 139.07 tons/m or 1.36×10^6 N/m

Summary of load calculation for all the 3 steps of uniform loading:

	Load on each skid beam Port side (#1 & #2)	Load on each skid beam Starboard side (#3 & #4)
4 skid beams load-out	6647.997 tons / 81.688 tons/m	5749.50261 tons / 70.648 tons/m
3 skid beams load-out	5958.317 tons/ 73.214 tons/m	12958.365 tons/ 159.228 tons/m
2 skid beams load-out	13635.032 tons / 167.543 tons/m	11317.967 tons/ 139.072 tons/m

Table 7.5 Summary of load calculation for all 3 steps of uniform loading

7.2.6 Analysis of Uniform loading cases

The following section describes the analysis and results of each step of uniform loading cases.

Hard tank on vessel with 4 skid beams:

The above calculated load for the load step hard tank on vessel with 4 skid beams using uniform load together with the ballast condition and draft have been applied in the model of the vessel with 4 skid beams. Fig 7.9 shows the model of the step hard tank on vessel with 4 skid beams by uniform loading with the calculated load, draft and ballast condition.

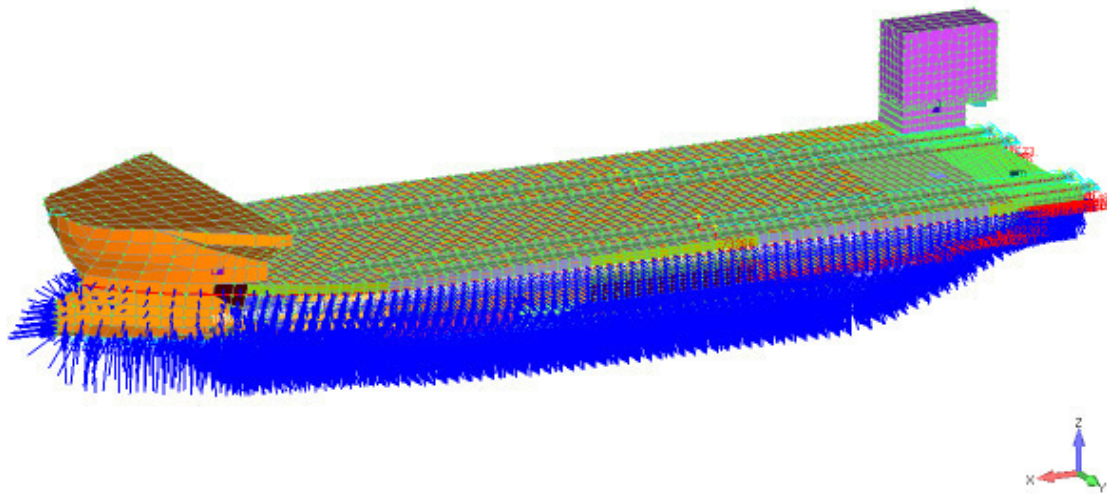


Fig. 7.9 FE model of analysis step hard tank on vessel with 4 skid beams by uniform loading

The results of static linear analysis of the step hard tank on vessel with 4 skid beams are illustrated below.

The total translation in the model is 0.82m. The highest equivalent stress found was about 178.983Mpa.

Fig 7.10 shows the total deformation of the model after the analysis. The scale of the results is increased by 10% of the actual value to visualize the actual deformation of the model. The red line shows the draft line of the vessel or the water surface level.

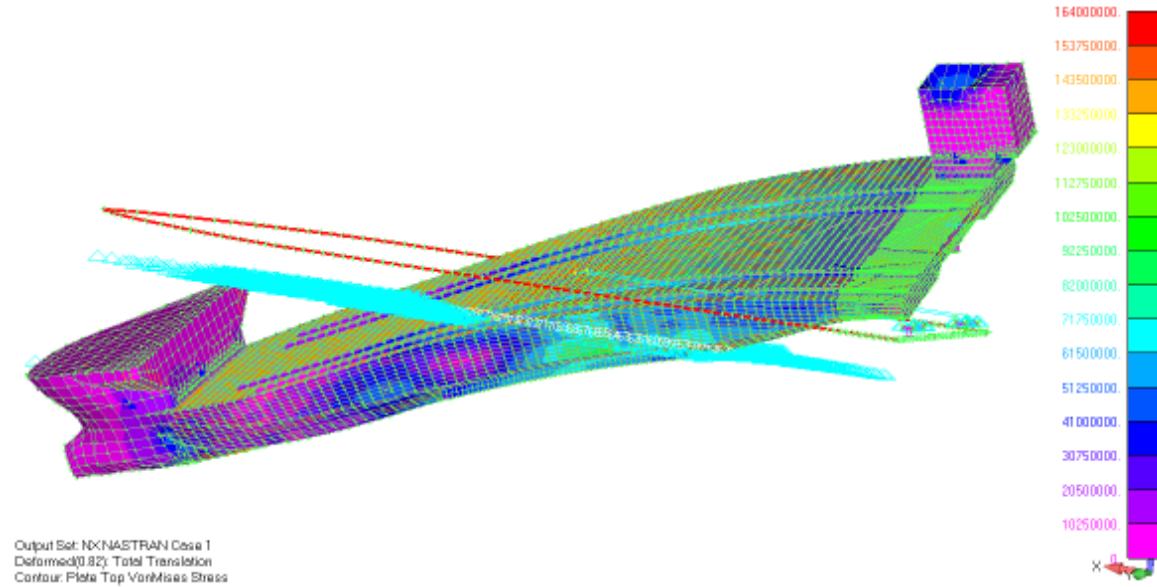


Fig 7.10 Scaled total deformation of the analysis step uniform loading with 4 skid beams

Hard tank on vessel with 3 skid beams:

Fig. 7.11 shows the FE model of the Analysis step hard tank on vessel with 3 skid beams. The application of loads on nodes in the centre line of the skid beams for a length of 81.382 m can be seen in the figure below.

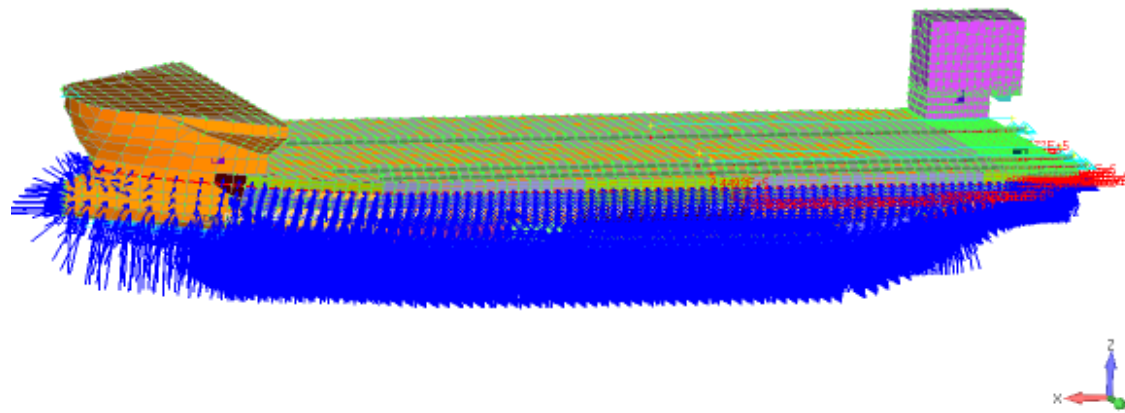


Fig 7.11 FE model of analysis step hard tank on vessel with 3 skid beams by uniform loading

The results of static linear analysis of the step hard tank on vessel with 3 skid beams are illustrated below.

The total translation in the model is 0.807m. The highest equivalent stress found was about 151.215Mpa.

Fig 7.12 shows the total deformation of the model after the analysis. The scale of the results is increased by 10% of the actual value to visualize the actual deformation of the model. The red line shows the draft line of the vessel or the water surface level

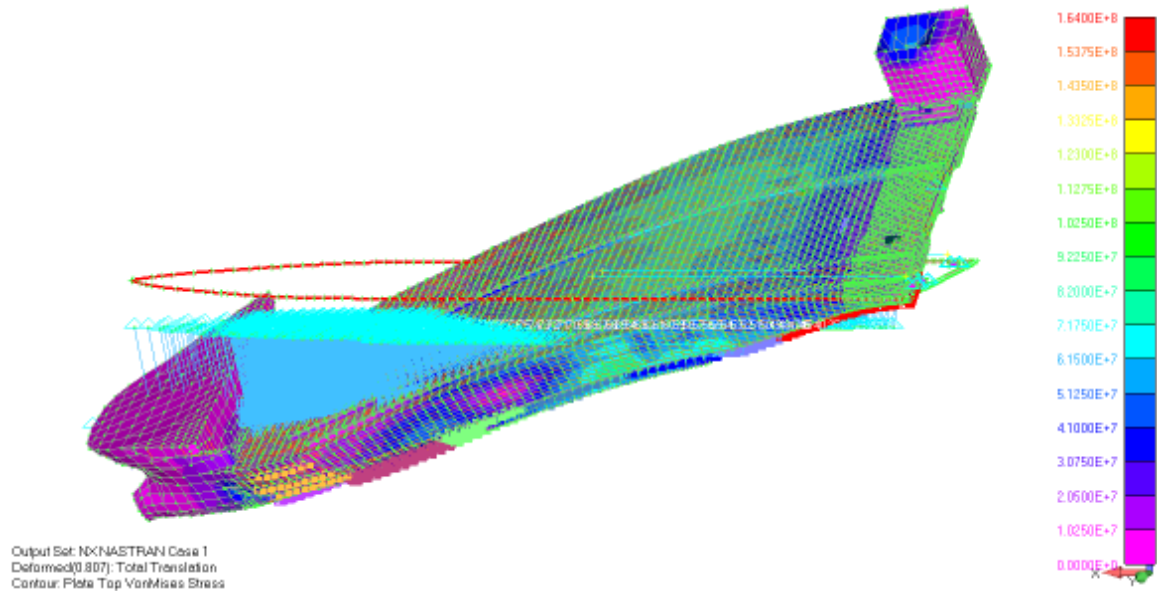


Fig 7.12 Scaled total deformation of the analysis step uniform loading with 3 skid beams

Hard tank on vessel with 2 skid beams:

Fig. 7.13 shows the FE model of the Analysis step hard tank on vessel with 2 skid beams. The application of loads on nodes in the centre line of the skid beams for a length of 81.382 m can be seen in the figure below.

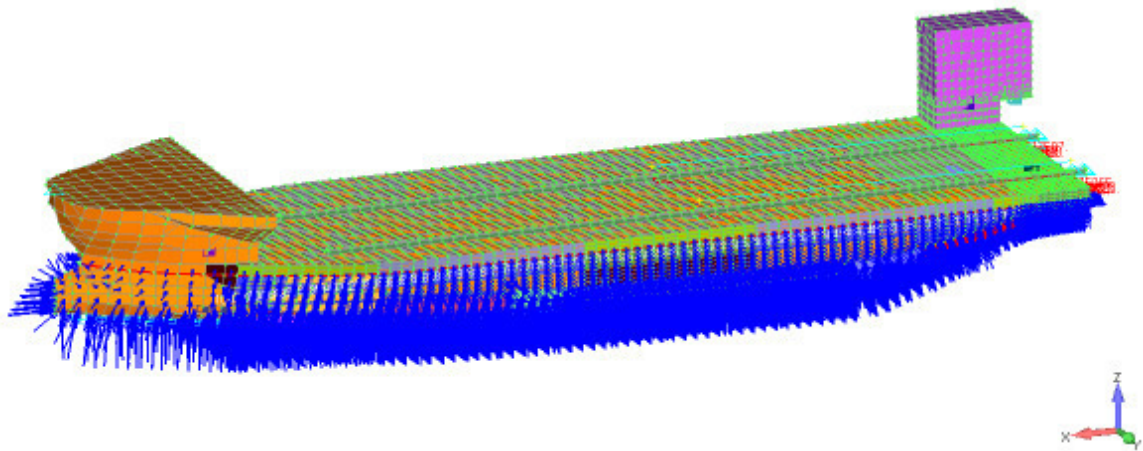


Fig 7.13 FE model of analysis step hard tank on vessel with 2 skid beams by uniform loading

The total translation in the model is 0.77m. The highest equivalent stress found was about 149.8Mpa.

Fig 7.14 shows the total deformation of the model after the analysis. The scale of the results is increased by 10% of the actual value to visualize the actual deformation of the model. The red line shows the draft line of the vessel or the water surface level

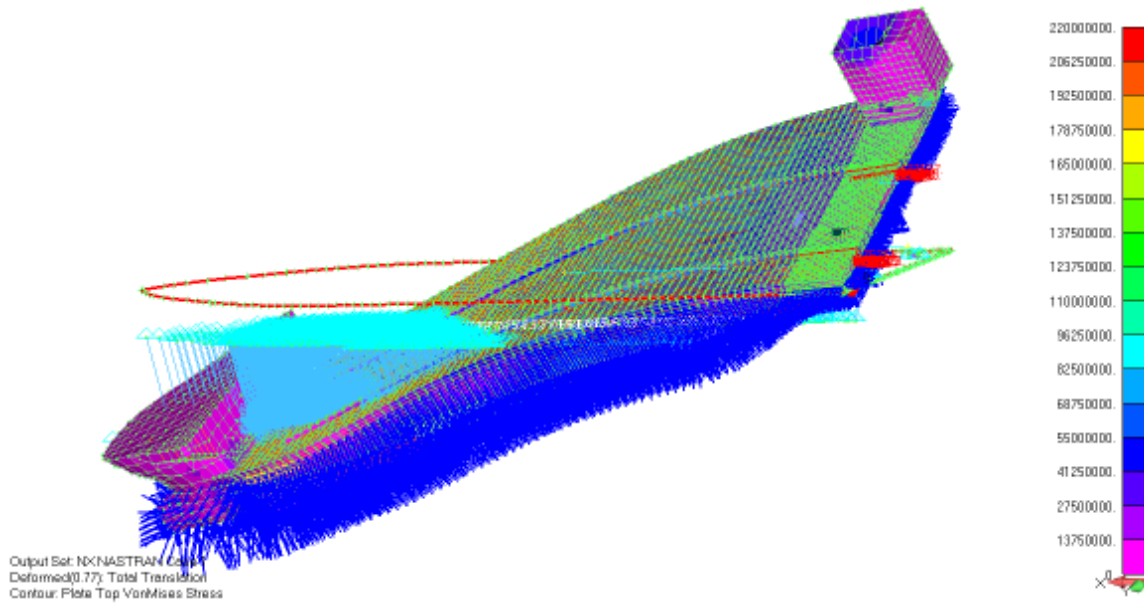


Fig 7.14 Scaled total deformation of the analysis step uniform loading with 2 skid beams

Summary of the results of uniform loading cases

Hard tank on vessel using uniform loading case	Total translation	Highest equivalent stress
4 skid beams	0.82m	178.983Mpa
3 skid beams	0.807m	151.215Mpa
2 skid beams	0.77m	149.8Mpa

Table 7.6 Summary of results of uniform loading cases

7.2.7 Location of the stress components.

During the analysis of all the 3 load steps of the uniform loading, namely 4 skid beams load-out, 3 skid beams load-out and 2 skid beams load-out, the highest equivalent stresses are found in almost same locations on the vessel model. Fig 7.15 shows the location where the highest equivalent stresses are found in vessel model.

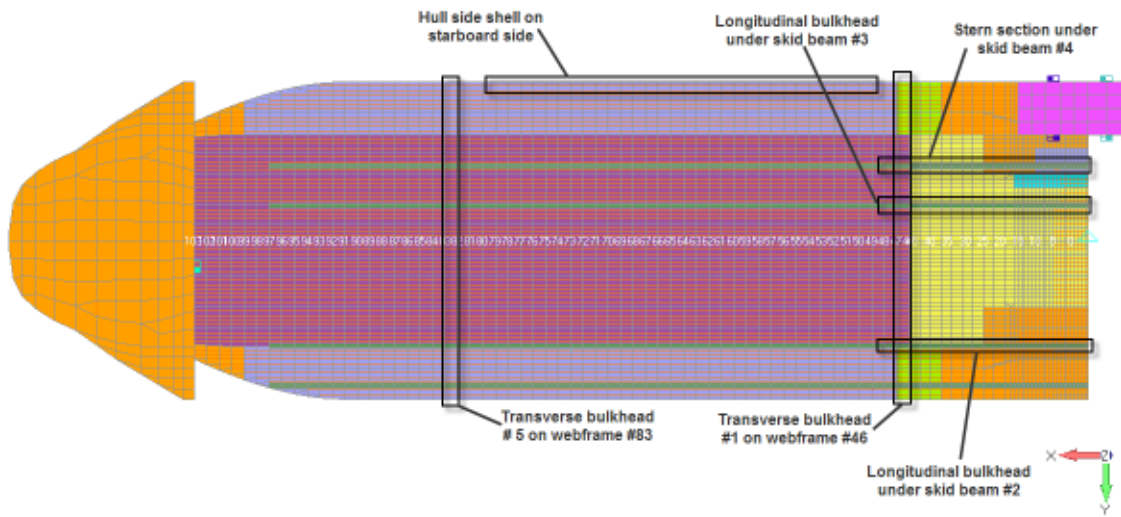


Fig. 7.15 Location of highest equivalent stresses in uniform loading case analysis.

7.2.8 Stress components of analysis

The results of the stress components in the locations mentioned above, on all the 3 steps analyzed are presented below;

Hard tank on vessel with 4 skid beams

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	T_{xy}	$\sigma_{\text{Equivalent}}$
Longitudinal bulkhead under skid beam #2	-35.660	-85.429	-45.901	108.831
Longitudinal bulkhead under skid beam #3	-67.105	-20.385	53.889	110.738
Stern section under skid beam #4	-76.254	-12.952	-94.939	178.983
Transverse bulkhead #1 on webframe #46	-10.033	-90.918	-72.358	152.190
Transverse bulkhead #5 on webframe #83	-113.543	16.072	1.180	122.391
Hull side shell on starboard side	-29.673	-8.366	64.880	115.459

Table 7.7 Highest equivalent stresses of the analysis step hard tank on vessel with 4 skid beams.

The highest equivalent stress of 178.983MPa is more than the allowable stress of 164.3MPa, which suggests that the load-out with 4 skid beams using uniform loading might not be a solution. But the factors affecting the results can be listed as follows:

1. The peak stress is found on a location of a duct which intersects a longitudinal frame in the stern to connect two sections to form a ballast tank. And also it is found on a triangular element, whose results are not so accurate as compared to quadrilateral elements.
2. The critical stress is found exactly under the skid beam no. 4, in location on the deck where there is no major bulkhead present.

The stress plot figures of the stress components location listed in the table 7.7 has been attached in the appendix no.4.

Hard tank on vessel with 3 skid beams

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	T_{xy}	$\sigma_{\text{Equivalent}}$
Longitudinal bulkhead under skid beam #2	-31.885	-71.238	-36.686	92.439
Longitudinal bulkhead under skid beam #3	-116.027	-28.710	33.522	151.215
Stern section under skid beam #4	-16.480	-22.310	72.583	127.305
Transverse bulkhead #1 on webframe #46	-3.159	-84.404	-64.353	138.894
Transverse bulkhead #5 on webframe #83	-113.197	16.074	1.187	122.048
Hull side shell on starboard side	-19.359	-7.222	66.923	117.146

Table 7.8 Highest equivalent stresses of the analysis step hard tank on vessel with 3 skid beams

The highest equivalent stress of 151.2Mpa is well below the allowable stress of 164.3MPa, so the critical step of loading-out hard tank of the SPAR on the vessel with 3 skid beams arrangement is possible with out causing any problems to the structure.

The highest stress of 151.215Mpa is found in the longitudinal bulkhead under the skid beam number 3, where there is a discontinuity in the bulkhead in the stern section above the aft perpendicular to interconnect the sections to form a ballast tank.

The stress plot figures of the locations listed above has been attached in the appendix no.5.

Hard tank on vessel with 2 skid beams

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	T_{xy}	$\sigma_{\text{Equivalent}}$
Longitudinal bulkhead under skid beam #2	-38.783	-73.229	-44.544	99.895
Longitudinal bulkhead under skid beam #3	-111.346	-28.435	59.994	144.293
Stern section under skid beam #4	0.161	-10.503	71.040	123.499
Transverse bulkhead #1 on webframe #46	-6.366	-90.168	-69.037	147.969
Transverse bulkhead #5 on webframe #83	16.127	-113.310	1.205	122.193
Hull side shell on starboard side	-30.198	-8.592	68.257	121.258

Table 7.9 Highest equivalent stresses of the analysis step hard tank on vessel with 2 skid beams

The highest equivalent stress of 147.969Mpa is well below the allowable stress of 164.3MPa, in contrary to the expected results the load-out of SPAR hard tank with 2 skid beams turn out to be possible by uniform loading as the complete load is transferred to the longitudinal bulkheads which is capable of withstanding heavy loads.

Since the load in skid beams are higher, the lowest stress among the stress concentration location is found on the longitudinal bulkhead under skid beam #2, which is also the case in 3 and 4 skid beams load-outs as well. So the stress concentration on the model reveals that the load-out using 2 skid beam by uniform loading is very well possible as of the 3 skid beam step.

The stress plot figures of the locations listed above has been attached in the appendix no.6.

7.3 SPAR model loading

The analysis and results of uniform loading with application of hydraulics to level out the peak loads were discussed in the previous chapter, which doesn't make use of the SPAR model. In this chapter the SPAR model is loaded on the vessel deck, to analyze the load-out by standard skidding method without hydraulics. The necessary details such as constraints, draft, and ballast condition are discussed in detail.

Two steps of the SPAR model loading are analyzed

1. hard tank on vessel to decide whether the load-out has to be carried out using hydraulics
2. Entire SPAR on vessel to see the overall stress in the vessel after the load-out.

Each of the above steps are further subdivided into load-out with 3 and 4 skid beams to decide on the number of skid beams needed for distribution of the SPAR load during load-out.

7.3.1 Hard tank on vessel by standard skidding method

Whole length of the SPAR hard tank model is loaded on the vessel model and analyzed to find the stress components on the vessel structure.

7.3.1.1 Connecting SPAR with skid beams

The SPAR model is moved on top of the vessel model such that the entire hard tank is above the skid beams and aligned so that the SPAR supports center lines are in same plane with the skid beams center lines.

During the skidding method the contact between the SPAR support and skid beams are by means of a roller as discussed in the chapter 4.3.1.4. The rollers are used to reduce the friction between the surfaces for the facilitation of easy movement of the load. The roller contact on the skid beam and SPAR support surfaces are usually a line contact.

The distance between the skid beams and the SPAR supports are maintained at about 1.5m as the nodes are located on the center of the beam elements cross section. The height of the support I-beam section below the node is 1.5m.

Since the friction does not comes in to play that much during the load-out process, the need for gap elements can be ruled out.

The nodes on the SPAR's support are edited to match the nodes on the center line of the skid beams, so that both line of nodes are in the same plane.

The nodes on the supports base and the nodes on the skid beams center are connected using rod elements. The area of cross section of the rod is chosen according the area of contact surface between the skid beams and SPAR supports.

Rod elements are axial elements which only take tension or compression loads and translates the loads to the connecting nodes. So the rod elements are very much suitable to simulate the rollers used during the load-out by skidding method.

Details about the rod element are depicted in the table below.

Description	Element type	Cross section	Area	Material Density
Connecting rod	Rod	Circular rod	2.25m ²	0

Table 7.10 Properties of rod elements

Fig 7.16 shows rod elements connecting the nodes on the SPAR supports and skid beam.

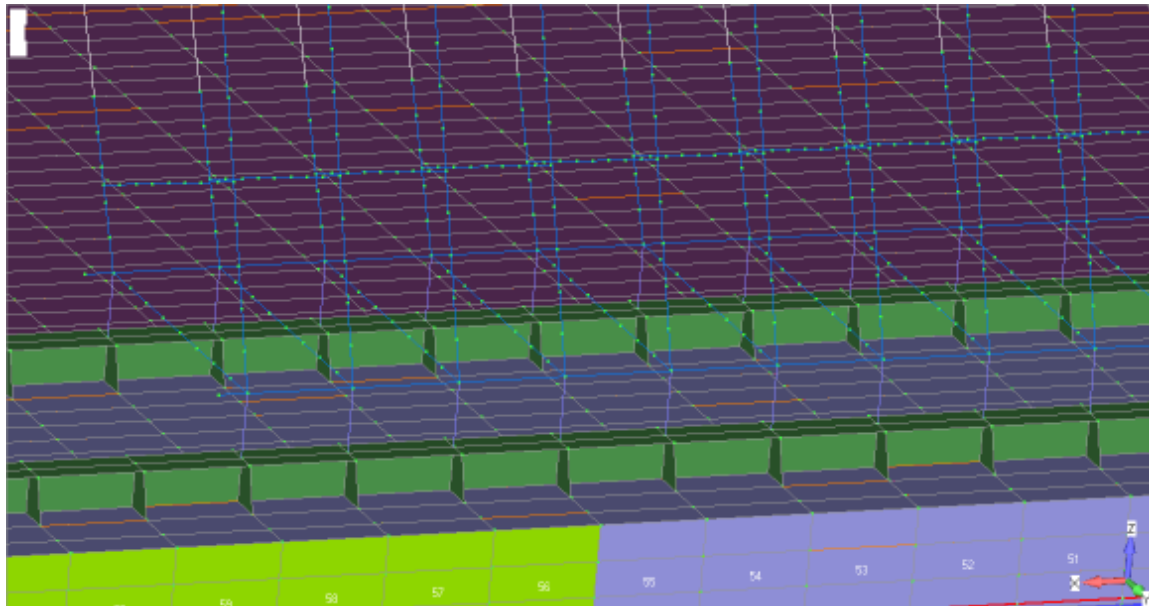


Fig 7.16 rod elements connecting nodes on supports and skid beams

7.3.1.2 Load case specific boundary conditions

All the constraints in the vessel model as explained in the chapter 7.2.2 for uniform loading condition are also utilized for the analysis using SPAR model. In addition to the constraints on the vessel model following constraints are also created on the SPAR model for the analysis of the step hard tank on vessel with SPAR model loading.

1. Constraints in the supports under heave plates.

The supports under the hard tank are not constrained as the load of the hard tank has to be transferred to the skid beam for loading the vessel structure.

All nodes on the supports under the heave plates are constrained in all 6 degrees of freedom. During load-out when the hard tank supports are on the vessel the heave plate supports will still be on the keel side, so it can't move or rotate in any direction.

Fig 7.17 shows the constraints of the supports under the heave plates.

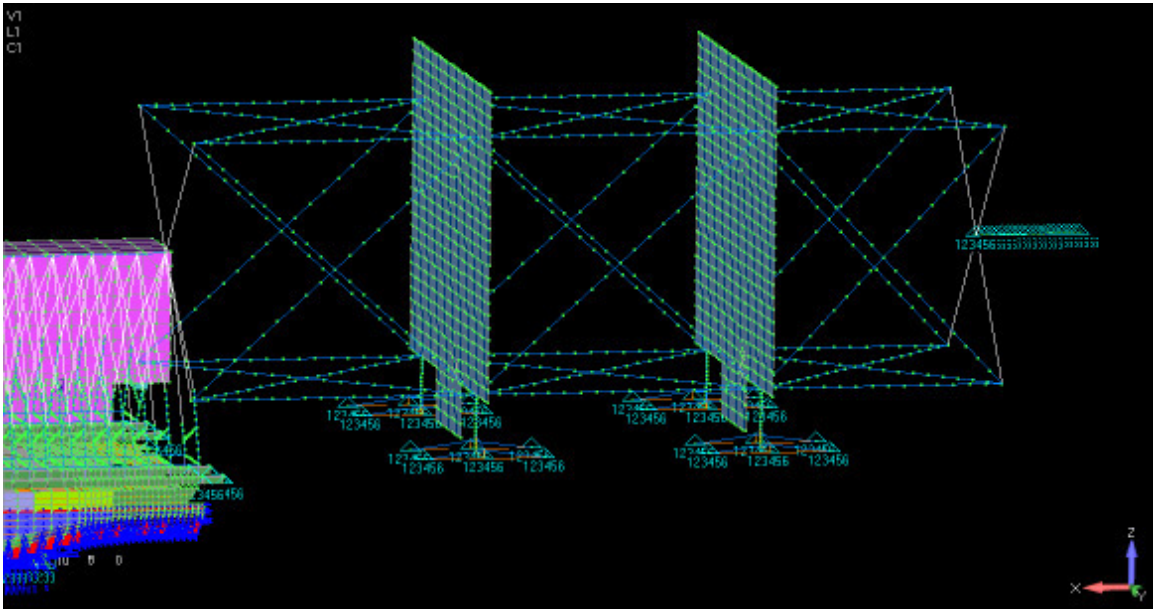


Fig 7.17 Constraints of the SPAR supports under the heave plates and soft tank

2. Constraints in soft tank

The soft tank doesn't have any permanent supports under it as it will be hanging out of the vessel during transportation, but during the load-out it will be supported on the skid beams using temporary supports until the SPAR is in the final stowage position on the vessel deck. This is explained in chapters 4.4.5 & 6.2.3.5

All the nodes on the soft tank are fixed in all 6 degrees of freedom as it will be on the skid beams and all its movements will be locked. The constraints in the soft tank can be visualized in the figure 7.17.

7.3.1.3 Draft and ballast condition

The draft and ballast condition are same as the uniform loading case. The mass of the hard tank is same in both the cases only difference is that the load is applied using hydraulics to level out the peak load and distribute it evenly in uniform loading case. But in this case the actual SPAR model is used in loading.

The draft of the vessel is 10.95m and the ballast condition is exactly the same as previous loading case. Please refer to chapter 7.2.3 and 7.2.4 for further details

7.3.1.4 Analysis of step hard tank on vessel

The following section describes the analysis and results of the steps hard tank on vessel with 4 skid beams, hard tank on vessel with 3 skid beams and hard tank on vessel with 2 skid beams by SPAR model loading case.

The SPAR model is loaded on the Vessel model so that the hard tank of the SPAR is completely on the vessel stern and the centre line of the supports is aligned with the centre line of the skid beams. Nodes on the supports are connected with nodes on skid beams using rod elements.

Hard tank on vessel with 4 skid beams

Fig 7.18 shows the analysis step hard tank on vessel with 4 skid beams.

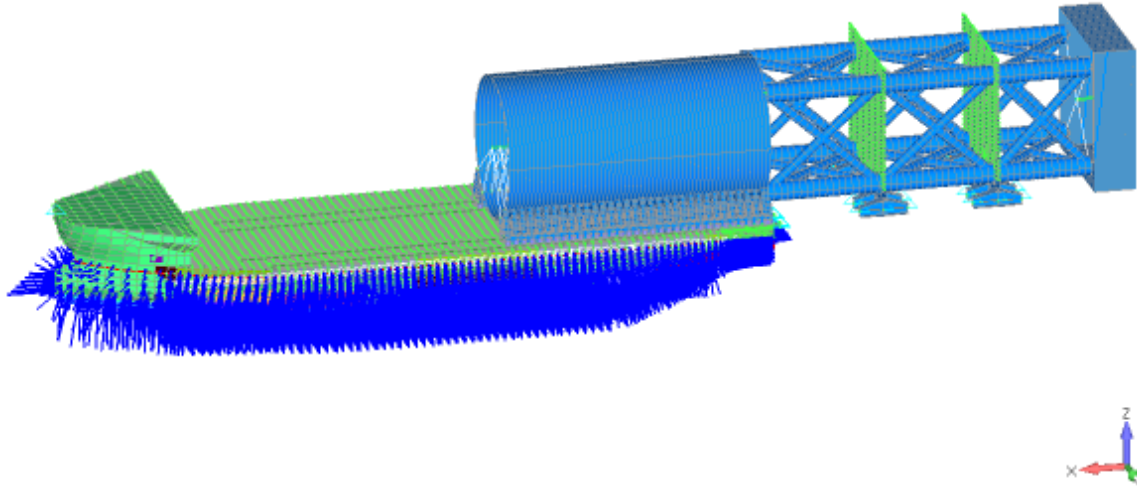


Fig. 7.18 FE model of analysis step hard tank on vessel with 4 skid beams by SPAR model loading

The results of the analysis have been discussed below:

The total translation in the model is 0.437m. The highest equivalent stress found was about 130.575Mpa.

Fig 7.19 shows the total deformation of the model after the analysis. The scale of the results is increased by 10% of the actual value to visualize the actual deformation of the model. The red line shows the draft line of the vessel or the water surface level. The total deformation includes the deformation of the SPAR as well.

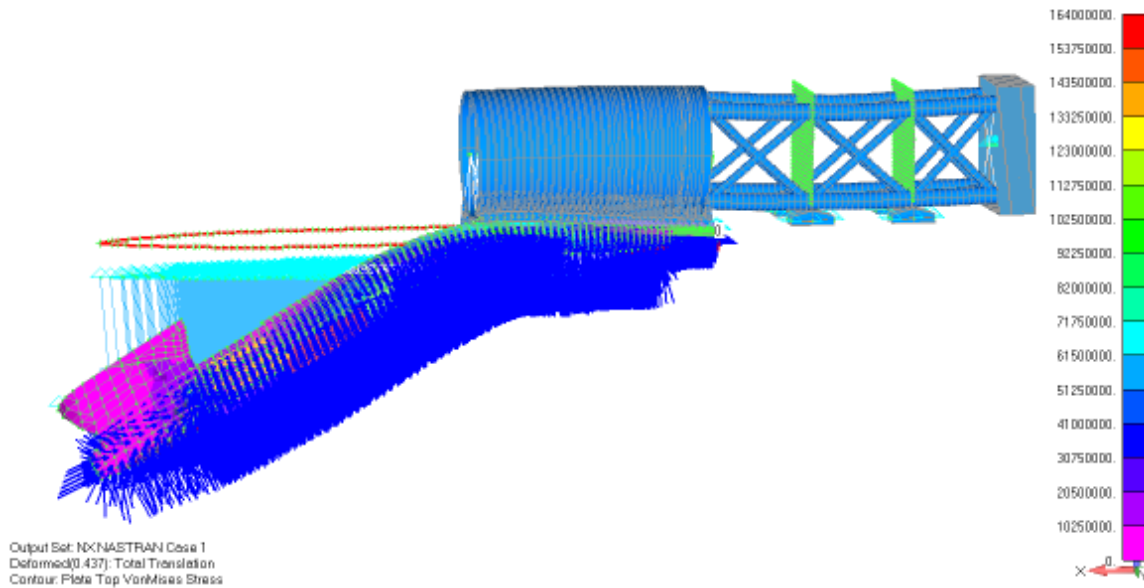
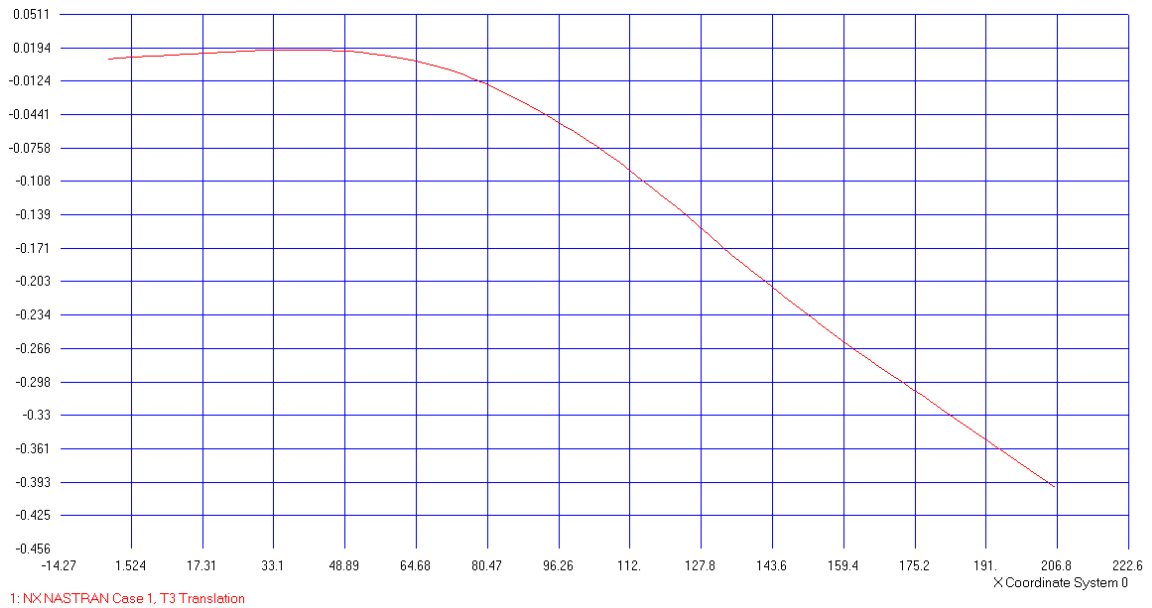


Fig 7.19 Scaled total deformation of the analysis step hard tank on vessel with 4 skid beams

Fig. 7.20 shows the plot of total translation in Z-axis verses its X-axis coordinates. The resulting plot reveals the bending of the whole vessel model.



1: NX/NASTRAN Case 1, T3 Translation
Fig. 7.20 Plot of vessel model translation in Z-axis for the step hard tank on vessel with 4 skid beams

Hard tank on vessel with 3 skid beams

Fig 7.21 shows the analysis step hard tank on vessel with 3 skid beams.

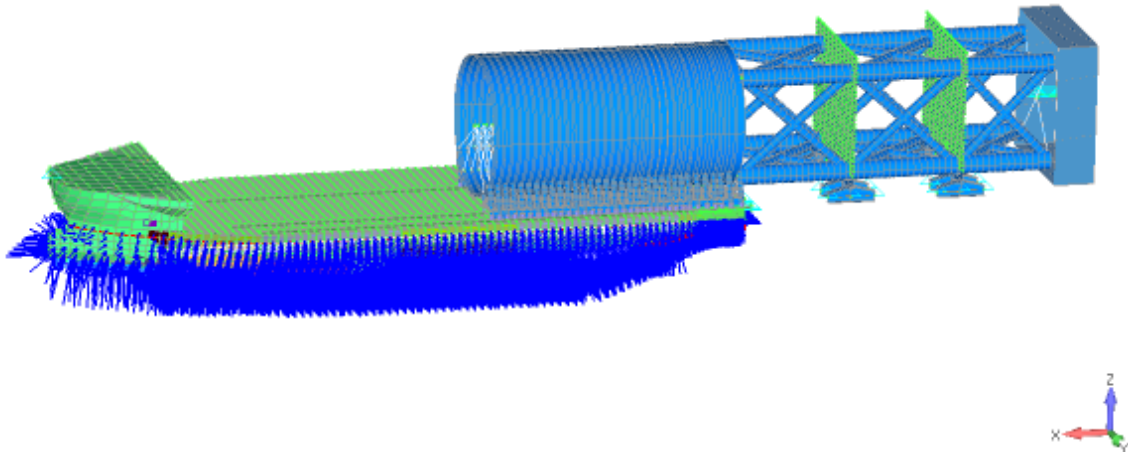


Fig. 7.21 FE model of analysis step hard tank on vessel with 3 skid beams by SPAR model loading

The results of the analysis have been discussed below:

The total translation in the model is 0.41m. The highest equivalent stress found was about 195.718Mpa.

Fig 7.22 shows the total deformation of the model after the analysis. The scale of the results is increased by 10% of the actual value to visualize the actual deformation of the model. The red line shows the draft line of the vessel or the water surface level. The total deformation includes the deformation of the SPAR as well.

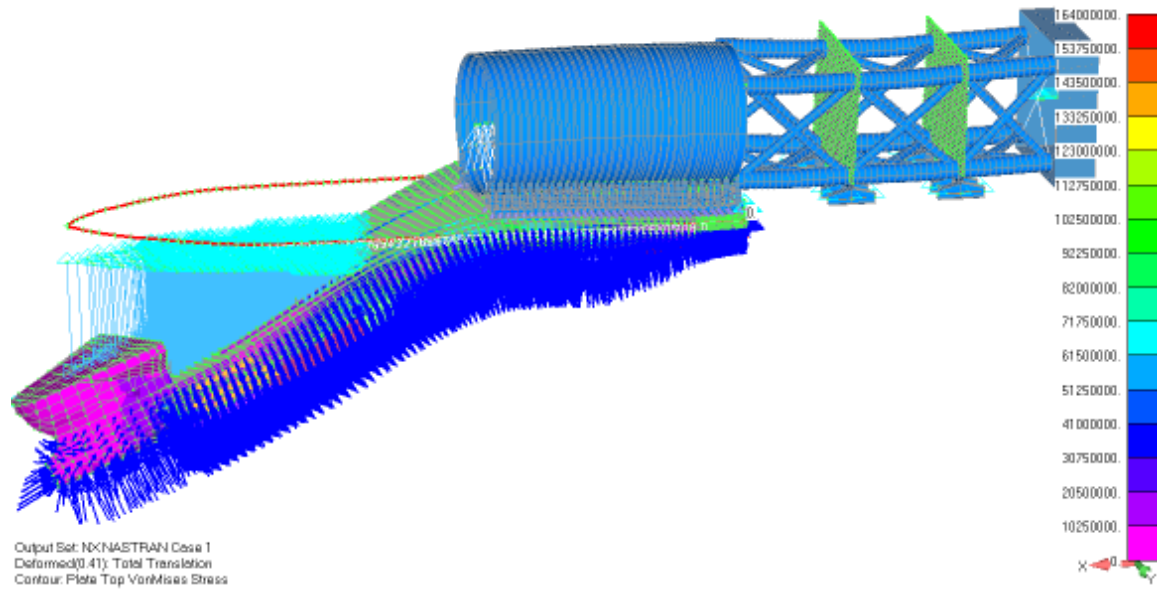


Fig 7.22 Scaled total deformation of the analysis step hard tank on vessel with 3 skid beams

Fig. 7.23 shows the plot of total translation in Z-axis versus its X-axis coordinates. The resulting plot reveals the bending of the whole vessel model.

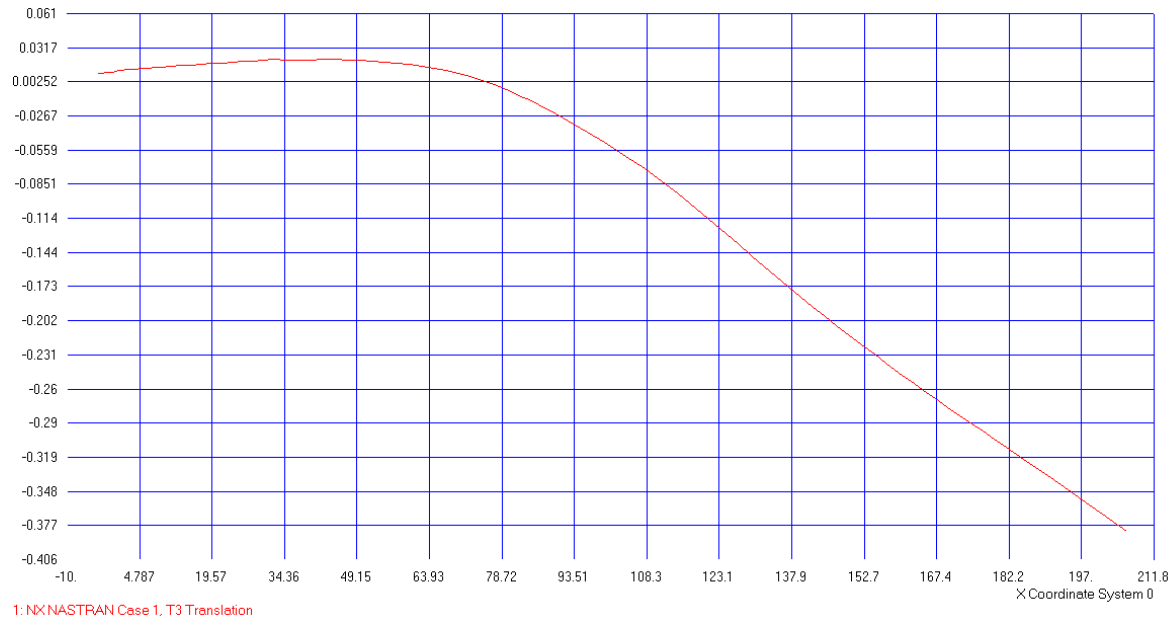


Fig. 7.23 Plot of vessel model translation in Z-axis for the step hard tank on vessel with 3 skid beams

Hard tank on vessel with 2 skid beams

Fig 7.24 shows the analysis step hard tank on vessel with 2 skid beams.

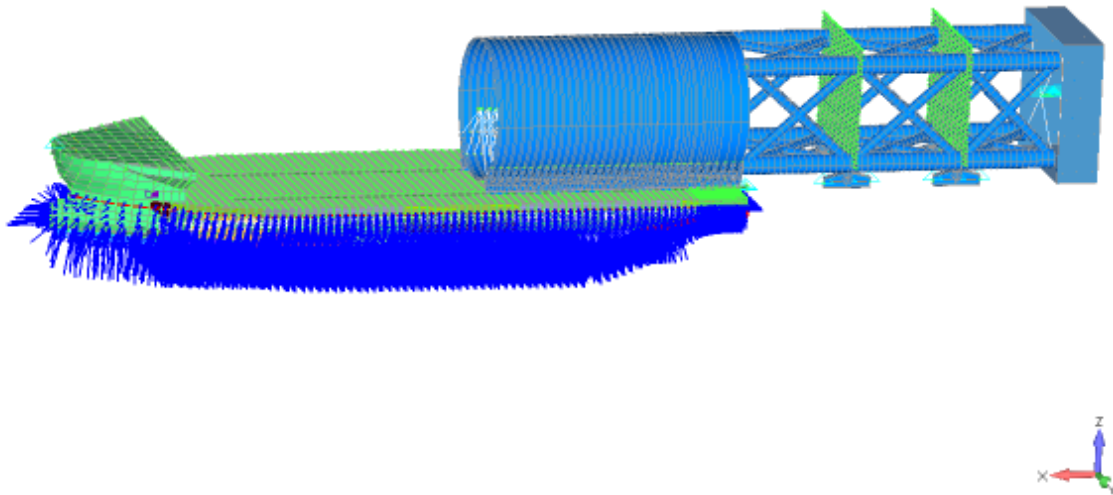


Fig. 7.24 FE model of analysis step hard tank on vessel with 2 skid beams by SPAR model loading

The results of the analysis have been discussed below:

The total translation in the model is 0.425m. The highest equivalent stress found was about 180.230Mpa.

Fig 7.25 shows the total deformation of the model after the analysis. The scale of the results is increased by 10% of the actual value to visualize the actual deformation of the model. The red line shows the draft line of the vessel or the water surface level. The total deformation includes the deformation of the SPAR as well.

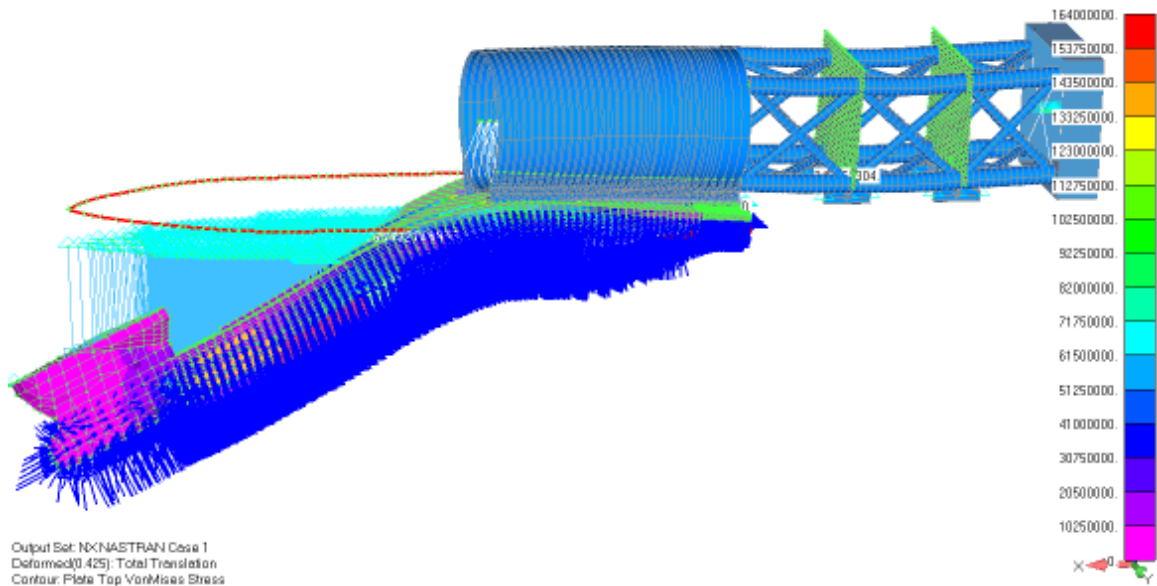
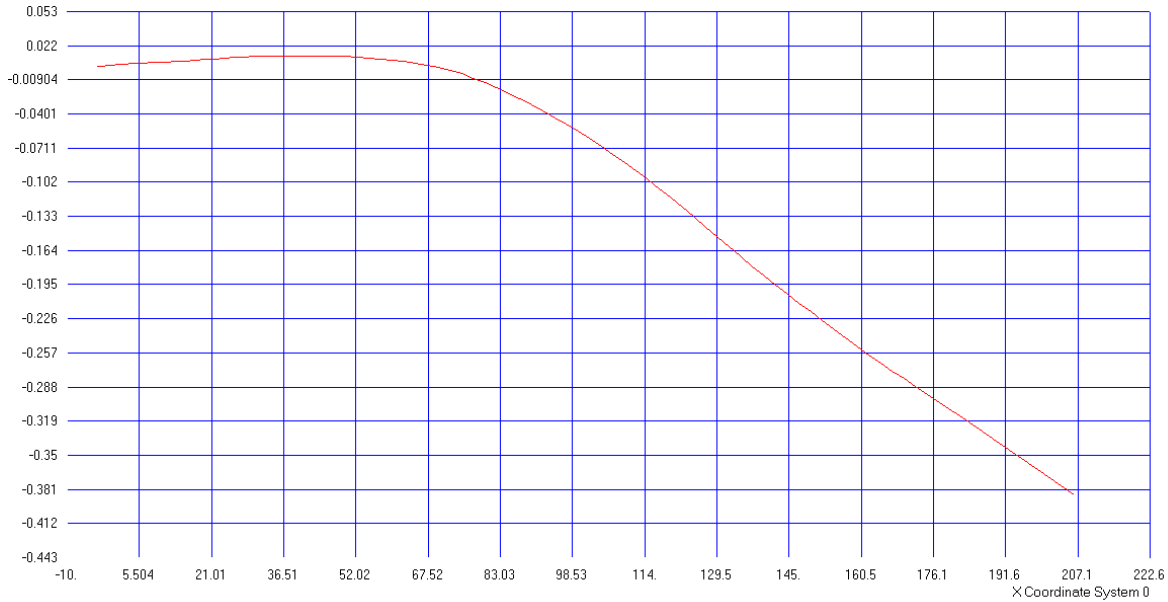


Fig 7.25 Scaled total deformation of the analysis step hard tank on vessel with 2 skid beams

Fig. 7.26 shows the plot of total translation in Z-axis verses its X-axis coordinates. The resulting plot reveals the bending of the whole vessel model.



1: NXNASTRAN Case 1, T3 Translation

Fig. 7.26 Plot of vessel model translation in Z-axis for the step hard tank on vessel with 2 skid beams

Summary of the results of hard tank on vessel by SPAR model loading cases

Hard tank on vessel by SPAR model loading	Total translation	Highest equivalent stress
4 skid beams	0.437m	130.575Mpa
3 skid beams	0.41m	195.718Mpa
2 skid beams	0.425m	180.230Mpa.

Table 7.11 Summary of results of hard tank on vessel by SPAR model loading cases

7.3.1.5 Loads on skid beams

Since it cannot be confirmed by viewing the model whether the vessel structure is loaded as expected, which is, loading by compression forces due the SPAR on top, the stresses in the connecting rod are evaluated. The tables and figures below show the magnitude and plot of all the axial forces on the rods, these forces are the loads on the skid beams. The following section explains the loads on the skid beam in each load step analyzed.

Hard tank on vessel with 4 skid beams

The axial forces on the rods are summed up and the total load acting on each skid beam is given in the table below.

	Force in Newton	Load in tons
Skid beam #1	46146891.1	4705.673
Skid beam #2	93538263.1	9538.248
Skid beam #3	80934120.3	8252.983
Skid beam #4	45070108	4595.871
Total load		27092.775 tons

Table 7.12 Load on skid beams in step hard tank on vessel with 4 skid beams

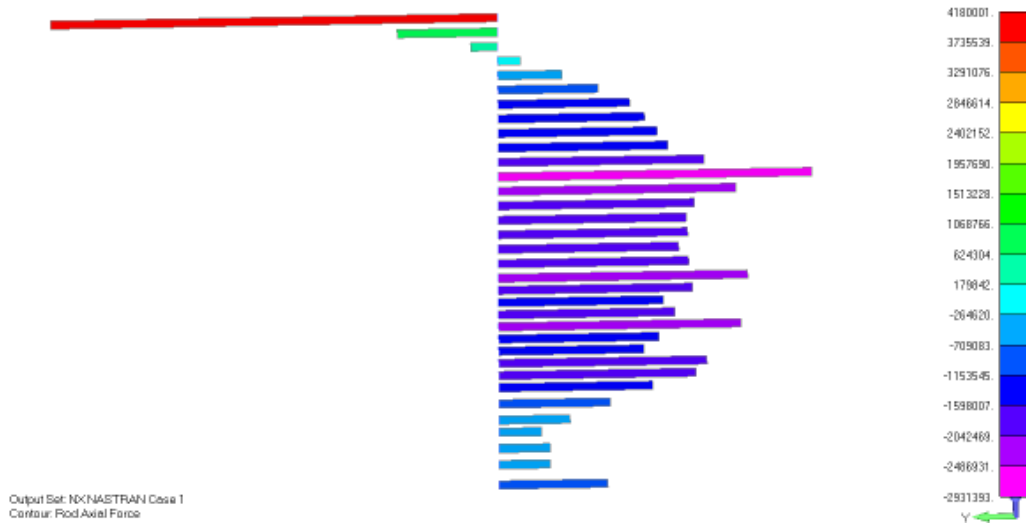


Fig. 7.27 Axial forces in rod elements on skid beam #1 – hard tank on vessel with 4 skid beams

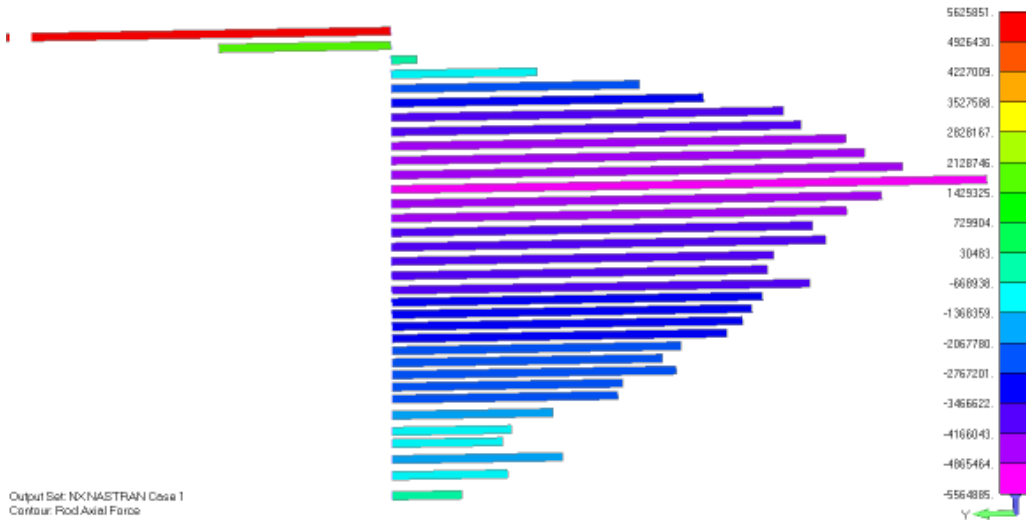


Fig. 7.28 Axial forces in rod elements on skid beam #2– hard tank on vessel with 4 skid beams

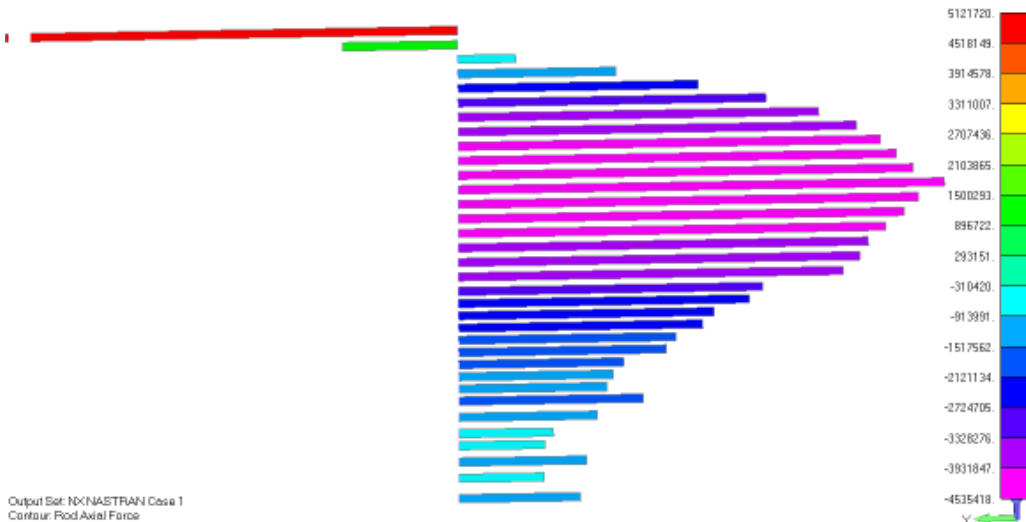


Fig. 7.29 Axial forces in rod elements on skid beam #3– hard tank on vessel with 4 skid beams

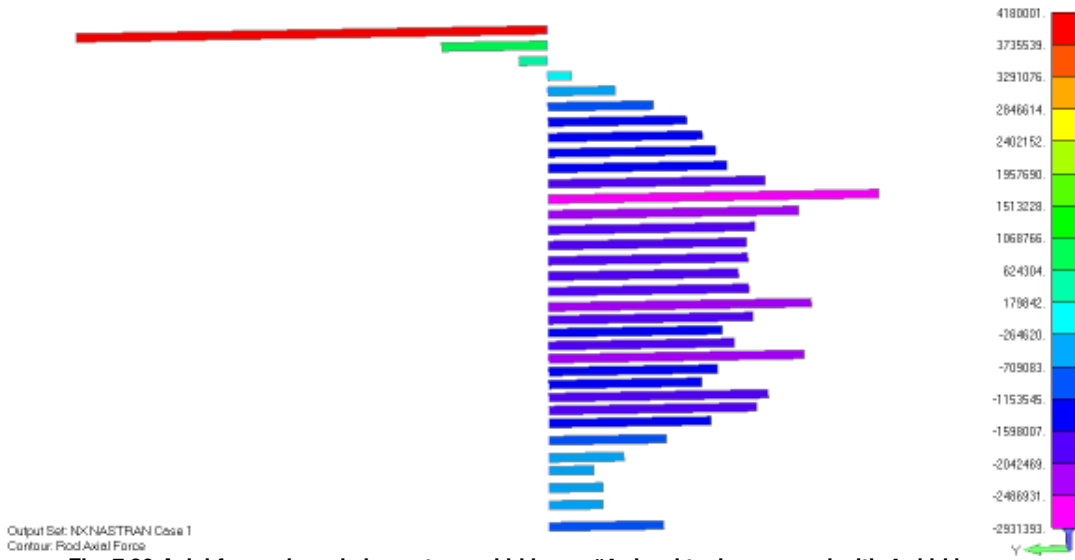


Fig. 7.30 Axial forces in rod elements on skid beam #4– hard tank on vessel with 4 skid beams

Hard tank on vessel with 3 skid beams

The axial forces on the rods are summed up and the total load acting on each skid beam is given in the table below.

	Force in Newton	Load in tons
Skid beam #1	50832664.4	5183.48
Skid beam #2	82246036.6	8386.76
Skid beam #3	142107838	14490.96
Total load		28061.20 tons

Table 7.13 Load on skid beams in step hard tank on vessel with 3 skid beams

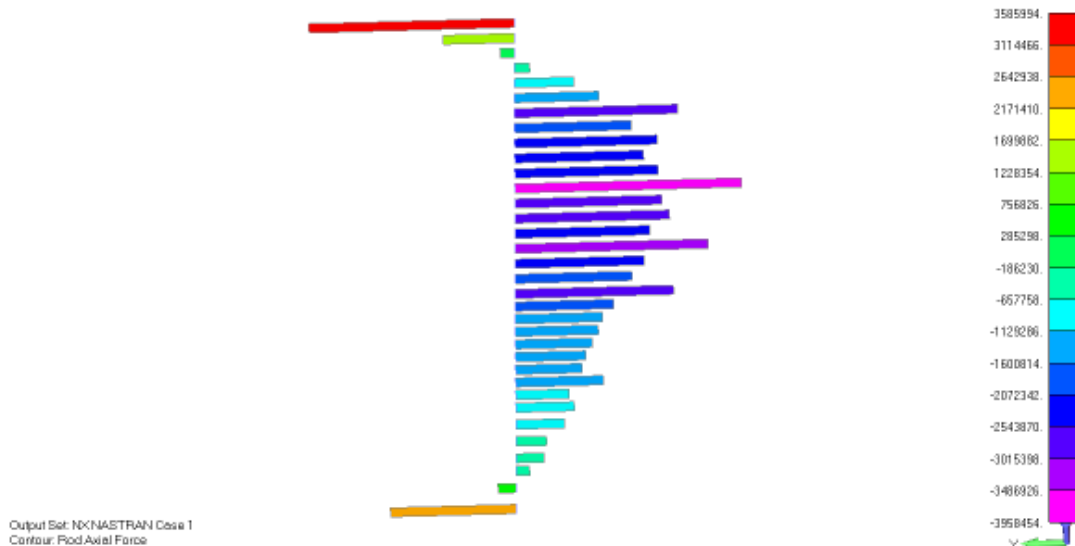


Fig. 7.31 Axial forces in rod elements on skid beam #1 - hard tank on vessel with 3 skid beams

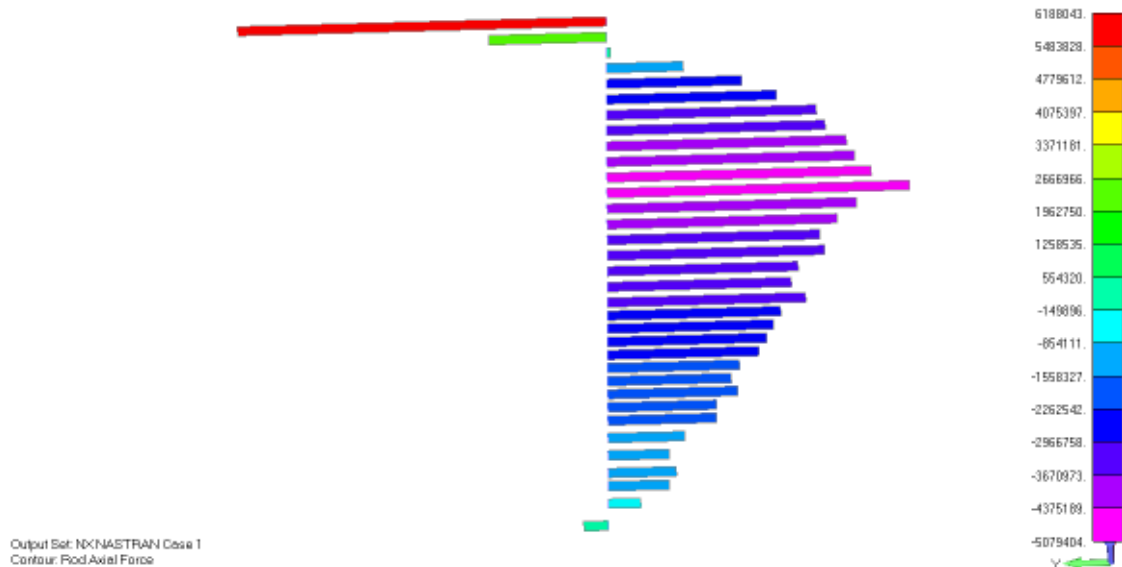


Fig. 7.32 Axial forces in rod elements on skid beam #2 - hard tank on vessel with 3 skid beams

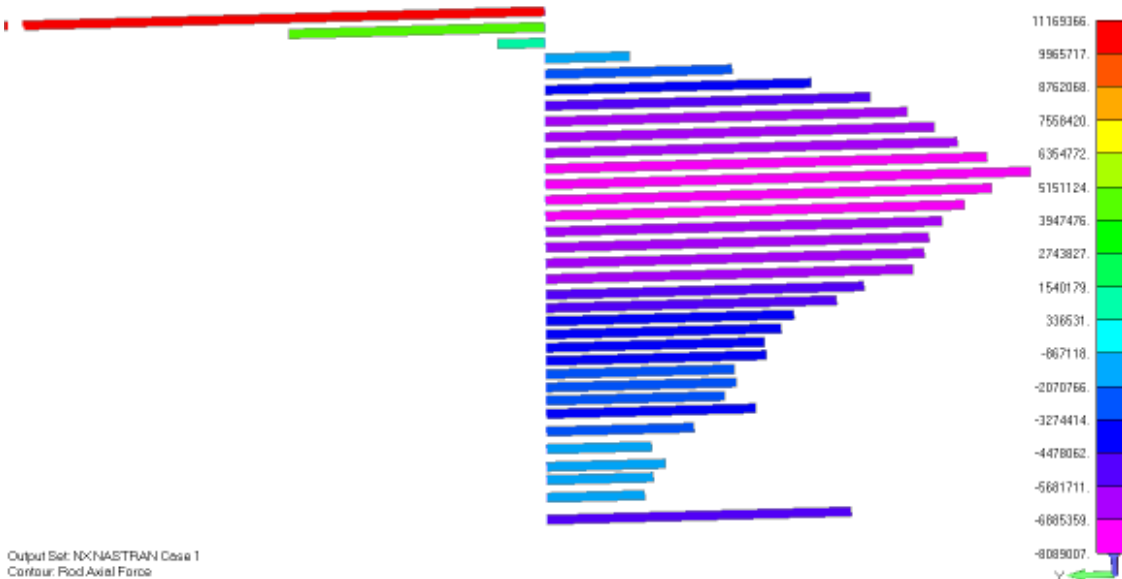


Fig. 7.33 Axial forces in rod elements on skid beam #3 - hard tank on vessel with 3 skid beams

Hard tank on vessel with 2 skid beams

The axial forces on the rods are summed up and the total load acting on each skid beam is given in the table below.

	Force in Newton	Load in tons
Skid beam #2	146159651	14904.13
Skid beam #3	130400410	13297.14
Total load		28201.27 tons

Table 7.14 Load on skid beams in step hard tank on vessel with 2 skid beams

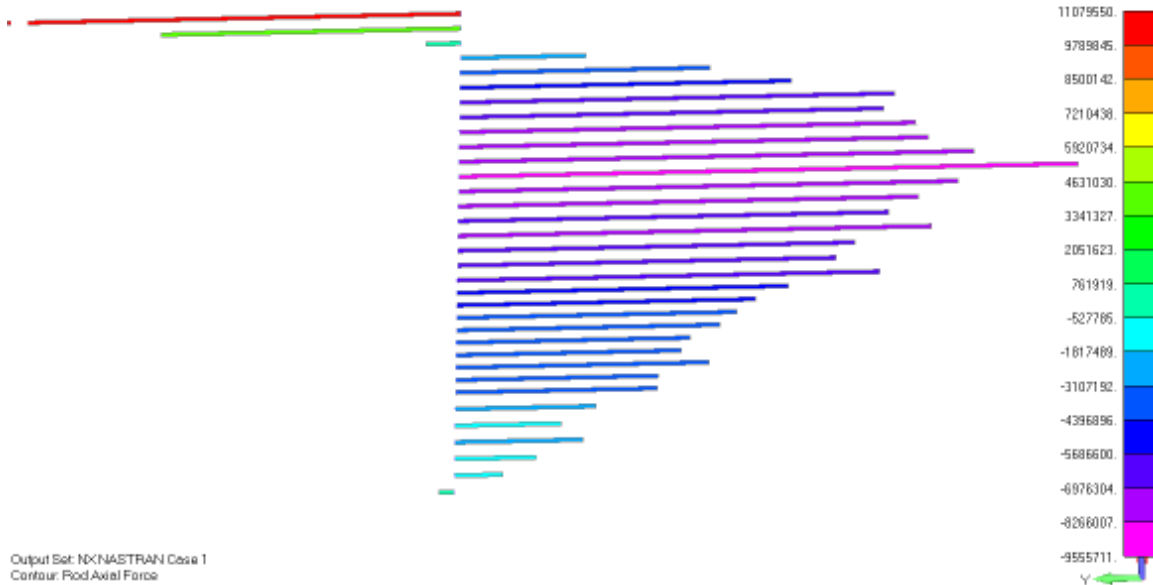


Fig. 7.34 Axial forces in rod elements on skid beam #2 - hard tank on vessel with 2 skid beams

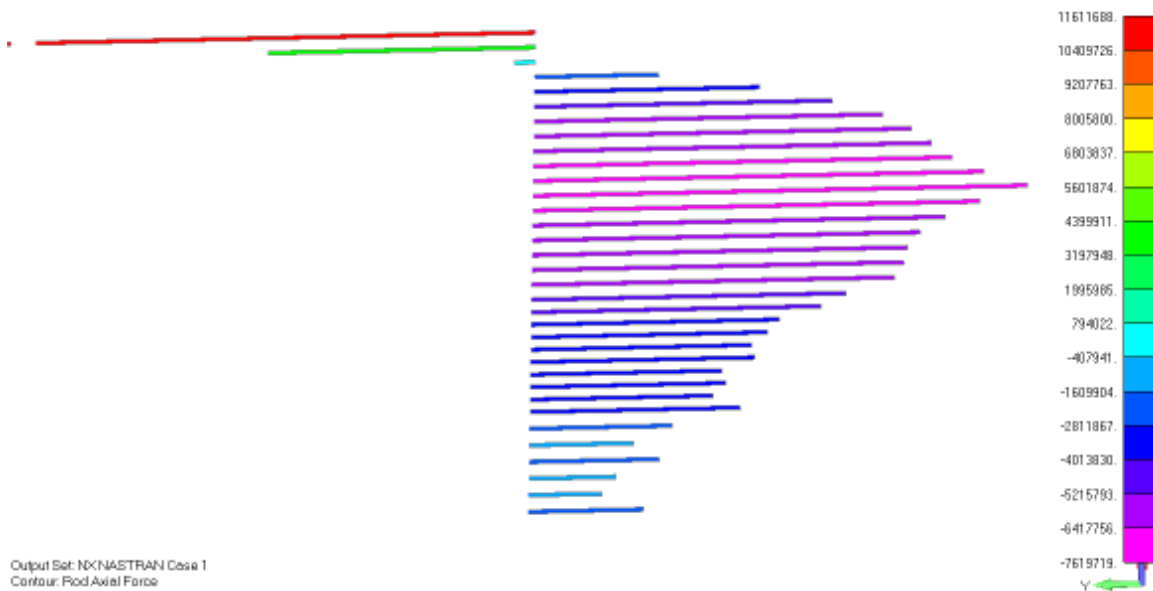


Fig. 7.35 Axial forces in rod elements on skid beam #3 - hard tank on vessel with 2 skid beams

Summary of load skid beams in hard tank on vessel by SPAR model loading case.

	Load on skid beam #1	Load on skid beam #2	Load on skid beam #3	Load on skid beam #4
4 skid beams load-out	4705.673	9538.248	8252.983	4595.871
3 skid beams load-out	5183.48	8386.76	14490.96	
2 skid beams load-out		14904.13	13297.14	

Table 7.15 Summary of load on skid beams in step hard tank on vessel by SPAR model loading

Negative sign indicates that the loading is compression and positive sign is tension. It is clear from the figures below that the forces in the rods are compressive and the vessel structure is loaded as expected.

The tensional forces on few nodes at the end of SPAR is due to the bending of the SPAR and vessel, in reality there will be minimal contact in those areas due to the bending. But in model it is translated into a tensional force as the nodes are connected. The small forces are due to the bending of the model can be neglected as it doesn't create any high stresses in the structure of the vessel model.

7.3.1.6 Location of stress components

During the analysis of all the 3 load steps of hard tank on vessel by SPAR model loading, namely 4 skid beams load-out, 3 skid beams load-out and 2 skid beams load-out, the highest equivalent stresses are found in almost same locations on the vessel model. Fig 7.36 shows the location where the highest equivalent stresses are found in vessel model

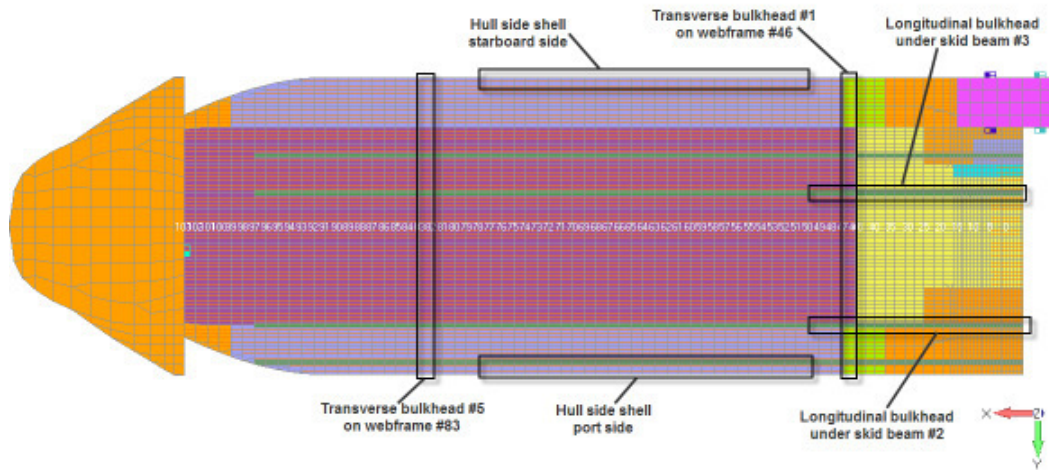


Fig. 7.36 Location of highest equivalent stresses in hard tank on vessel by SPAR model loading case analysis.

7.3.1.7 Stress components of analysis

The results of the stress components in the locations mentioned above, on all the 3 steps analyzed are presented below;

Hard tank on vessel with 4 skid beams

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	τ_{xy}	$\sigma_{\text{Equivalent}}$
Longitudinal bulkhead under skid beam #2	-44.086	-93.621	-53.116	122.658
Longitudinal bulkhead under skid beam #3	-121.474	-31.967	1.707	109.103
Transverse bulkhead #1 on webframe #46	-14.255	-75.791	63.725	130.575
Transverse bulkhead #5 on webframe #83	-118.907	16.810	1.394	128.159
Hull side shell on port side	-42.456	-10.509	69.254	125.903
Hull side shell on starboard side	-31.512	-8.500	60.363	108.298

Table 7.16 Highest equivalent stresses of the analysis step hard tank on vessel with 4 skid beams by SPAR model loading

The highest equivalent stress of 130.575Mpa is well below the allowable stress of 164.3MPa, it is possible to load-out the SPAR using 4 skid beam without the need for hydraulics for leveling the peak loads. The highest stress is found on the transverse bulkhead stiffeners, where, on the backside of the stiffeners the engine room section is present. The stress plot figures of the locations listed above has been attached in the appendix no.7.

Hard tank on vessel with 3 skid beams

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	T_{xy}	$\sigma_{\text{Equivalent}}$
Longitudinal bulkhead under skid beam #2	-42.570	-89.147	-50.920	117.231
Longitudinal bulkhead under skid beam #3	-215.916	-55.936	-14.541	195.718
Transverse bulkhead #1 on webframe #46	-8.561	-61.450	-53.632	109.328
Transverse bulkhead #5 on webframe #83	-119.407	16.820	1.391	128.667
Hull side shell on port side	-42.162	-10.499	73.491	132.845
Hull side shell on starboard side	-31.629	-8.561	61.448	110.139

Table 7.17 Highest equivalent stresses of the analysis step hard tank on vessel with 3 skid beams by SPAR model loading

The highest equivalent stress of 195.718Mpa is above the allowable stress of 164.3MPa, the load imposed on the vessels structure causes high stress concentration, it is not possible to load-out the SPAR using 3 skid beam without the hydraulics for leveling the peak loads. The high stress concentration is found on the longitudinal bulkhead under skid beam #3, where there is a opening in the bulkhead for cables and pipes. The stress plot figures of the locations listed above has been attached in the appendix no.8.

Hard tank on vessel with 2 skid beams

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	T_{xy}	$\sigma_{\text{Equivalent}}$
Longitudinal bulkhead under skid beam #2	-111.042	-27.874	63.218	148.330
Longitudinal bulkhead under skid beam #3	-197.698	-51.111	-17.229	180.230
Transverse bulkhead #1 on webframe #46	-11.310	-63.624	-55.042	112.006
Transverse bulkhead #5 on webframe #83	-119.197	16.764	1.375	128.424
Hull side shell on port side	-41.350	-10.977	65.698	119.688
Hull side shell on starboard side	-31.431	-8.555	61.747	110.591

Table 7.18 Highest equivalent stresses of the analysis step hard tank on vessel with 2 skid beams by SPAR model loading

The highest equivalent stress of 180.230Mpa is above the allowable stress of 164.3MPa, the load imposed on the vessels structure causes high stress concentration, it is not possible to load-out the SPAR using 3 skid beam without the hydraulics for leveling the peak loads. The high stress concentration is found on the longitudinal bulkhead under skid beam #3, where there is an opening in the bulkhead for cables and pipes, in the location similar to the 3 skid beam load-out. The stress plot figures of the locations listed above has been attached in the appendix no.9.

7.3.2 Entire SPAR on vessel

Entire length of the SPAR is loaded on the vessel model and analyzed to find the stress components on the vessel structure.

The main purpose of analysis of this position of SPAR is to check the capability of the vessel structure in the final stowage position for voyage. Whether the SPAR is loaded-out using standard skidding method or uniform loading by using hydraulics, once the SPAR is in the final stowage position on the vessel deck, the hydraulic cylinders (in case of uniform loading) and the other equipments used for load-out under the supports will be removed and the SPAR will be rested on the vessel deck directly. The skid beams may or may not be present under the supports for final voyage. Then the SPAR will be sea fastened in the final position to prevent the SPAR from moving during voyage. During this step of the analysis, suitable position for the stowage of the SPAR for voyage conditions is determined.

As per the data provided by the client regarding the design of the SPAR, the mass of hard tank with outfitings and supports is 25122 tons which is the critical load acting on the vessel structure. The loads exerted by the supports under heave plates is, 2958 tons for the upper heave plate and 2957 tons for the lower heave plates when the soft tank is still resting on the key side.

Until the SPAR reaches the final position the load-out is carried by one of the suitable steps explained in the previous topics (uniform loading or standard skidding). The soft tank will still be supported on the keyside until the SPAR reaches its final position on deck, so the loads will be less on the supports under the truss.

The total load on the vessel structure under the heave plates supports is 5915.4 tons when the SPAR reaches its final position on the vessel deck. During this step of the analysis, the vessel structure's capability to withstand the loads due to the heave plates supports is also investigated, but the load acting on the vessel structure at any unit area due to the combined mass of truss and heave plates will always be less than the hard tank load when the soft tank is supported on the key side. So the need to analyze the vessel structure until the SPAR reaches its final position when the soft tank is fixed is ruled out.

When the SPAR reaches the final stowage position, the SPAR is sea fastened for its voyage and the vessel's draft is decreased by discharging the ballast water so that the soft tank is lifted off its temporary supports from the keyside and left hanging over the vessel stern. Only during this step the whole weight of the SPAR will be acting on the vessel deck. Especially the loads on the supports under the truss and heave plates will be increased due to the additional weight of the soft tank.

In this section the final stowage position for voyage is analyzed to find a suitable position for the SPAR on vessel deck using 3 different skid beams configuration namely;

1. Load-out using 4 skid beams
2. Load-out using 3 skid beams
3. Load-out using 2 skid beams

7.3.2.1 Position of the SPAR

The SPAR model is moved on top of the vessel model such that the entire SPAR is above skid beams and the hard tank is at the end of the skid beams, the SPAR is aligned so that the SPAR supports center lines are in same plane with the skid beams center lines. Fig 7.37 shows the position of hard tank at the end of the skid beams near the bow section of the vessel model.

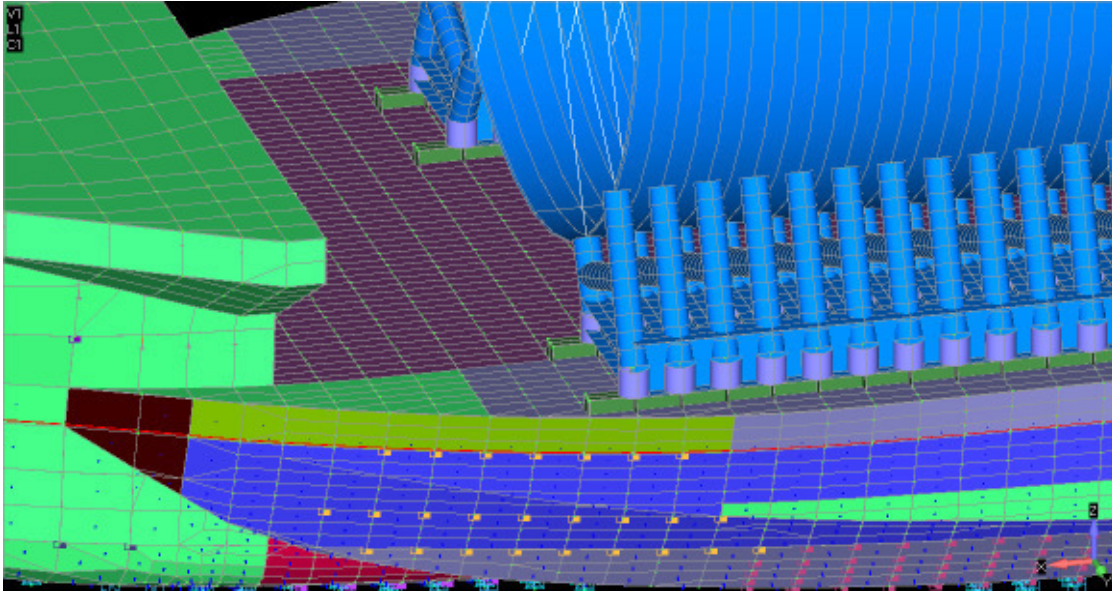


Fig 7.37 Final position of SPAR hard tank supports on skid beams

It is very clear from the figure 7.37 that the skid beam #1 is at the maximum length of 163.2m on the vessel deck. It cannot be extended further on the deck to increase the length of the skid beams, as the vessel structure is converging toward the bow. But the skid beams #2, #3 and #4 can be extended further to increase its length on deck.

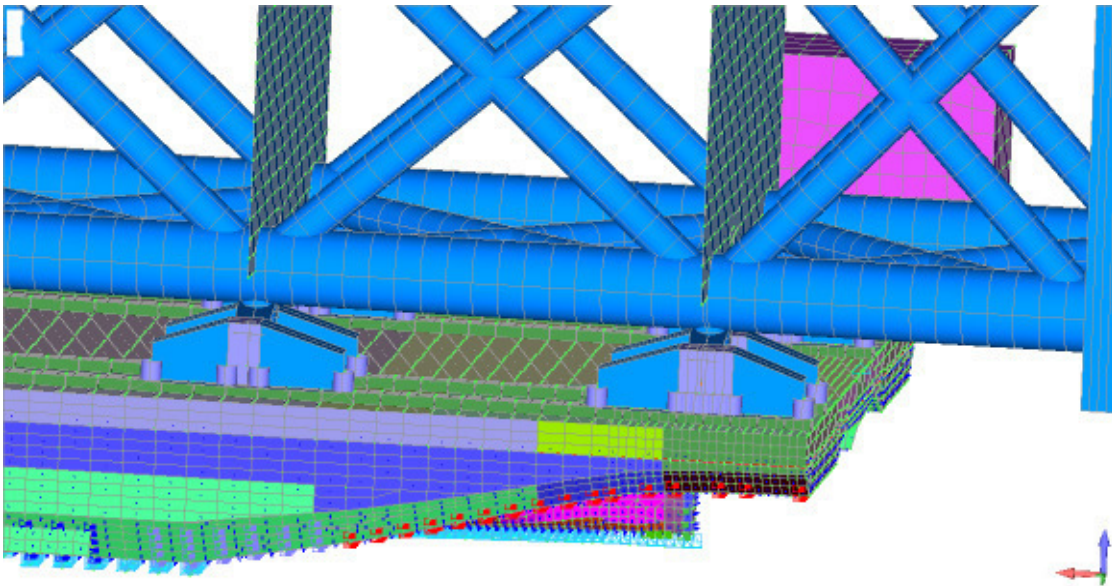


Fig 7.38 Final position of SPAR truss supports on skid beams

Fig. 7.38 shows the position of the truss supports on vessel deck. The SPAR is located almost on the edge of the stern section.

7.3.2.2 Connecting SPAR with skid beams

The connection between the SPAR and skid beams are made using rod elements as explained in chapter 7.3.1.1.

7.3.2.3 Load case specific boundary conditions

All the constraints in the vessel model as explained in the chapter 7.2.2 are also utilized for the analysis using SPAR model. In addition to the constraints on the vessel model following constraints are also created on the SPAR model for the analysis of the step entire SPAR on vessel by SPAR model loading.

1. Constraints in the SPAR supports under the heave plates

The supports under the heave are connected to the skid beam using rod elements. The bottom of the support is fixed in x and y axis to prevent further movement of the SPAR, as the loading will only be in the z-axis. It is also needed to match the constraints on the vessel stern. Fig 7.70 shows the constraints in the supports under the heave plates.

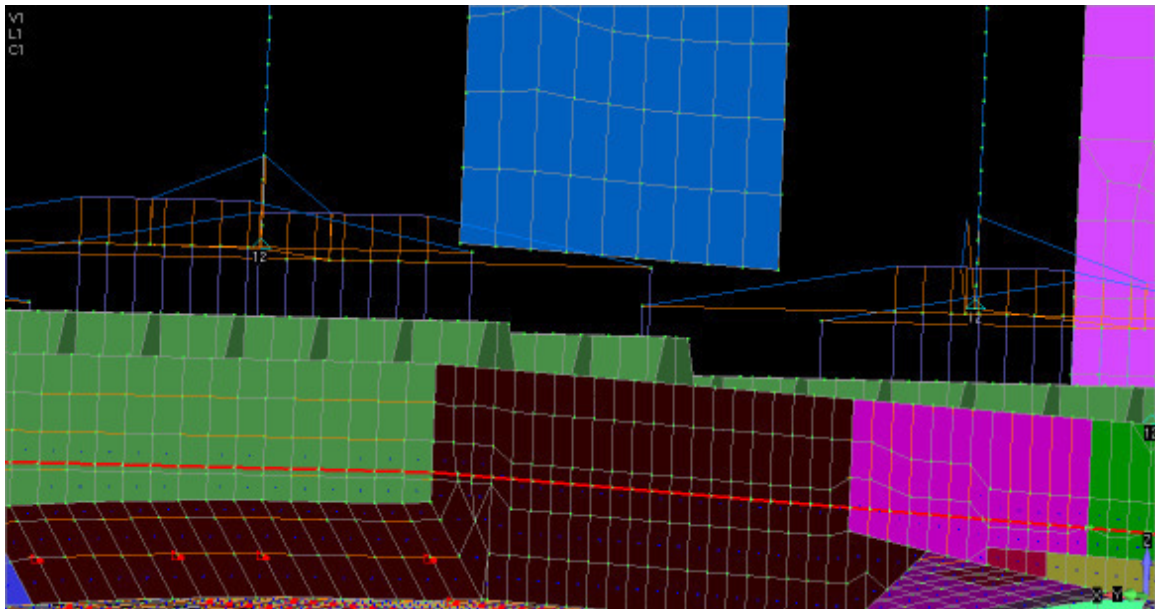


Fig 7.39 Constraints in supports under heave plates for the step entire SPAR on vessel

7.3.2.4 Draft and ballast condition

The draft of the vessel is same as the other loading cases, which is 10.95m.

The ballast masses will not be the same as the step hard tank on vessel, since the loading is done with the entire SPAR. This step of the analysis is done for final position of the SPAR on deck. This analysis step is for the final stowage position of SPAR when the whole weight of the SPAR (34855 tons) is acting on the vessel structure.

But the ballast condition used for the analysis is when the soft tank is still resting on the keyside on its temporary supports; this is due to the reason that the ballast calculation was readily available at the time of the thesis. The total mass of SPAR on the vessel will be 31038 Tons, and is taken into consideration for calculating the ballast masses required to maintain the vessel in the required draft of 10.95m.

The model will be translating a lot longitudinally from bow to stern due to the difference in the mass of SPAR used for ballast calculation and the whole SPAR. But this does not affect the analysis in anyway as the entire SPAR is on the vessel deck and is free to move in all degrees of freedom except the X and Y axial movements. So the total load of SPAR will be acting on the vessel model and the vessel structure will be loaded as needed.

Table 7.19 shows the mass of ballast water required in each tank for maintaining the vessel draft for step entire SPAR on vessel when the soft tank is still supported on the keystone.

Tank Description	Name	Capacity in kg	% filled	Mass in Kg
1 upper S	WBT1U.S	839760	0	0
1 upper P	WBT1U.P	851280	0	0
1 upper C	WBT1U.C	624050	6.2	38691.1
2 upper S	WBT2U.S	839340	100	839340
2 upper P	WBT2U.P	861430	100	861430
2 upper C	WBT2U.C	839210	0	0
3 upper S	WBT3U.S	861430	100	861430
3 upper P	WBT3U.P	850380	100	850380
3 upper C	WBT3U.C	861290	100	861290
4 upper S	WBT4U.S	850840	0	0
4 upper P	WBT4U.P		0	0
4 upper C	WBT4U.C	839210	0	0
5 upper S	WBT5U.S	862475	29.5	254430.1
5 upper P	WBT5U.P	849650	28.7	243850
5 upper C	WBT5U.C	861910	97.4	839210
6 upper S	WBT6U.S	585330	100	585330
6 upper P	WBT6U.P	607420	100	607420
6 upper C	WBT6U.C	585240	100	585240
1 middle S	WBT1M.S	2444290	0	0
1 middle P	WBT1M.P	2444290	0	0
1 middle C	WBT1M.C	846690	0	0
2 middle S	WBT2M.S	2467700	30.6	756070
2 middle P	WBT2M.P	2487600	17.4	432870
	FO3.C			
3 middle S	WBT3M.S		0	0
3 middle P	WBT3M.P	2467700	0	0
3 middle C	WBT3M.C		0	0
4 middle S	WBT4M.S	2467710	100	2467710
4 middle P	WBT4M.P	2487610	100	2487610
4 middle C	WBT4M.C	2321520	100	2321520
5 middle S	WBT5M.S	2487600	0	0
5 middle P	WBT5M.P	2467700	0	0
5 middle C	WBT5M.C	2332400	0	0
6 middle S	WBT6M.S	1711630	100	1711630
6 middle P	WBT6M.P	1732380	100	1732380
6 middle C	WBT6M.C	1588290	100	1588290
1 lower S	WBT1L.S	1214410	100	1214410
1 lower P	WBT1L.P	1214410	100	1214410
1 lower C	WBT1L.C	1116960	100	1116960
2 lower S	WBT2L.S	1302220	100	1302220

2 lower P	WBT2L.P	1307690	100	1307690
2 lower C	WBT2L.C	1325950	100	1325950
3 lower S	WBT3L.S	1309480	100	1309480
3 lower P	WBT3L.P	1304220	100	1304220
3 lower C	WBT3L.C	1327370	100	1327370
4 lower S	WBT4L.S	1303230	0	0
4 lower P	WBT4L.P	1310214	0	0
4 lower C	WBT4L.C	1325897	0	0
5 lower S	WBT5L.S	1309430	0	0
5 lower P	WBT5L.P	1309430	100	1309430
5 lower C	WBT5L.C	1328750	0	0
6 lower S	WBT6L.S	782700	0	0
6 lower P	WBT6L.P	788170	0	0
6 lower C	WBT6L.C	789920	0	0
water bal oflow	WBTOVERF.S			0
	FO1C.S			0
	FO2.S			0
	FO2.P			0
	DOA.P			0
	LO.P			0
	FWTFW.S			0
	FWTFWD.S			0
	FWTAFWD.P			0
	FWTAFW.S			0
fwd lower WB P	WBTFLL.P		0	0
fwd lower WB S	WBTFLL.S	1592033	0	0
fwd upper WB S	WBTFU.S		0	0
fwd upper WB P	WBTFU.P		0	0
aft WB P	WBTA.P		0	0
poop aft WB S	WBTPA.S		0	0
poop fwd WB S	WBTPF.S		0	0
engine RM TOP S	WBTERTOP.S		0	0
engine RM TOP P	WBTERTOP.P		0	0
aft ballast S	WBTAALWL.S		0	0
aft peak C	WBTAPEAK.S		0	0
lower peak C	WBTLOWPEAK.C		0	0
high peak C	WBTHIGHPEAK.C	2995970	0	0
WB overf fwd	WBTOVERFWD.C		0	0
aft poop lower WB P	WBTAAPL.P		0	0
aft poop upper WB P	WBTAAPU.P		0	0
1 outer wing P	WBT10.P	1291440	0	0
1 outer wing S	WBT10.S	1291470	0	0
2 outer wing P	WBT20.P	2708360	0	0
2 outer wing S	WBT20.S	2708360	0	0
3 outer wing P	WBT30.P	3168290	0	0
3 outer wing S	WBT30.S	3168290	80.4	2546810
4 outer wing P	WBT40.P	3262750	6.5	210730
4 outer wing S	WBT40.S	3262750	75	2447063

5 outer wing P	WBT50.P	3276980	75.2	2464040
5 outer wing S	WBT50.S	3276980	100	3276980
6 outer wing P	WBT60.P	2126910	0	0
6 outer wing S	WBT60.S	2126900	100	2126900
7 outer wing P	WBT70.P	2596050	0	0
7 outer wing S	WBT70.S	1859960	100	1859960
	STORES CREW			
	STORES ENGINE			
		Total Mass		48590744kg

Table 7.19 Ballast condition for the step entire SPAR on vessel

7.3.2.5 Analysis of the step entire SPAR on vessel

The analysis and summary of the results of the step entire SPAR on vessel with 4 skid beam, 3 skid beam and 2 skid beam load-out have been explained below.

Entire SPAR on vessel with 4 skid beams

Fig 7.40 show the FE model of the step entire SPAR on vessel with 4 skid beam. It has been modeled with the all the necessary steps and boundary conditions explained earlier in this chapter.

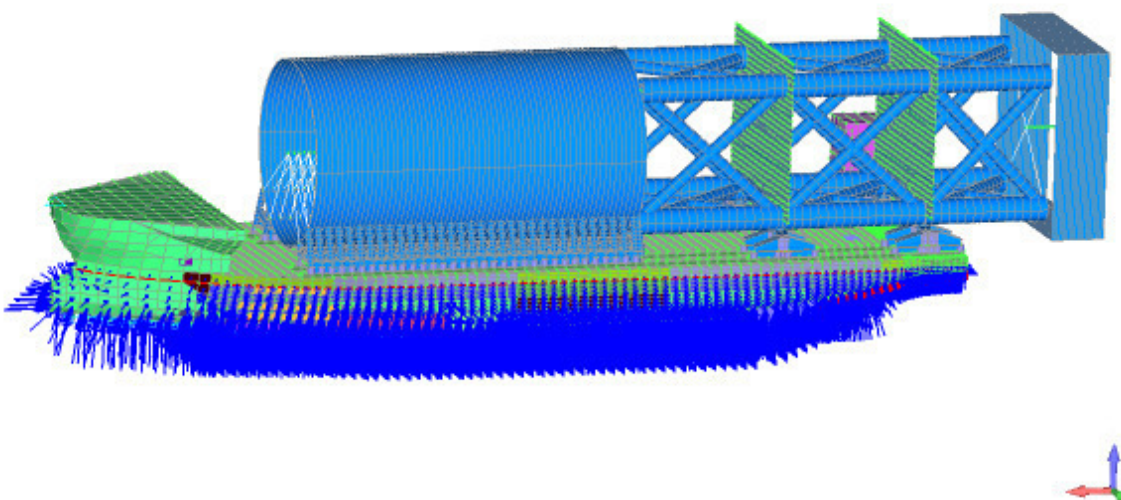


Fig 7.40 FE model of analysis step entire SPAR on vessel with 4 skid beams.

The above FE model of the step entire SPAR on vessel with 4 skid beams is analyzed by linear static analysis and the results of the analysis is given below.

The total translation in the model is 12.56m. The highest equivalent stress found was about 225.169Mpa.

The total translation of the model after the analysis can be seen in the fig 7.41. The high deformation is due to the reason that the ballast condition used is without the mass of the soft tank (i.e, when the soft tank is still supported on the keyside, which is already explained in the section draft and ballast condition).

So it is very clear from the model that the vessel is tilted towards the stern in Y-axis due to the additional weight of the soft tank.

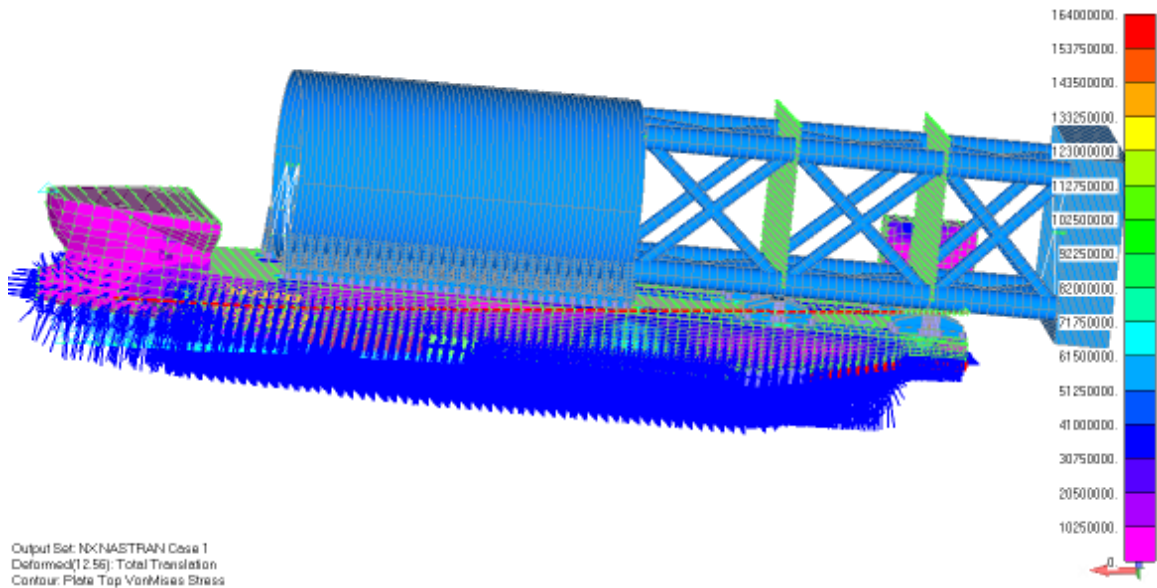


Fig 7.41 Total deformation of the analysis step entire spar on vessel with 4 skid beams

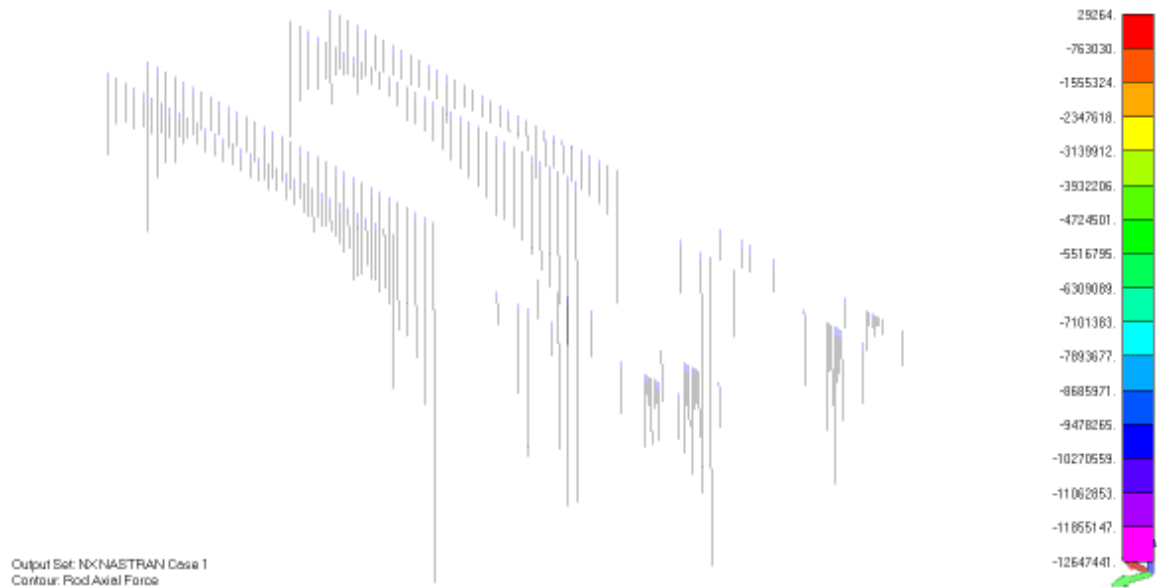


Fig 7.42 Axial forces on the rod elements in the analysis step entire spar on vessel with 4 skid beams

Fig. 7.42 shows the axial forces on the rod elements in the analysis step entire SPAR on vessel with 4 skid beams. It is clear from the figure that the vessel structure is loaded with the entire weight of the SPAR. There are no tensional forces on any of the rod elements, all the forces are compressive.

Entire SPAR on vessel with 3 skid beams

Fig 7.43 show the FE model of the step entire SPAR on vessel with 3 skid beam. It has been modeled with the all the necessary steps and boundary conditions explained earlier in this chapter.

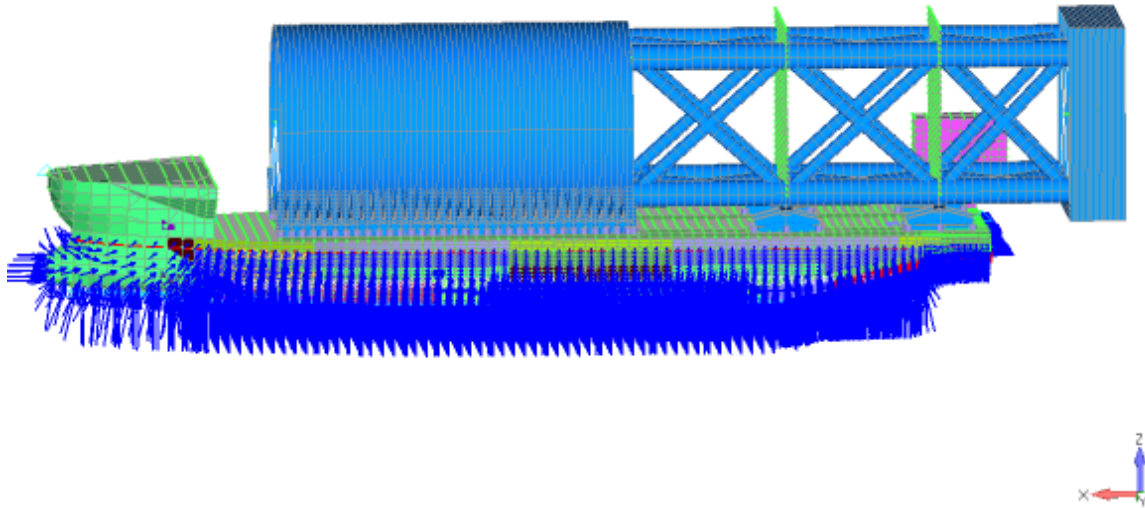
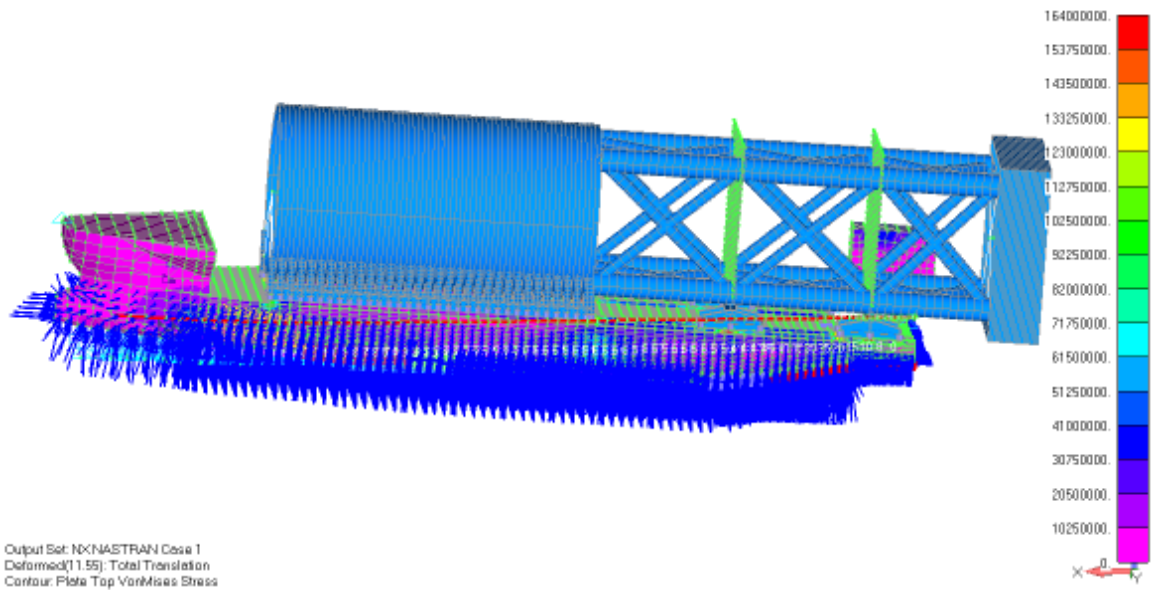


Fig 7.43 FE model of analysis step entire SPAR on vessel with 3 skid beams.

The above FE model of the step entire SPAR on vessel with 3 skid beams is analyzed by linear static analysis and the results of the analysis is given below.

The total translation in the model is 11.55m. The highest equivalent stress found was about 283.518MPa.

The total translation of the model after the analysis can be seen in the fig 7.44.



Output Set: NX/NASTRAN Case 1
Deformed(11.55): Total Translation
Contour: Plate Top VonMises Stress

Fig 7.44 Total deformation of the analysis step entire spar on vessel with 3 skid beams

Fig. 7.45 shows the axial forces on the rod elements in the analysis step entire SPAR on vessel with 3 skid beams. It is clear from the figure that the vessel structure is loaded with the entire weight of the SPAR. There are no tensional forces on any of the rod elements, all the forces are compressive.

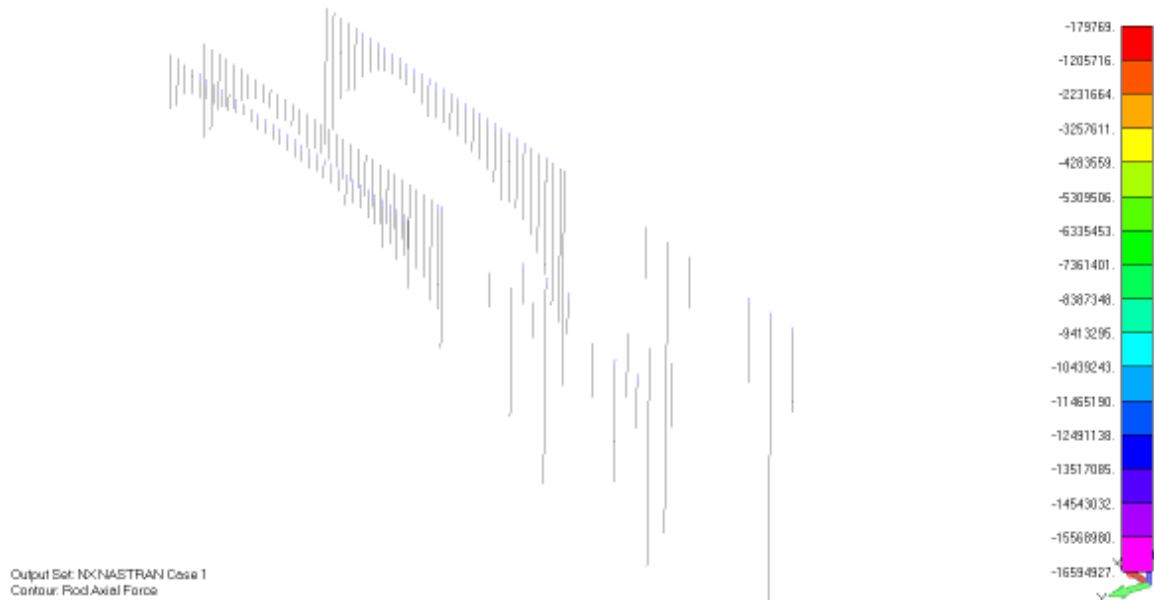


Fig 7.45 Axial forces on the rod elements in the analysis step entire spar on vessel with 3 skid beams

Entire SPAR on vessel with 2 skid beams

Fig 7.46 show the FE model of the step entire SPAR on vessel with 2 skid beam. It has been modeled with the all the necessary steps and boundary conditions explained earlier in this chapter.

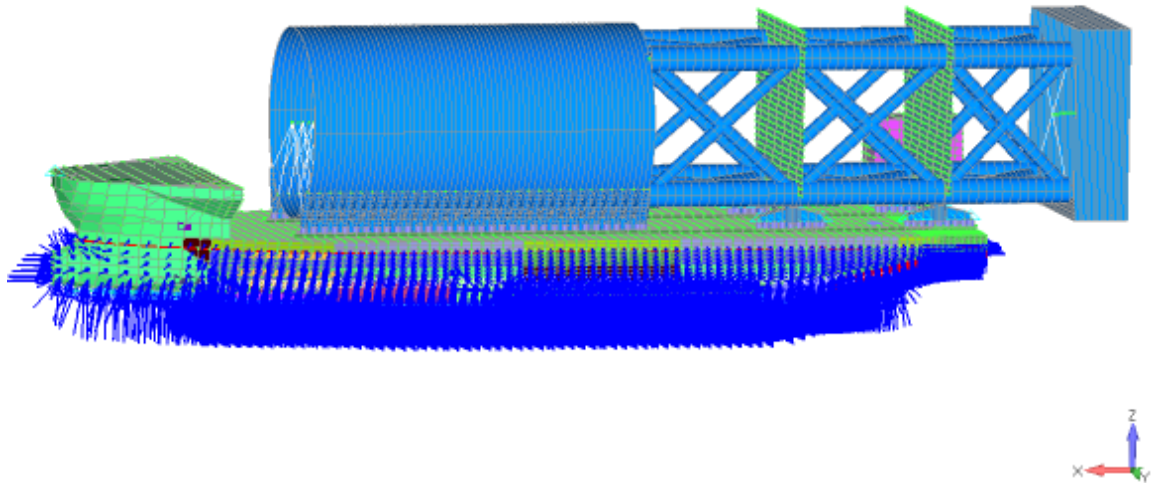


Fig 7.46 FE model of analysis step entire SPAR on vessel with 2 skid beams.

The above FE model of the step entire SPAR on vessel with 2 skid beams is analyzed by linear static analysis and the results of the analysis is given below.

The total translation in the model is 12.46m. The highest equivalent stress found was about 284.992MPa.

The total translation of the model after the analysis can be seen in the fig 7.47.

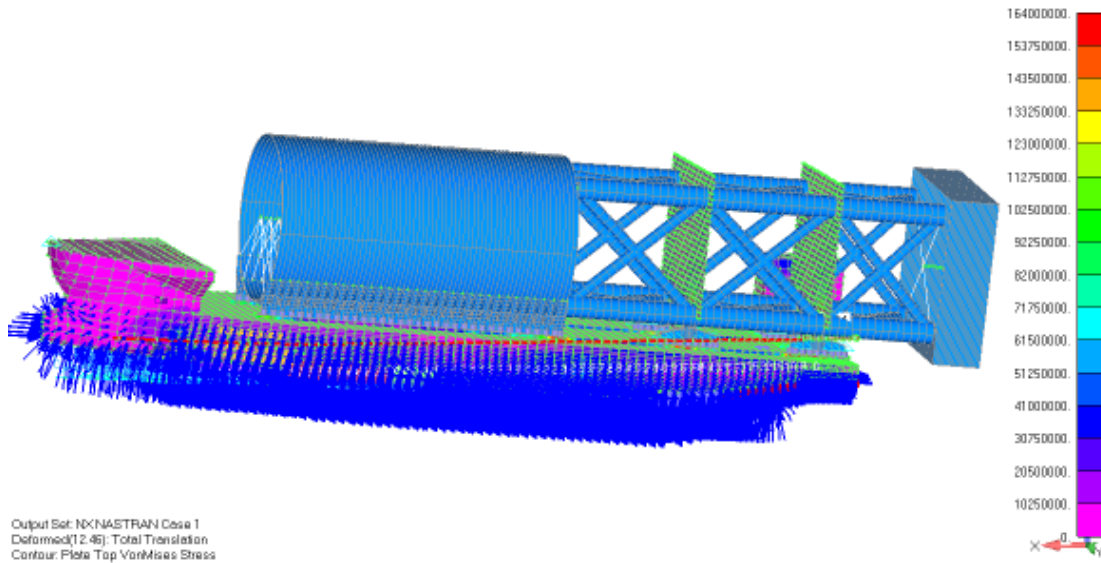


Fig 7.47 Total deformation of the analysis step entire spar on vessel with 2 skid beams

Fig. 7.48 shows the axial forces on the rod elements in the analysis step entire SPAR on vessel with 2 skid beams. It is clear from the figure that the vessel structure is loaded with the entire weight of the SPAR. There are no tensional forces on any of the rod elements, all the forces are compressive.

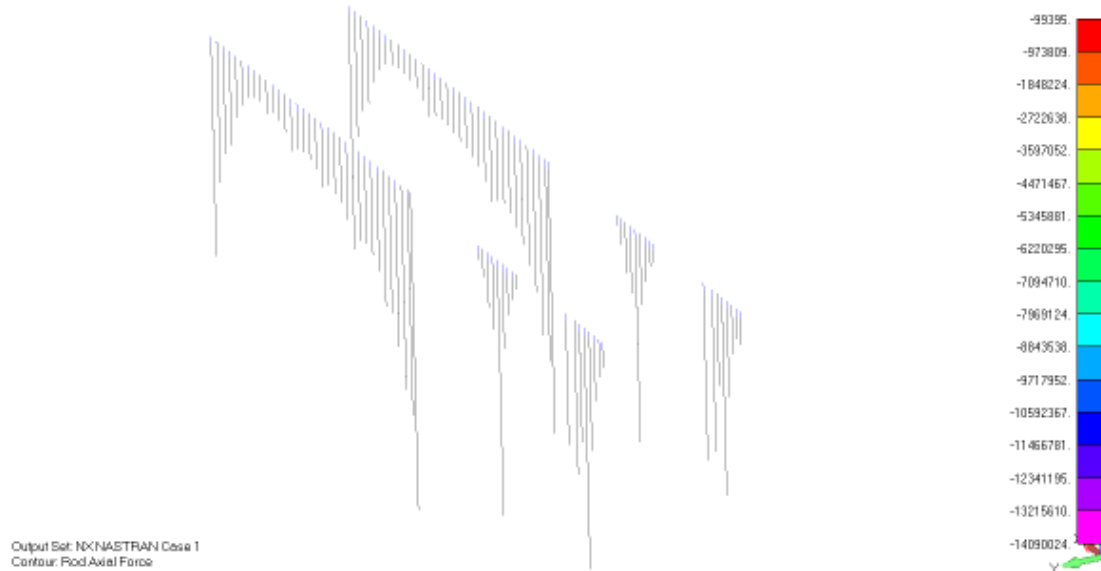


Fig 7.48 Axial forces on the rod elements in the analysis step entire spar on vessel with 2 skid beams

Summary of the results of entire SPAR on vessel by SPAR model loading cases

Entire SPAR on vessel by SPAR model loading	Total translation	Highest equivalent stress
4 skid beams	12.56m	225.169MPa
3 skid beams	11.55m	283.518MPa
2 skid beams	12.46m	284.992MPa

Table 7.20 Summary of results of entire SPAR on vessel by SPAR model loading cases

7.3.2.6 Location of stress components

Fig 7.49 shows the location where the highest equivalent stresses are found in vessel model during analysis of the entire SPAR on vessel by SPAR model loading case.

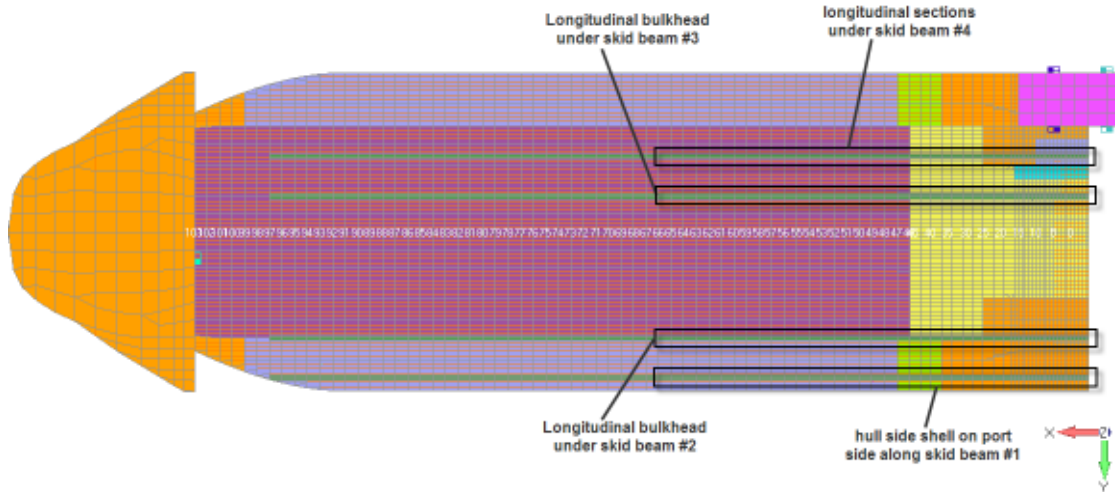


Fig. 7.49 Location of highest equivalent stresses in entire SPAR on vessel by SPAR model loading case analysis.

7.3.2.7 Stress components of analysis

The results of the representative stress components in the locations mentioned above, on all the 3 steps analyzed are presented below;

In this case of the analysis, the skid beams has a lot of triangular elements due to the supports under the truss. Since the support of the truss are not much easier to modify according to the nodes on the skid beam as like the hard tank, due to the usage of tapered beam elements. The skid beam nodes have to be modified to adapt to the nodes on the truss supports.

It is very much clear from the previous analysis cases, hard tank on vessel by uniform loading and hard tank on vessel by SPAR model loading, that the stresses due to the critical load of the hard tank does not impose any critical stresses on the skid beam elements if the elements are quadrilateral and follows the webframe locations of the vessel. If the quadrilateral mesh of the skid beams are modified the stresses are very high on the triangular elements. The stresses are highly localized to the triangular element, so the stresses on the triangular elements of the skid beam can be safely omitted from the results of this analysis steps.

Entire SPAR on vessel with 4 skid beams

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	τ_{xy}	$\sigma_{\text{Equivalent}}$
Hull side shell on port side along the skid beam # 1	10.070	6.153	-51.746	90.058
Longitudinal bulkhead under skid beam #2	-8.515	-36.169	-74.498	133.127
Longitudinal bulkhead under skid beam #3	-161.915	-41.453	99.126	225.169
longitudinal sections under skid beam # 4	-22.871	-24.677	78.155	137.449

Table 7.21 Highest equivalent stresses of the analysis step entire SPAR on vessel with 4 skid beams

The highest equivalent stress of 225.169Mpa is very high above the allowable stress of 164.3MPa; it is not possible to position the SPAR with 4 skid beam in this stowage position.

The highest stress is found on the longitudinal bulkhead, where there is a discontinuity in the structure for interconnecting two sections to form a ballast tank.

The stress plot figures of the locations listed above has been attached in the appendix no.11.

Entire SPAR on vessel with 3 skid beams

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	T_{xy}	$\sigma_{\text{Equivalent}}$
Hull side shell on port side along the skid beam # 1	20.072	2.268	-36.476	65.985
Longitudinal bulkhead under skid beam #2	-94.293	-14.261	-117.124	221.144
Longitudinal bulkhead under skid beam #3	-264.736	-7.410	63.781	283.518
longitudinal sections under skid beam # 4	-12.964	-17.759	54.902	96.416

Table 7.22 Highest equivalent stresses of the analysis step entire SPAR on vessel with 3 skid beams

The highest equivalent stress of 283.518Mpa is very high above the allowable stress of 164.3MPa; it is not possible to position the SPAR with 3 skid beam in this stowage position.

The stresses above the allowable stress are found in longitudinal bulkhead under skid beam #2 and longitudinal bulkhead under skid beam #3.

The highest stress is found on the longitudinal bulkhead, where there is a discontinuity in the structure for interconnecting two sections to form a ballast tank. The location of the critical stress is found in same location as like the step entire SPAR on vessel with 4 skid beams.

The stress plot figures of the locations listed above has been attached in the appendix no.12.

Entire SPAR on vessel with 2 skid beams

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	T_{xy}	$\sigma_{\text{Equivalent}}$
Hull side shell on port side along the skid beam # 1	-9.628	-4.402	-30.869	54.115
Longitudinal bulkhead under skid beam #2	-0.782	-0.940	-16.446	284.992
Longitudinal bulkhead under skid beam #3	-174.418	-44.231	95.080	227.561
longitudinal sections under skid beam # 4	1.771	-10.414	78.844	137.037

Table 7.23 Highest equivalent stresses of the analysis step entire SPAR on vessel with 2 skid beams

The highest equivalent stress of 284.992Mpa is very high above the allowable stress of 164.3MPa; it is not possible to position the SPAR with 2 skid beam in this final stowage position.

The stresses above the allowable stress are found in longitudinal bulkhead under skid beam #2 and longitudinal bulkhead under skid beam #3.

The highest stress is found on the longitudinal bulkhead, where there is a discontinuity in the structure for interconnecting two sections to form a ballast tank. The location of the critical stress is found in same location as like the step entire SPAR on vessel with 4 and 3 skid beams.

The stress plot figures of the locations listed above has been attached in the appendix no.13.

7.3.3 Final stowage position of SPAR on vessel

It turns out that the steps analyzed in the case of entire SPAR on vessel for determining the final stowage position of the SPAR on the vessel is not possible by any of the skid beam configurations. The critical or failure stress is found in at least 2 locations of the longitudinal bulkhead structure at the stern end of the vessel in all the 3 load-out steps. The location of the critical stress is same in all 3 steps, so it is very clear that the structure in that location is weak for taking heavy loads.

So the SPAR's final stowage location has to be changed, The SPAR has to be stowed in a position by avoiding the use of the particular stern section, it has to be moved more forward longitudinally. The position chosen for the analysis steps of the case entire SPAR on vessel is due to the maximum length of the skid beam #1, which is located almost on the edge of the port side of the vessel. Even though there is 17.5m length of deck area in front of the SPAR, it is not possible to load-out the SPAR up to that location by using 4 and 3 skid beams configuration due to the restriction in length of the skid beam #1.

But the 2 skid beams configuration does not make use of skid beam #1, so it is possible to use the 2 skid beam configuration to change the stowage position of the SPAR and move it forward longitudinally towards the bow. The step of entire SPAR on vessel with the modified final stowage position is analyzed in this section.

7.3.3.1 Position of the SPAR

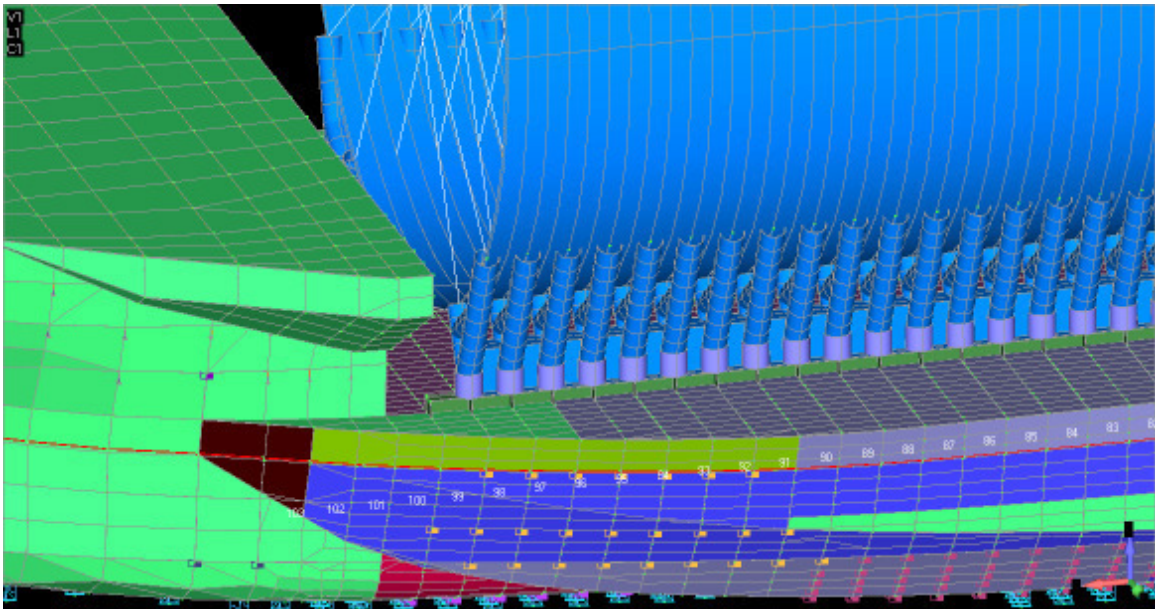


Fig 7.50 Final stowage position of SPAR hard tank supports on skid beams

The additional length of the skid beams are modeled until distance between the end of the deck and the skid beam is about 5m. SPAR model is moved on top of the vessel model such that the entire SPAR is above skid beams and the hard tank is at a distance of 5m from the end of the deck, the SPAR is aligned so that the SPAR supports center lines are in same plane with the skid beams center lines. Fig 7.50 shows the position of hard tank at the end of the skid beams near the bow section of the vessel model.

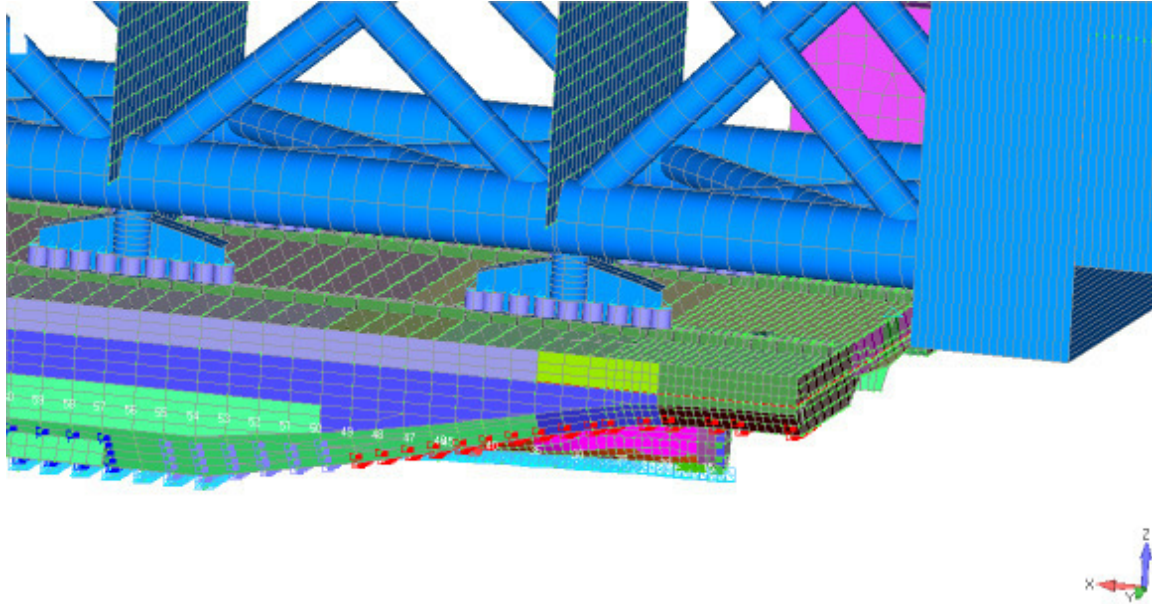


Fig 7.51 Final stowage position of SPAR truss supports on skid beams

Fig. 7.51 shows the position of the truss supports on vessel deck. The SPAR location has been moved about 12m from its previous position.

7.3.3.2 Connecting SPAR with skid beams

The connection between the SPAR and skid beams are made using rod elements as explained in chapter 7.3.1.1.

7.3.3.3 Load case specific boundary conditions

The boundary conditions are all same as the analysis case of entire SPAR on vessel explained in chapter 7.3.2.3.

7.3.3.4 Draft and ballast condition

The draft and ballast conditions are the same as explained in the chapter 7.3.2.4,

7.3.3.5 Analysis

The analysis and summary of the results of the final stowage position of the SPAR using 2 skid beams have been explained below.

Fig 7.52 show the FE model of the step final stowage position of the SPAR with 2 skid beams. It has been modeled with the all the necessary steps and boundary conditions explained above.

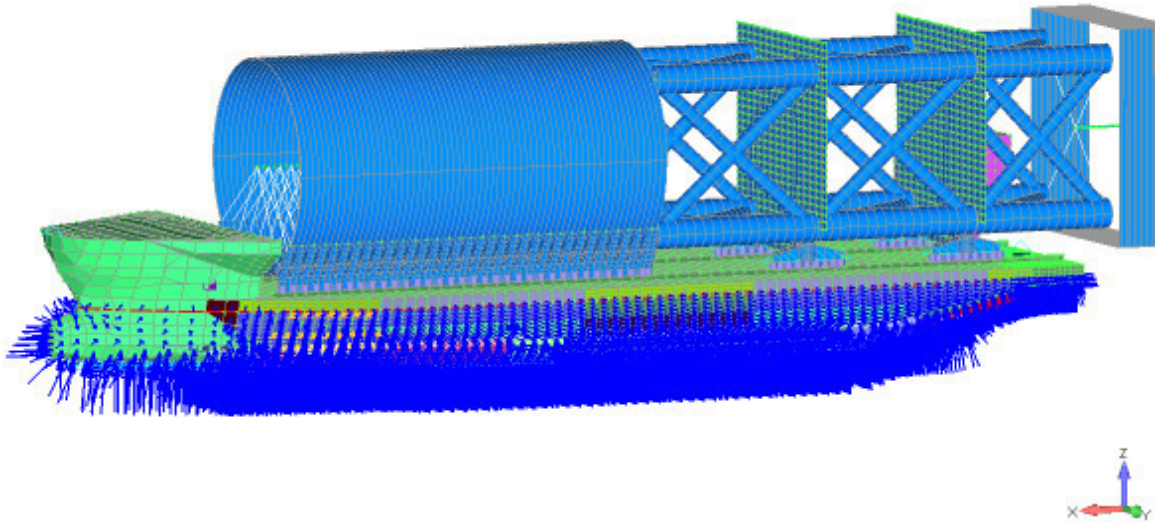


Fig 7.52 FE model of analysis step final stowage position of the SPAR with 2 skid beams.

The above FE model of the step final stowage position of the SPAR with 2 skid beams is analyzed by linear static analysis and the results of the analysis is given below.

The total translation in the model is 7.003m. The highest equivalent stress found was about 145.239Mpa.

The total translation of the model after the analysis can be seen in the fig 7.53. The high deformation is due to the reason that the ballast condition used is without the mass of the soft tank (i.e, when the soft tank is still supported on the keyside, which is already explained in the section draft and ballast condition). So it is very clear from the model that the vessel is tilted towards the stern in Y-axis due to the additional weight of the soft tank.

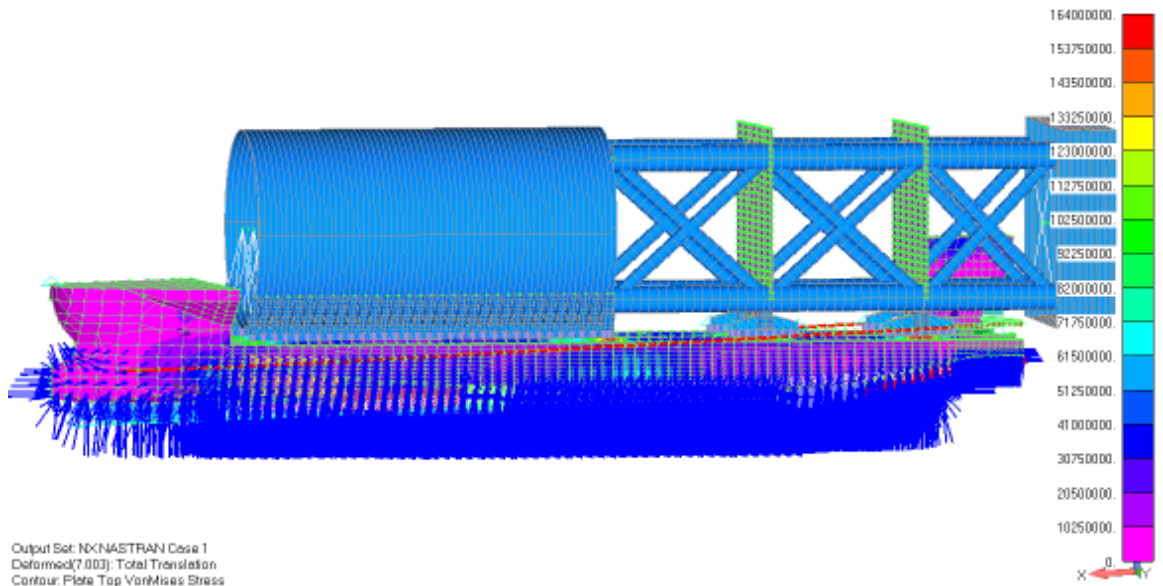


Fig 7.53 Total deformation of the analysis step final stowage position of SPAR with 2 skid beams

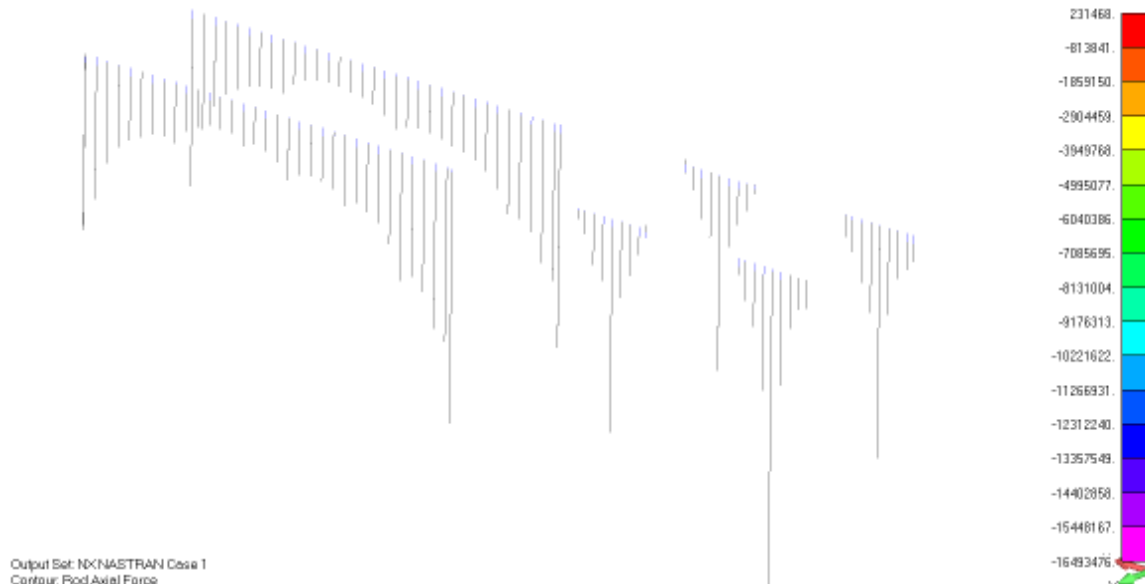


Fig 7.54 Axial forces on the rod elements in the analysis step final stowage position of SPAR with 2 skid beams

Fig. 7.54 shows the axial forces on the rod elements in the analysis step final stowage position of SPAR with 2 skid beams. It is clear from the figure that the vessel structure is loaded with the entire weight of the SPAR. There are no tensional forces on any of the rod elements, all the forces are compressive.

7.3.3.6 Location of stress components

The location of the stress components are the same as explained in the chapter 7.3.2.6.

7.3.3.7 Stress components of analysis.

The results of the triangular elements on the skid beams are omitted.

Locations / Stress MPa	σ_{Vertical}	$\sigma_{\text{Horizontal}}$	τ_{xy}	$\sigma_{\text{Equivalent}}$
Hull side shell on port side along the skid beam # 1	-7.634	-3.546	-38.834	67.587
Longitudinal bulkhead under skid beam #2	-68.499	-0.934	-74.084	145.239
Longitudinal bulkhead under skid beam #3	-35.314	-10.775	-69.754	124.819
longitudinal sections under skid beam # 4	-4.286	-59.916	-11.355	61.184

Table 7.24 Highest equivalent stresses of the analysis step final stowage position of SPAR with 2 skid beams

The highest equivalent stress of 145.239Mpa is well below the allowable stress of 164.3MPa; it is possible to position the SPAR with 2 skid beam in this final stowage position.

The highest stress is found on the longitudinal bulkhead under skid beam #2, where the supports under the lower heave plates are positioned. The high stress is right on the longitudinal bulkhead.

The stress plot figures of the locations listed above has been attached in the appendix no.14.

CHAPTER 8

CONCLUSION

Comparison and Load-out step selection

In the case of hard tank on vessel by uniform loading, it is very clear from the results that the load-out is possible with 3 skid beams and 2 skid beams. Since the load on skid beam all along the length of the beam is equal, there won't be much difference in the loading condition through out the load-out process. Load-out with 4 skid beams is also possible, the critical stress is found on the location where there is a triangular element and it is highly localized, so it can be safely neglected.

In the analysis case of load-out by standard skidding without hydraulics, only the 4 skid beam load-out method proved to have well balanced stress distribution within the allowable values. But the 3 and 2 skid beams load-out causes critical stresses in the longitudinal bulkhead section under skid beam #3 where there is a duck opening for cables and piping in the vessel. It is clear from the stress plots that the load distribution for the 3 and 2 skid beam load-out without hydraulics could be harmful for the vessel structure.

The overall stress components of the load-out step by uniform loading using 2 skid beams turns out to be the best method when taken into consideration the amount of work and also the economical point of view. There is not much difference between values of the stress components of the 2 skid beam uniform loading when comparing with the 3 and 4 skid beams load-out. The reason for the little difference in the stress values is mainly due to the load distribution on the supports on skid beam #1 and #4 based on its relation from the centre of gravity of the SPAR. In the 2 skid beams load-out the load distribution is more even between the 2 supports as the #1 and #4 skid beams and supports are not present.

Load-out by SPAR model loading, i.e, without hydraulics could be the most affordable method. But considering the enormous weight of the SPAR and the complexity of the weight distribution of the SPAR when supported using more than 2 skid beams, it should be better avoided.

Location of high stresses in the vessel

During the analysis of all the steps discussed in this thesis, the structure of the vessel on the stern end appears to be weak as the critical stresses are found here; the reason for this is mainly due to the water pressure under the vessel. The height of the vessel structure at the stern section gradually decreases from the starting of the vessel stern, the height is lowest at the transom of the vessel, due to the presence of propeller and rudder below the stern of vessel. This profiling in the stern section provides the ability for the vessel to dock along the stern to load-out cargoes.

Since the height of the vessel structure is decreased and also the water pressure acting under the stern section will be decreased, as the pressure will be more at the deepest part of the vessel. This leads to a condition where the support provided by the water pressure under the stern is not enough to compensate the loading on the deck of the stern. Thus leading to the high stresses in the stern section especially at the transom of the vessel.

There is an increase in the stress concentration in the vessel structure during the final stowage position of the SPAR, i.e., when the SPAR is positioned on the deck after removal of the hydraulic cylinders and skid beam. The stress activity is concentrated on the corners of the supports towards the soft tank side. This is mainly due to the stiffness of the SPAR, when the soft tank is allowed to hang over the stern. Even though during the analysis it does not create critical stresses in the vessel structure, the loading at the support corners could be prevented by providing additional supports at the end of hard tank and heave supports.

Recommended load-out process

The SPAR can be loaded out using 2 skid beams by utilizing hydraulics to level out the peak loads. The following points should be adhered to when the load-out is carried out.

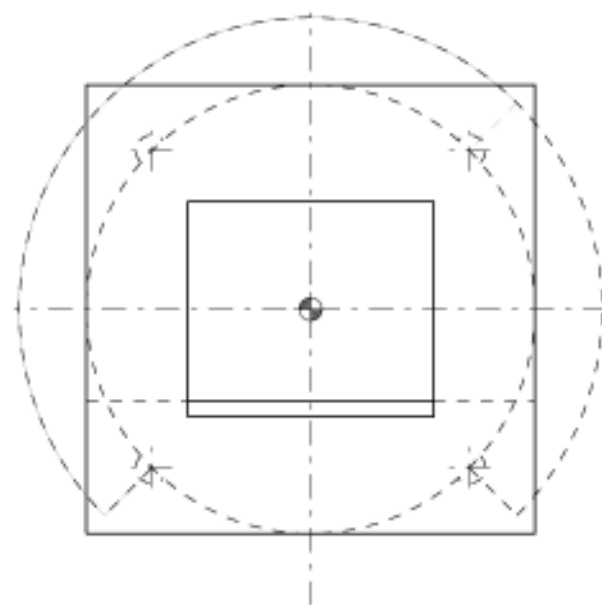
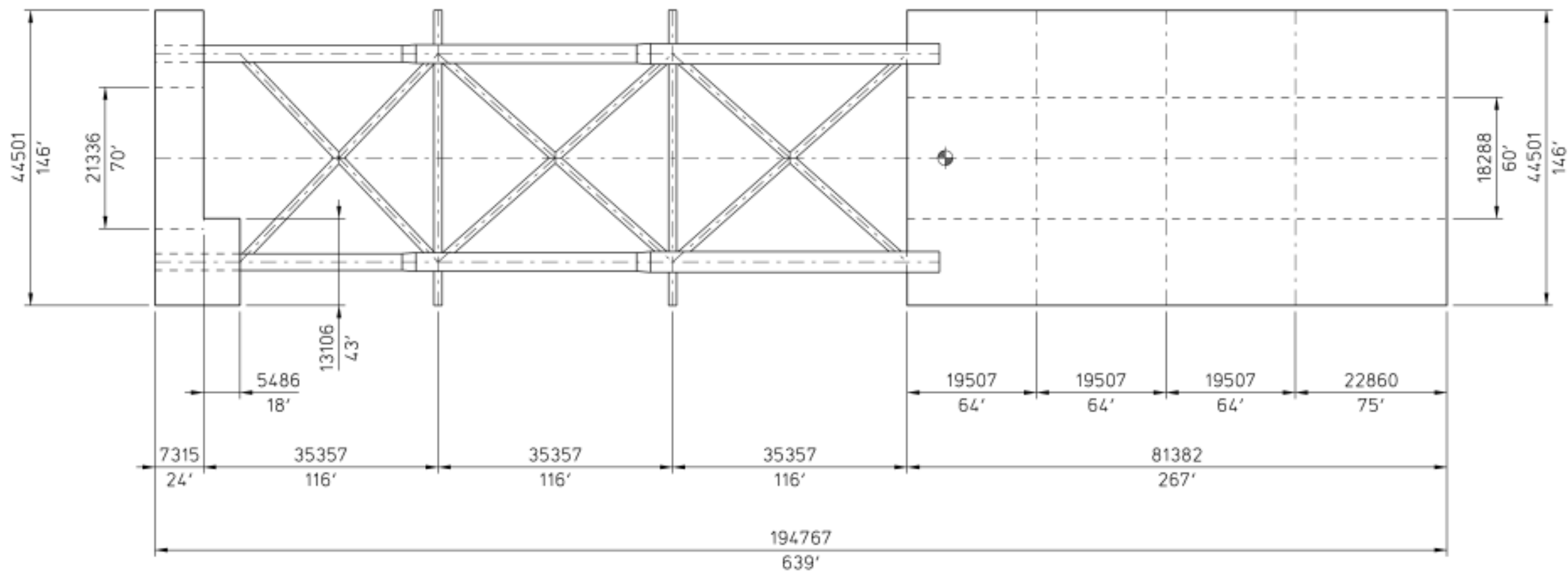
1. Number of skid beams used is 2; the supports should be appropriately designed to match the location of the skid beams.
2. The skid beams should be positioned on the longitudinal bulkheads.
3. The load-out should be carried by uniform loading by the use of hydraulic cylinders in between the SPAR and skid beams to distribute the load equally on the skid beam.
4. During the whole load-out operation the soft tank should be temporarily supported on the skid beams, until the SPAR reached the final stowage position as explained in chapter 7.3.3
5. When the SPAR reaches the final stowage position the hydraulic cylinders must be removed and the SPAR maybe rested on the skid beam or directly on the vessel deck for sea fastening and final voyage.

Further analysis

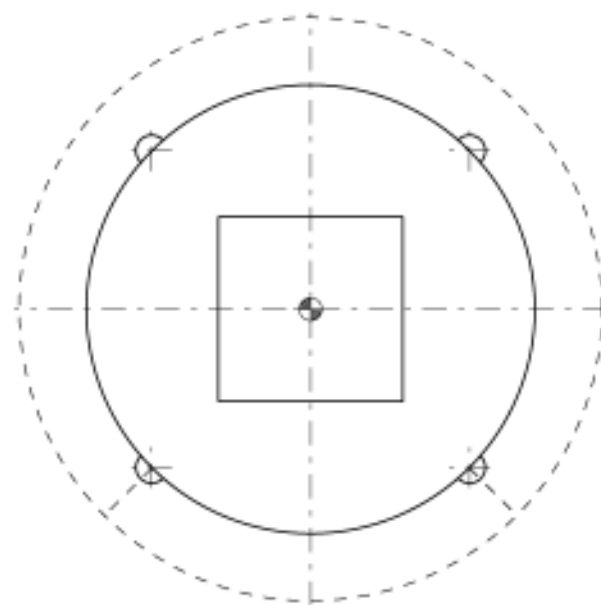
Since the whole analysis is carried out using the estimated design of the SPAR, when the design details of the actual SPAR is known the vessel should be analyzed again with the exact SPAR model to make sure the load-out of the real SPAR matches with the results of this thesis. If possible the 3D model of the SPAR with all the exact details of the inner design of the SPAR should be utilized to narrow down the assumptions used in this thesis concerning the SPAR model.

The vessel structure should be investigated for buckling; to make sure the plate sections of the vessel structure does not buckle during load-out of the SPAR. The vessel structure can be further investigated and analyzed for the stowage position of the SPAR with 1.7m offset from the centre of the vessel.

APPENDIX 1 SPAR DIMENSIONS



LEFT VIEW



RIGHT VIEW

REVISION DESCRIPTION	REVISION DATE
FIRST ISSUE	01/JUL/2008
STATUS	RESPONSIBLE PERSON
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CHECKED - TRANSPORT ENGINEER	HANSC
CHECKED - DISCIPLINE	JACKP
CHECKED - ORIGINATOR	
DEVELOPMENT	
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REVISION DATE: 09/07/2008

APPENDIX 2
Ballast plan of Blue Marlin

APPENDIX 3
Ballast calculation for the step hard tank on vessel

REFERENCE NUMBER : 0611266

MINIMUM DRAFT AT FPP TO AVOID SLAMMING > 8.16M OBTAINED 10.95M
AT A DRAFT OF 10.95M @ APP, THE PROPELLER IMMERSION = 145%

DRAFTS SUMMARY

DRAFT @ PERPENDICULARS	DRAFT @ MARKS
10.95M @ FPP 206.50f FROM APP	10.95M @ BOW 204.50f FROM APP
10.95M @ MID 103.25f FROM APP	10.95M @ MIDSHIPS 103.25f FROM APP
10.95M @ APP 0.00a FROM APP	10.95M @ RUDDER 3.50a FROM APP
	10.95M @ ACCOM.BULKHEAD 174.70f FROM APP
	10.95M @ CASING 10.50f FROM APP

HYDROSTATIC PROPERTIES

Trim: 0.00/206.50, Heel: Port 0.11 deg., VCG = 13.561

LCF	Displacement	Buoyancy-Ctr.	Weight/	Moment/
Draft	Weight (MT)	LCB	VCB	cm trim
10.949	113,840.16	99.088f	5.858	121.46
				91.356f
				1774.28
				321.84
				24.258

Distances in METERS.-----Specific Gravity = 1.025.-----Moment in m.-MT.
Trim is per 206.50m.
Draft is from Baseline. Free Surface included. GMT is from RA curve.
Caution: Standard GMT is 24.253

WEIGHT STATUS

Trim: 0.00/206.50, Heel: Port 0.11 deg.

Part	Weight (MT)	LCG	TCG	VCG	FSM
Total Fixed	54,224.22	69.479f	3.390p	21.404	
Total Tanks	59,620.82	126.017f	3.002s	6.428	40485.0
Total Weight	113,845.05	99.088f	0.042p	13.561	
Free Surface Adjustment				0.356	
Adjusted CG		99.088f	0.042p	13.917	

Distances in METERS.-----Moments in m.-MT.

DISPLACEMENT STATUS

Baseline draft: 10.948 @ 206.50f, 10.949 @ 0.00

Trim: 0.00/206.50, Heel: Port 0.11 deg.

Part	SpGr	Displ (MT)	LCB	TCB	VCB
HULL	1.025	113,840.16	99.088f	0.057p	5.858
PSCASING	1.025	0.00			
Total Displacement	1.025	113,840.16	99.088f	0.057p	5.858

Distances in METERS.-----

WEIGHT STATUS

Part-----	Weight (MT)	LCG	TCG	VCG
LIGHT SHIP+	27,935.69	103.855f	0.255s	9.956
STARBOARD CASING	615.41	0.600f	26.130s	27.040
STARBOARD CASING ADDITION	79.30	3.500f	26.130s	15.800
PORT CASING	0.24	3.150f	26.196p	26.600
PORT CASING ADDITION	0.08	3.150f	26.196p	15.800
CREW AND EFFECTS	5.70	186.600f	0.000	31.910
PROVISIONS	7.69	189.750f	0.000	24.000
STORES FORE	23.45	194.330f	0.000	23.110
STORES AFT	19.19	15.170f	0.000	9.980
SMALL TANK IN E/R (FORE)	52.22	184.720f	0.000	15.410
SMALL TANK IN E/R (AFT)	362.65	22.890f	0.000	6.150
Skid load Hard Tank	25,122.60	33.445f	8.322p	34.250
Total Fixed----->	54,224.22	69.479f	3.390p	21.404

Distances in METERS.-----

TANK STATUS

Trim: 0.00/206.50, Heel: Port 0.11 deg.

Part-----	Load	SpGr	Weight (MT)	LCG	TCG	VCG
SEA WATER	0.375	1.025	54,420.03	127.308f	3.236s	6.352
HEAVY FO	0.955	0.991	4,290.77	119.566f	0.537s	6.330
DIESEL OIL	0.980	0.850	308.37	13.696f	14.344p	9.871
LUBE OIL	0.980	0.900	33.69	18.585f	9.910p	6.444
FRESH WATER	1.000	1.000	567.96	118.466f	9.409s	12.569
WATER 1.001	0.000	1.001	0.00			
Total Tanks----->			59,620.82	126.017f	3.002s	6.428

Distances in METERS.-----

LOAD STATUS

Trim: 0.00/206.50 Heel: Port 0.11 deg.

Tank Description-----	Name-----	Contents-----	Load Wt MT	Load%	Sounding
1 UPPER C	WBT1U.C	SEA	624.05	100.0	15.710
1 UPPER P	WBT1U.P	SEA	851.28	100.0	15.710
1 UPPER S	WBT1U.S	SEA	839.76	100.0	15.710
2 UPPER C	WBT2U.C	SEA	839.21	100.0	15.710
2 UPPER P	WBT2U.P	SEA	861.43	100.0	15.710
2 UPPER S	WBT2U.S	SEA	839.34	100.0	15.710
3 UPPER C	WBT3U.C	SEA	0.00	0.0	0.000
3 UPPER P	WBT3U.P	SEA	850.38	100.0	15.710
3 UPPER S	WBT3U.S	SEA	861.43	100.0	15.710
4 UPPER C	WBT4U.C	SEA	0.00	0.0	0.000
4 UPPER P	WBT4U.P	SEA	0.00	0.0	0.000
4 UPPER S	WBT4U.S	SEA	212.71	25.0	0.574
5 UPPER C	WBT5U.C	SEA	0.00	0.0	0.000
5 UPPER P	WBT5U.P	SEA	0.00	0.0	0.000
5 UPPER S	WBT5U.S	SEA	0.00	0.0	0.000
6 UPPER C	WBT6U.C	SEA	0.00	0.0	0.000
6 UPPER P	WBT6U.P	SEA	0.00	0.0	0.000
6 UPPER S	WBT6U.S	SEA	0.00	0.0	0.000
1 MIDDLE C	WBT1M.C	SEA	846.69	100.0	22.750
1 MIDDLE P	WBT1M.P	SEA	2,444.29	100.0	22.750

LOAD STATUS, continued

Tank Description	Name	Contents	Load Wt MT	Load%	Sounding
1 MIDDLE S	WBT1M.S	SEA	2,444.29	100.0	22.750
1 OUTER WING P	WBT1O.P	SEA	1,291.44	100.0	26.510
1 OUTER WING S	WBT1O.S	SEA	1,291.47	100.0	26.510
2 MIDDLE P	WBT2M.P	SEA	2,487.60	100.0	22.750
2 MIDDLE S	WBT2M.S	SEA	2,467.70	100.0	22.750
2 OUTER WING P	WBT2O.P	SEA	2,708.36	100.0	26.510
2 OUTER WING S	WBT2O.S	SEA	2,708.36	100.0	26.510
3 MIDDLE C	WBT3M.C	SEA	0.00	0.0	0.000
3 MIDDLE P	WBT3M.P	SEA	0.00	0.0	0.000
3 MIDDLE S	WBT3M.S	SEA	0.00	0.0	0.000
3 OUTER WING P	WBT3O.P	SEA	0.00	0.0	0.000
3 OUTER WING S	WBT3O.S	SEA	3,168.29	100.0	26.510
4 MIDDLE C	WBT4M.C	SEA	2,321.52	100.0	22.750
4 MIDDLE P	WBT4M.P	SEA	2,487.61	100.0	22.750
4 MIDDLE S	WBT4M.S	SEA	1,963.33	79.6	5.524
4 OUTER WING P	WBT4O.P	SEA	0.00	0.0	0.000
4 OUTER WING S	WBT4O.S	SEA	3,262.75	100.0	26.510
5 MIDDLE C	WBT5M.C	SEA	0.00	0.0	0.000
5 MIDDLE P	WBT5M.P	SEA	0.00	0.0	0.000
5 MIDDLE S	WBT5M.S	SEA	0.00	0.0	0.000
5 OUTER WING P	WBT5O.P	SEA	0.00	0.0	0.000
5 OUTER WING S	WBT5O.S	SEA	114.69	3.5	0.539
6 MIDDLE C	WBT6M.C	SEA	0.00	0.0	0.000
6 MIDDLE P	WBT6M.P	SEA	0.00	0.0	0.000
6 MIDDLE S	WBT6M.S	SEA	0.00	0.0	0.000
6 OUTER WING P	WBT6O.P	SEA	0.00	0.0	0.000
6 OUTER WING S	WBT6O.S	SEA	0.00	0.0	0.000
7 OUTER WING P	WBT7O.P	SEA	0.00	0.0	0.000
7 OUTER WING S	WBT7O.S	SEA	0.00	0.0	0.000
1 LOWER C	WBT1L.C	SEA	1,116.96	100.0	26.510
1 LOWER P	WBT1L.P	SEA	1,214.41	100.0	26.510
1 LOWER S	WBT1L.S	SEA	1,214.41	100.0	26.510
2 LOWER C	WBT2L.C	SEA	1,325.95	100.0	26.510
2 LOWER P	WBT2L.P	SEA	1,307.69	100.0	26.510
2 LOWER S	WBT2L.S	SEA	1,302.22	100.0	26.510
3 LOWER C	WBT3L.C	SEA	1,327.37	100.0	26.510
3 LOWER P	WBT3L.P	SEA	1,304.22	100.0	26.510
3 LOWER S	WBT3L.S	SEA	1,309.48	100.0	26.510
4 LOWER C	WBT4L.C	SEA	1,005.03	75.8	2.759
4 LOWER P	WBT4L.P	SEA	1,163.47	88.8	3.248
4 LOWER S	WBT4L.S	SEA	1,178.12	90.4	3.321
5 LOWER C	WBT5L.C	SEA	0.00	0.0	0.000
5 LOWER P	WBT5L.P	SEA	0.00	0.0	0.000
5 LOWER S	WBT5L.S	SEA	0.00	0.0	0.000
6 LOWER C	WBT6L.C	SEA	0.00	0.0	0.000
6 LOWER P	WBT6L.P	SEA	0.00	0.0	0.000
6 LOWER S	WBT6L.S	SEA	0.00	0.0	0.000
FWD LOWER WB P	WBTFL.P	SEA	0.00	0.0	0.000
FWD LOWER WB S	WBTFL.S	SEA	861.29	54.1	8.439
FWD UPPER WB P	WBTFU.P	SEA	0.00	0.0	0.000

LOAD STATUS, continued

Tank Description	Name	Contents	Load Wt	MT	Load%	Sounding
FWD UPPER WB S	WBTFU.S	SEA	0.00	0.0	0.000	0.000
AFT WB P	WBTA.P	SEA	0.00	0.0	0.000	0.000
POOP AFT WB S	WBTPA.S	SEA	0.00	0.0	0.000	0.000
POOP FWD WB S	WBTPF.S	SEA	0.00	0.0	0.000	0.000
AFT L BALLAST S	WBALWL.S	SEA	0.00	0.0	0.000	0.000
AFT PEAK C	WBAPC.C	SEA	0.00	0.0	0.000	0.000
AFT POOP LOWER WB P	WBAPL.P	SEA	0.00	0.0	0.000	0.000
AFT POOP UPPER WB P	WBAPU.P	SEA	0.00	0.0	0.000	0.000
ENGINE RM TOP P	WBERTOP.P	SEA	0.00	0.0	0.000	0.000
ENGINE RM TOP S	WBERTOP.S	SEA	0.00	0.0	0.000	0.000
LOWER PEAK C	WBLOWPEAK.C	SEA	0.00	0.0	0.000	0.000
HIGH PEAK C	WBHIGHPEAK.C	SEA	0.00	0.0	0.000	0.000
WB OVRFL FWD	WBTOVERFWD.C	SEA	0.00	0.0	0.000	0.000
WATER BAL OFLOW	WBTOVERF.S	SEA	0.00	0.0	0.000	0.000
Total as loaded				54,418.60		
Soundings in m.						

LONGITUDINAL STRENGTH LIMIT APPLIED: SHELTERED CONDITION
SHELTERED CRITERION LONGITUDINAL STRENGTH SUMMARY at Heel = Port 0.11 deg.

Largest Shear: -8,041.2 MT at 124.700f
Largest Bending Moment: 318,494 MT-m. at 69.100f (Hogging)

LONGITUDINAL STRENGTH at Heel = Port 0.11 deg.

FRAME	LOCATION	SHEAR FORCE			LIMIT	BENDING MOMENT			LIMIT
		MT	%	MT		MT-m.	%	MT-m.	
Fr.-5	3.500a	181.65	3	6,538.00	621.1	1	119,623.0		
Fr.17	11.900f	4,783.89	81	5,888.00	39,799.8	45	89,073.8		
Fr.29	20.300f	6,548.95	49	13,275.00	88,068.3	46	191,178.6		
Fr.47	34.700f	7,211.03	39	18,703.00	191,501.1	58	329,713.2		
Fr.53	49.700f	4,195.02	29	14,682.00	278,242.8	47	597,778.0		
Fr.60	67.199f	378.64	3	15,015.00	318,162.2	48	664,318.4		
Fr.63	74.700f	-2,702.82	19	-14,124.00	311,780.5	45	686,598.2		
Fr.73	99.700f	-3,068.39	22	-14,124.00	240,033.8	38	635,562.0		
Fr.83	124.700f	-8,041.25	53	-15,272.00	100,923.0	16	635,669.8		
Fr.93	149.700f	-1,985.97	13	-14,869.00	-22,806.0	4	-533,195.0		
Fr.103	174.700f	2,148.14	39	5,491.00	-12,794.3	5	-237,181.0		
Fr.131	194.300f	522.35	12	4,421.00	6,218.8	9	66,269.0		

SHELTERED CRITERION SUMMARY

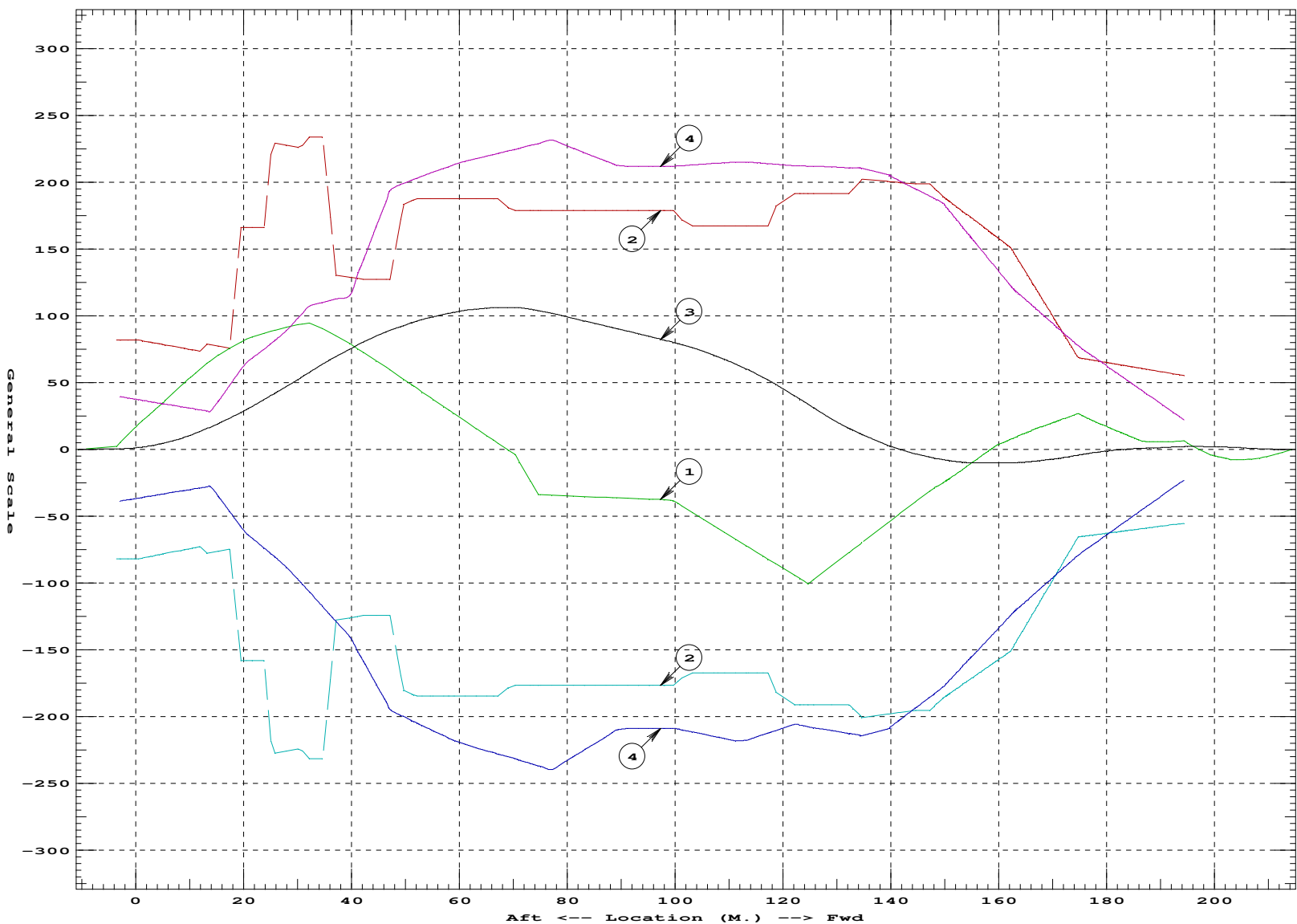
Largest Shear: 99.9% at 17.500f
Largest Bending Moment: 65.1% at 39.700f (Hogging)

SHELTERED criterion LONGITUDINAL STRENGTH at 0.11 degrees PORT HEEL

07/15/08 11:44:44
GHS 10.50

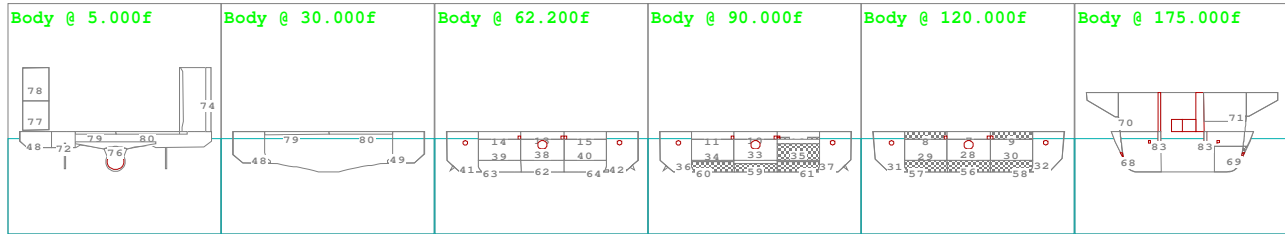
Dockwise Shipping B.V.
BLUE MARLIN
REFERENCE 0611266, STEP 3

Page 21
L003

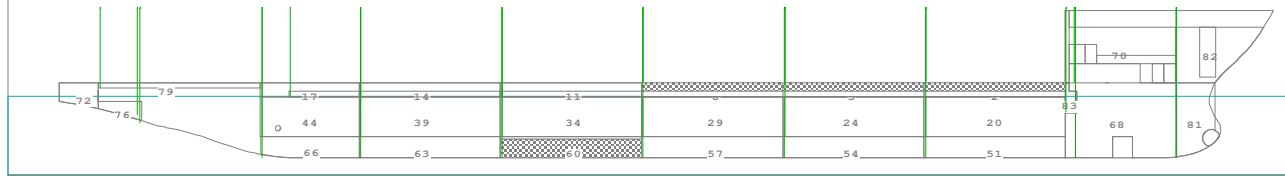


- | | |
|----------------------|-----------------------------|
| ① Shear 1=80 MT | ③ Bending Mom. 1=3000 MT-M. |
| ② Shear Lim. 1=80 MT | ④ Bending Lim. 1=3000 MT-M. |

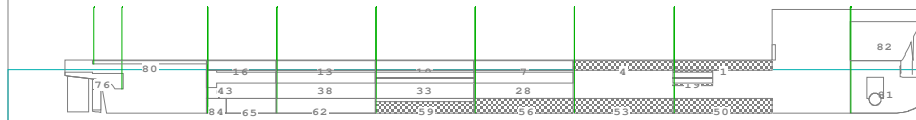
CG - Draft: 10.948 @ 206.500f, 10.949 @ 0.000 Heel: port 0.11 deg.



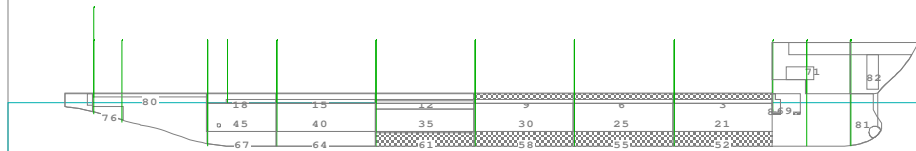
Profile View @ 7.500p



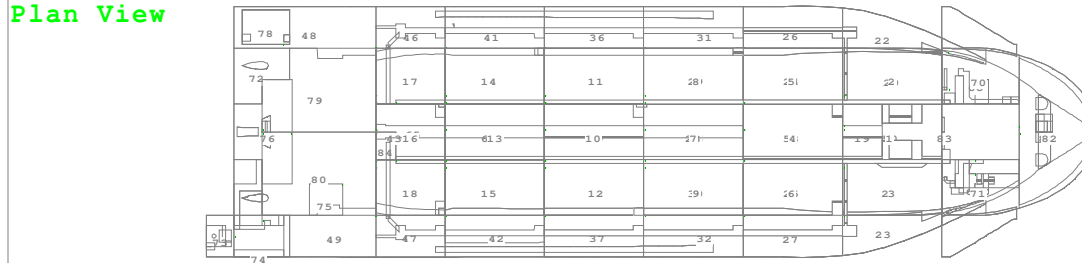
Profile View @ 0.000



Profile View @ 7.500s



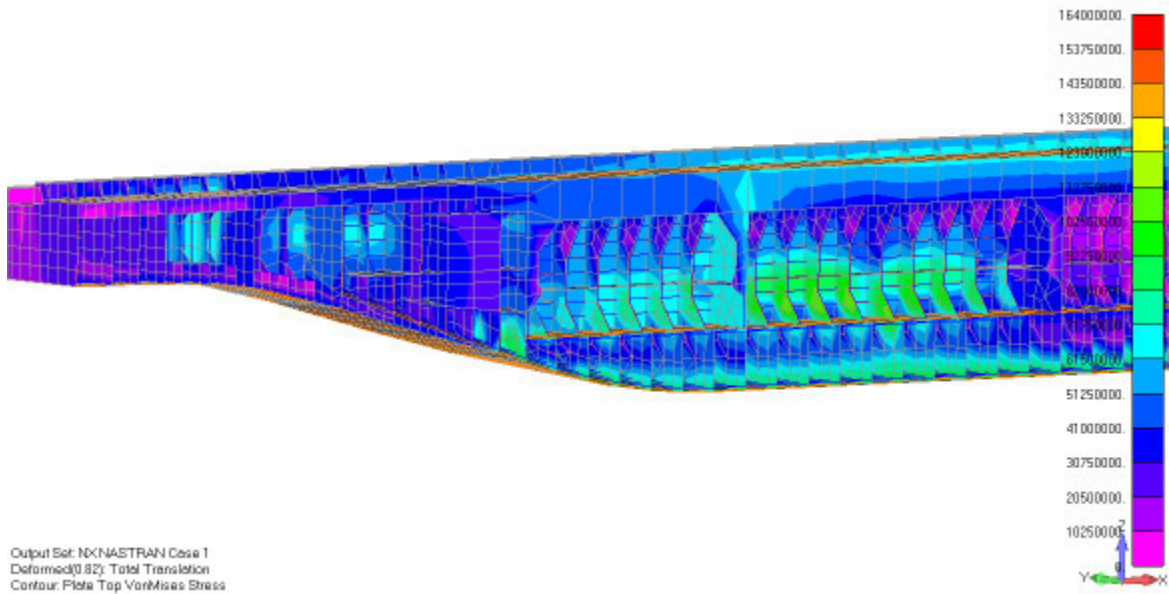
Plan View



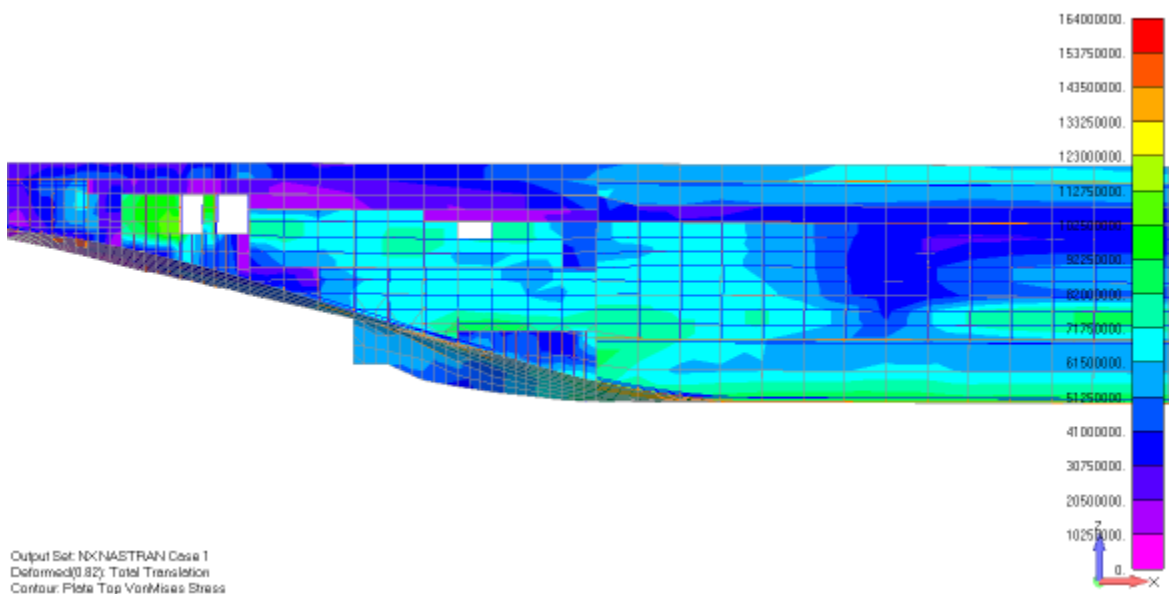
Tanks

1	WBT1U.C.....100%	17	WBT6U.P.....0%	34	WBT4M.P.....100%	51	WBT1L.P.....100%	68	WBTFLL.P.....0%
2	WBT1U.P.....100%	18	WBT6U.S.....0%	35	WBT4M.S.....80%	52	WBT1L.S.....100%	69	WBTFLL.S.....54%
3	WBT1U.S.....100%	19	WBT1M.C.....100%	36	WBT4O.P.....0%	53	WBT2L.C.....100%	70	WBTFU.P.....0%
4	WBT2U.C.....100%	20	WBT1M.P.....100%	37	WBT4O.S.....100%	54	WBT2L.P.....100%	71	WBTFU.S.....0%
5	WBT2U.P.....100%	21	WBT1M.S.....100%	38	WBT5M.C.....0%	55	WBT2L.S.....100%	72	WBTA.P.....0%
6	WBT2U.S.....100%	22	WBT1O.P.....100%	39	WBT5M.P.....0%	56	WBT3L.C.....100%	73	WBTPA.S.....0%
7	WBT3U.C.....0%	23	WBT1O.S.....100%	40	WBT5M.S.....0%	57	WBT3L.P.....100%	74	WBTFP.S.....0%
8	WBT3U.P.....100%	24	WBT2M.P.....100%	41	WBT5O.P.....0%	58	WBT3L.S.....100%	75	WBTAWL.S.....0%
9	WBT3U.S.....100%	25	WBT2M.S.....100%	42	WBT5O.S.....3%	59	WBT4L.C.....76%	76	WBTA.P.C.....0%
10	WBT4U.C.....0%	26	WBT2O.P.....100%	43	WBT6M.C.....0%	60	WBT4L.P.....89%	77	WBTA.P.L.....0%
11	WBT4U.P.....0%	27	WBT2O.S.....100%	44	WBT6M.P.....0%	61	WBT4L.S.....90%	78	WBTA.P.U.P.....0%
12	WBT4U.S.....25%	28	WBT3M.C.....0%	45	WBT6M.S.....0%	62	WBT5L.C.....0%	79	WBTA.P.T.P.....0%
13	WBT5U.C.....0%	29	WBT3M.P.....0%	46	WBT6O.P.....0%	63	WBT5L.P.....0%	80	WBTA.P.T.S.....0%
14	WBT5U.P.....0%	30	WBT3M.S.....0%	47	WBT6O.S.....0%	64	WBT5L.S.....0%	81	WBTA.P.L.W.L.S.....0%
15	WBT5U.S.....0%	31	WBT3O.P.....0%	48	WBT7O.P.....0%	65	WBT6L.C.....0%	82	WBTHIGHPEAK.C.....0%
16	WBT6U.C.....0%	32	WBT3O.S.....100%	49	WBT7O.S.....0%	66	WBT6L.P.....0%	83	WBTOVERFWD.C.....0%
		33	WBT4M.C.....100%	50	WBT1L.C.....100%	67	WBT6L.S.....0%	84	WBTOVERF.S.....0%

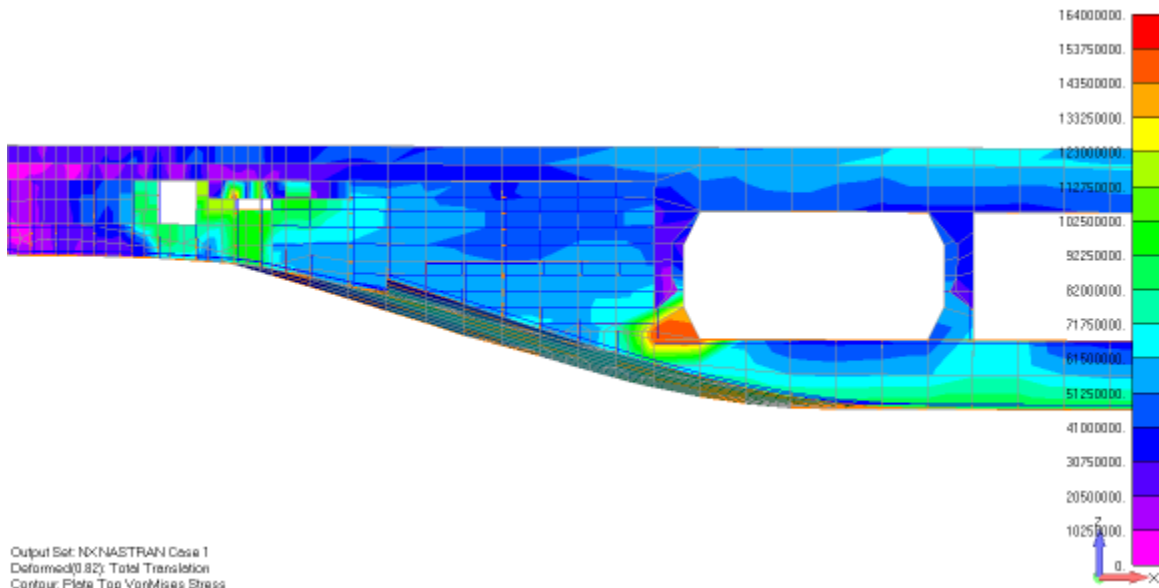
APPENDIX 4
Stress plots of the analysis step hard tank on vessel
with 4 skid beams by uniform loading



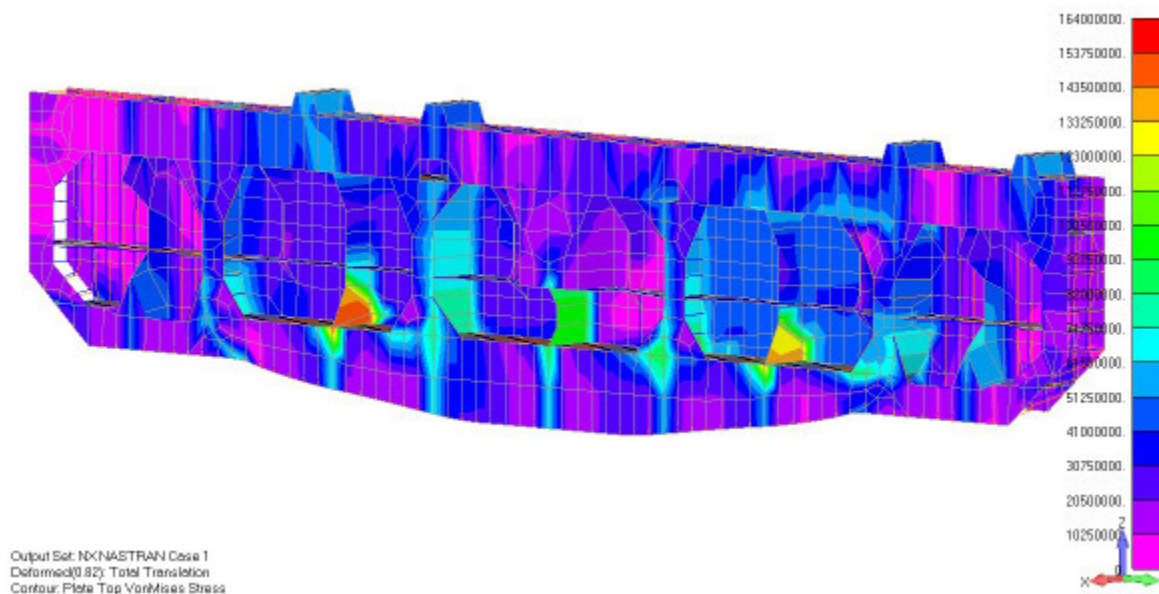
1. Stress components on longitudinal bulkhead under skid beam #2



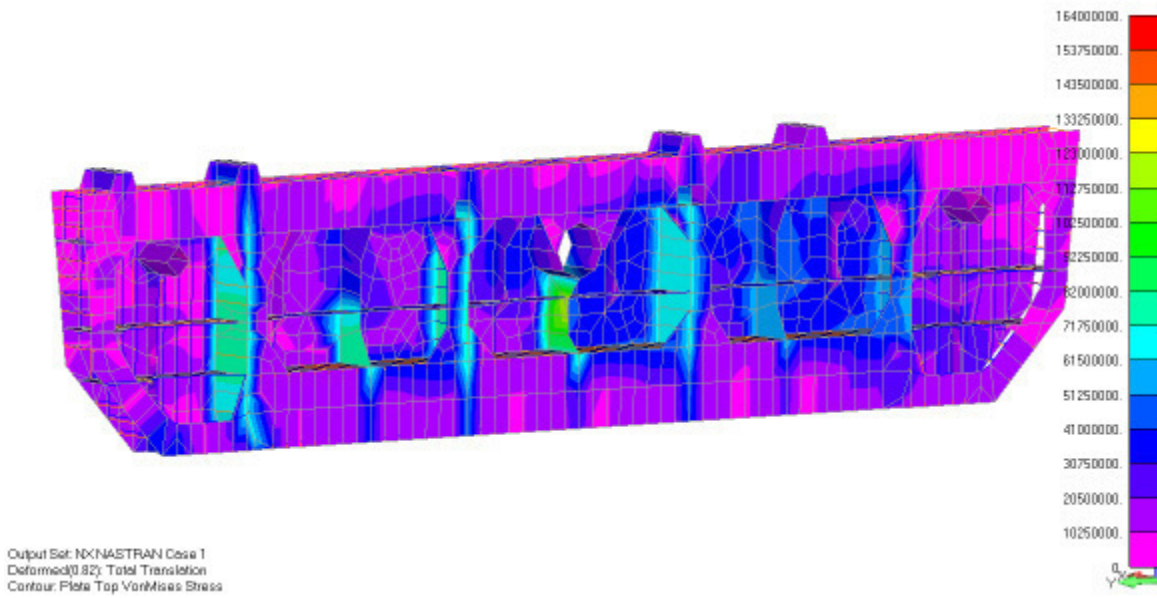
2. Stress components on longitudinal bulkhead under skid beam #3



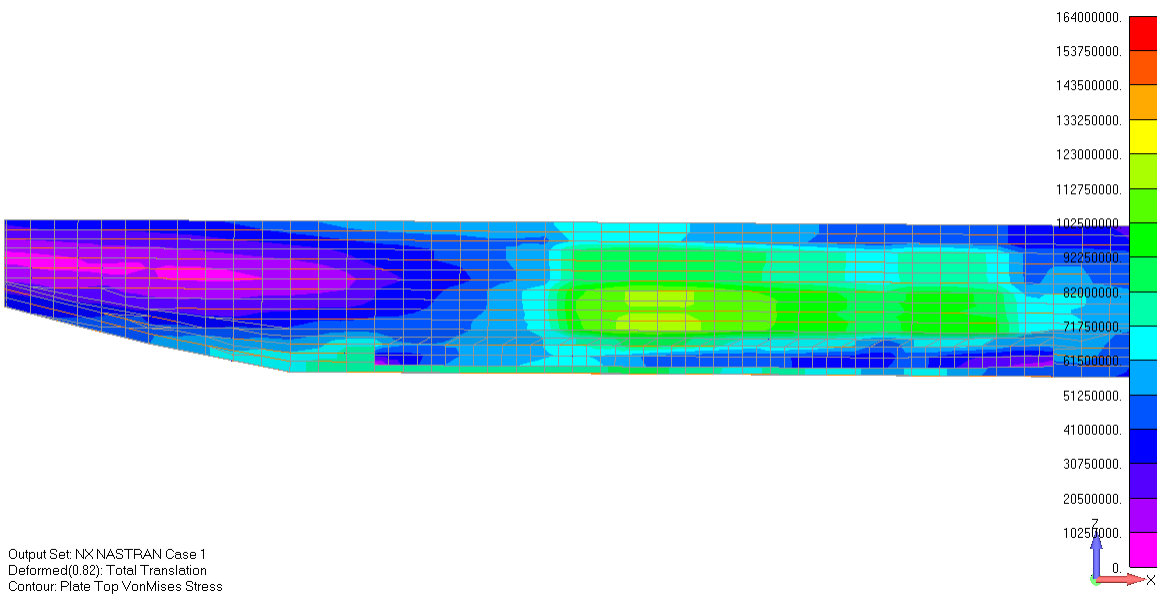
3. Stress components on stern section under skid beam#4



4. Stress components on transverse bulkhead #1 on webframe #46

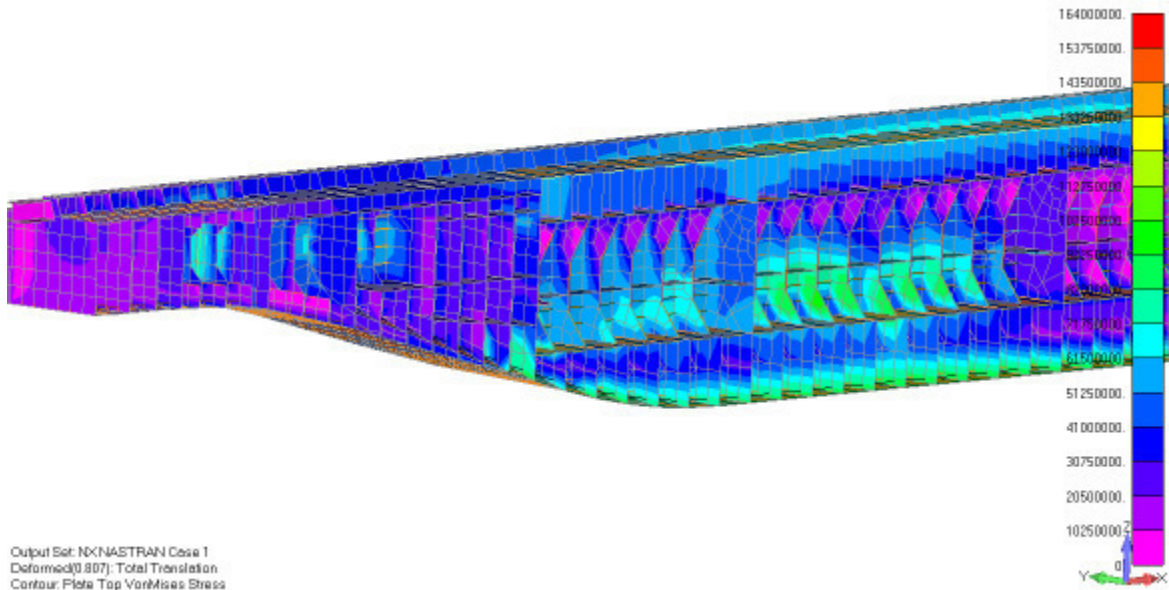


5. Stress components on transverse bulkhead #5 on webframe #83

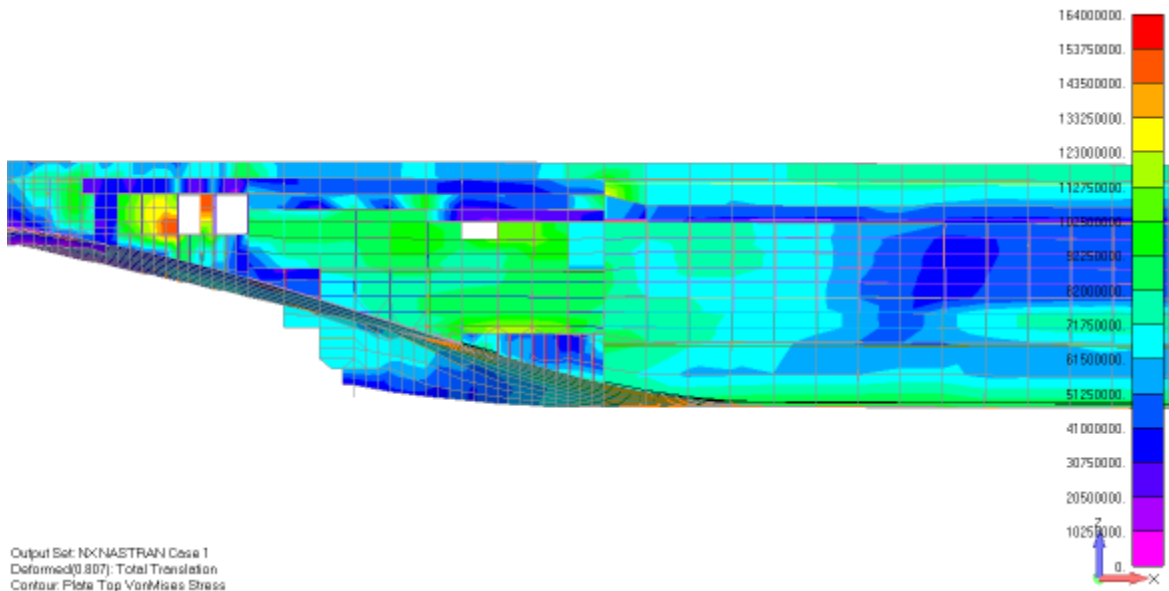


6. Stress components on hull side shell on starboard side

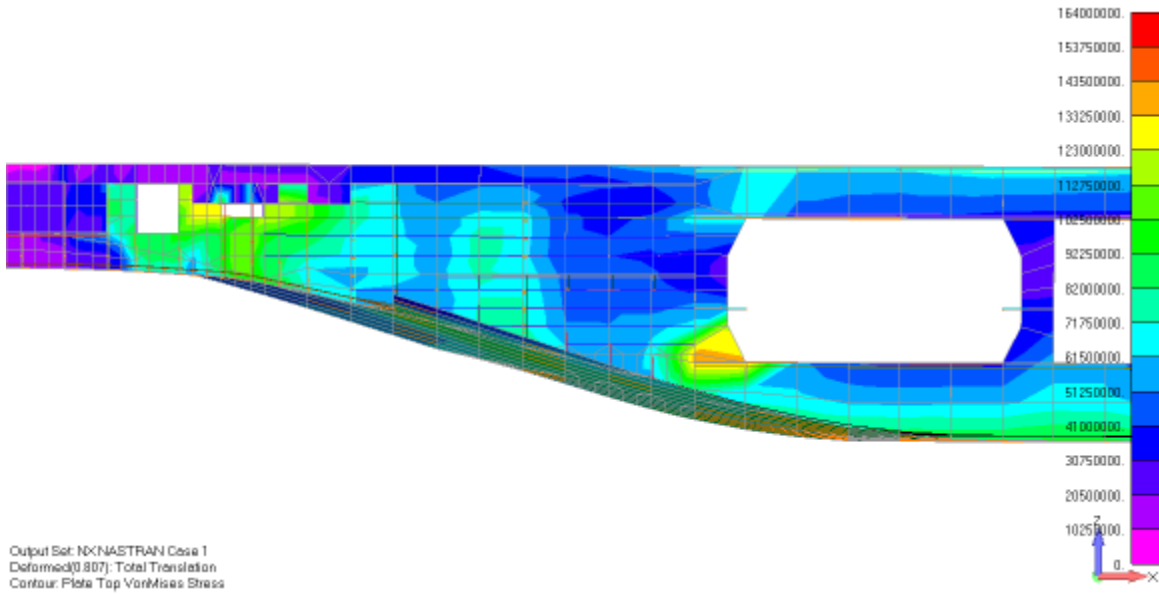
APPENDIX 5
Stress plots of the analysis step hard tank on vessel
with 3 skid beams by uniform loading



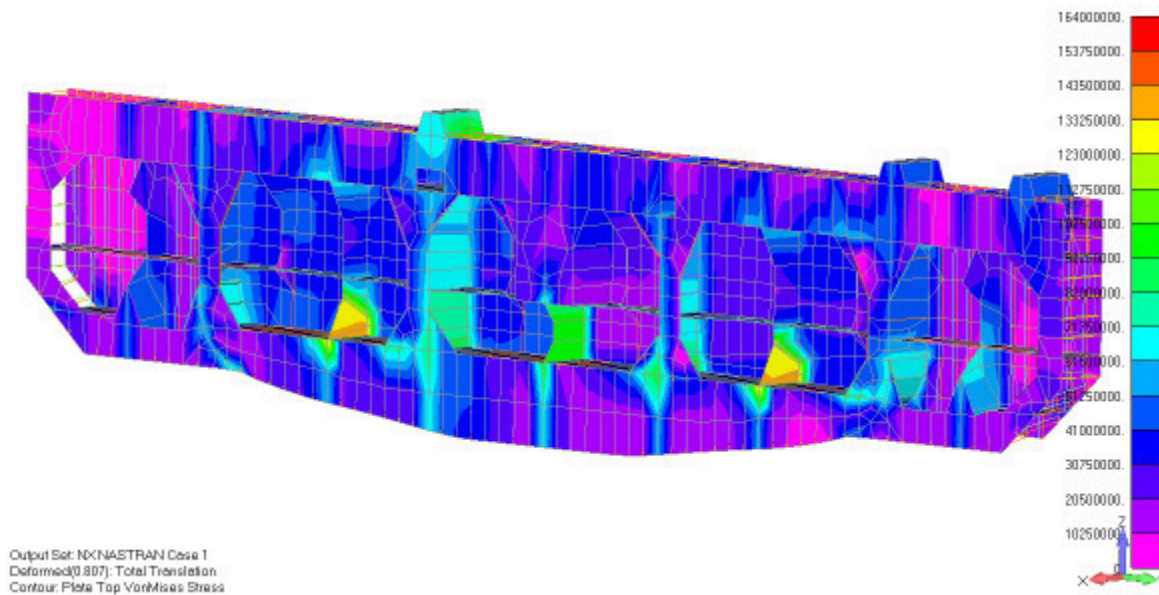
1. Stress components on longitudinal bulkhead under skid beam #2



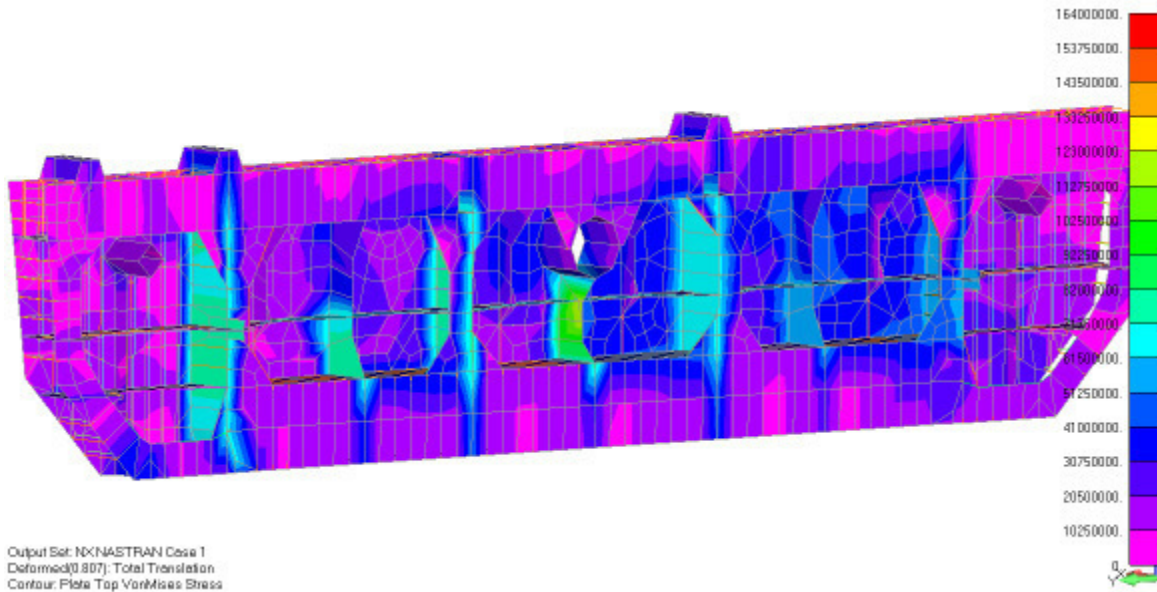
2. Stress components on longitudinal bulkhead under skid beam #3



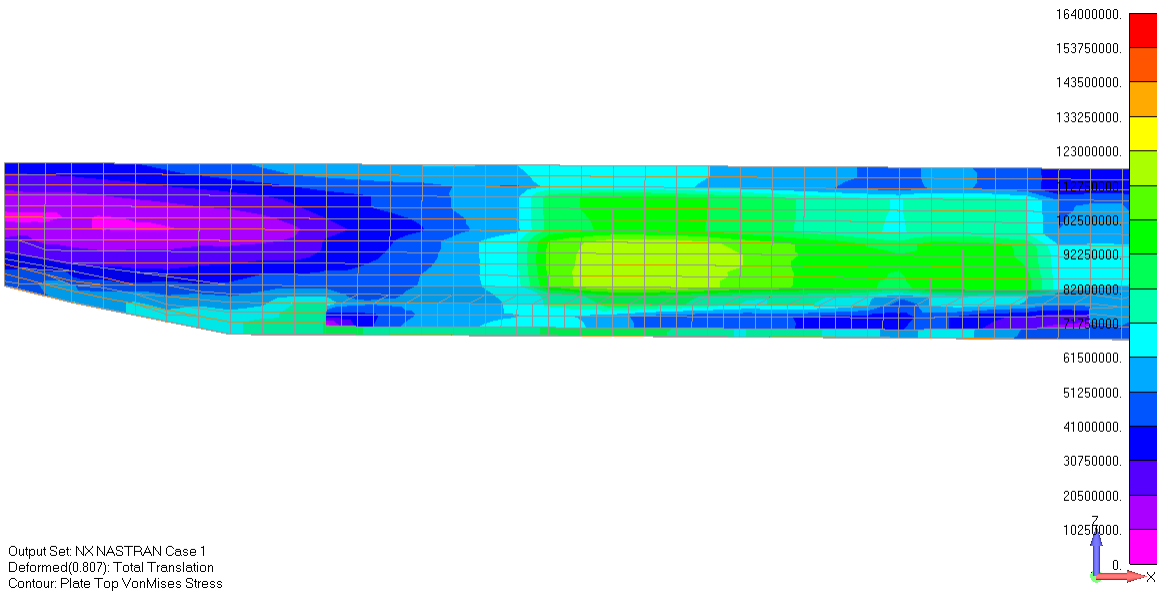
3. Stress components on stern section under skid beam#4



4. Stress components on transverse bulkhead #1 on webframe #46

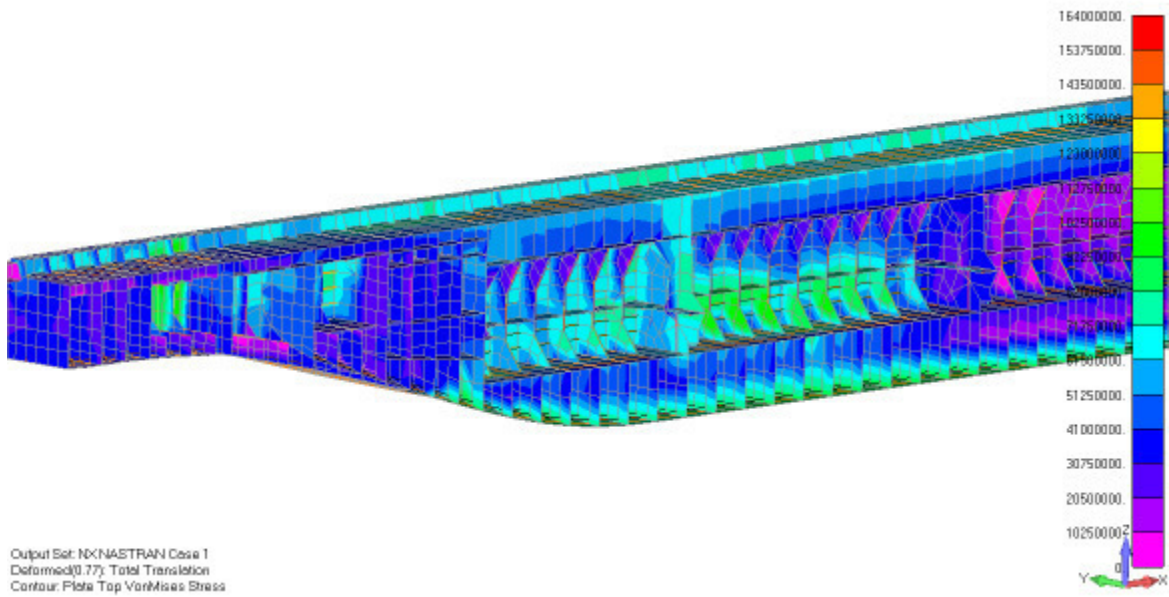


5. Stress components on transverse bulkhead #5 on webframe #83

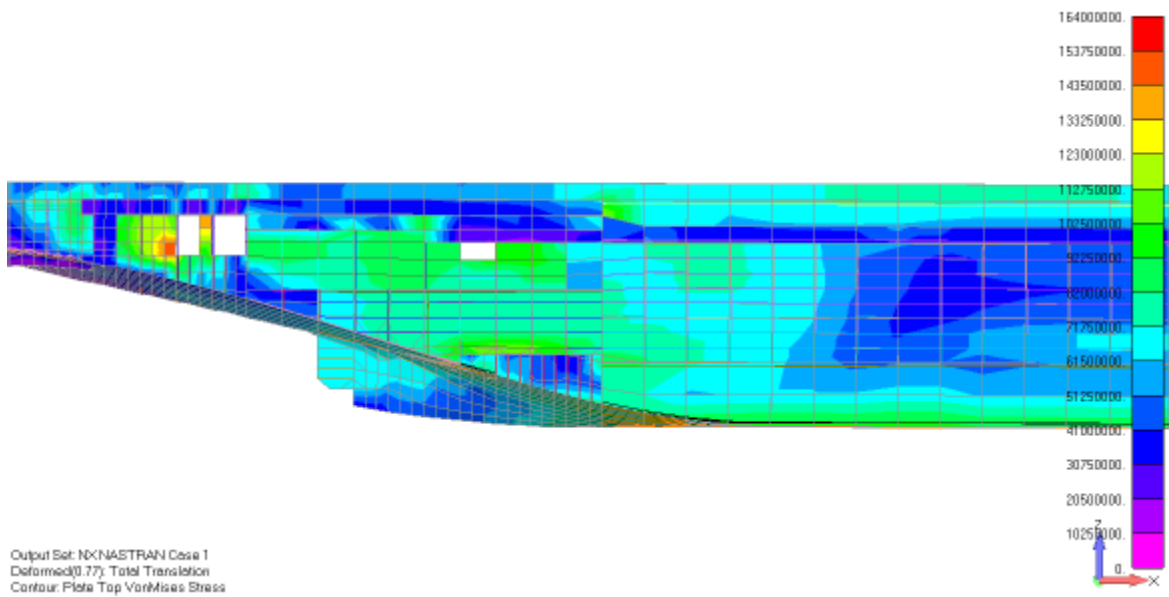


6. Stress components on hull side shell on starboard side

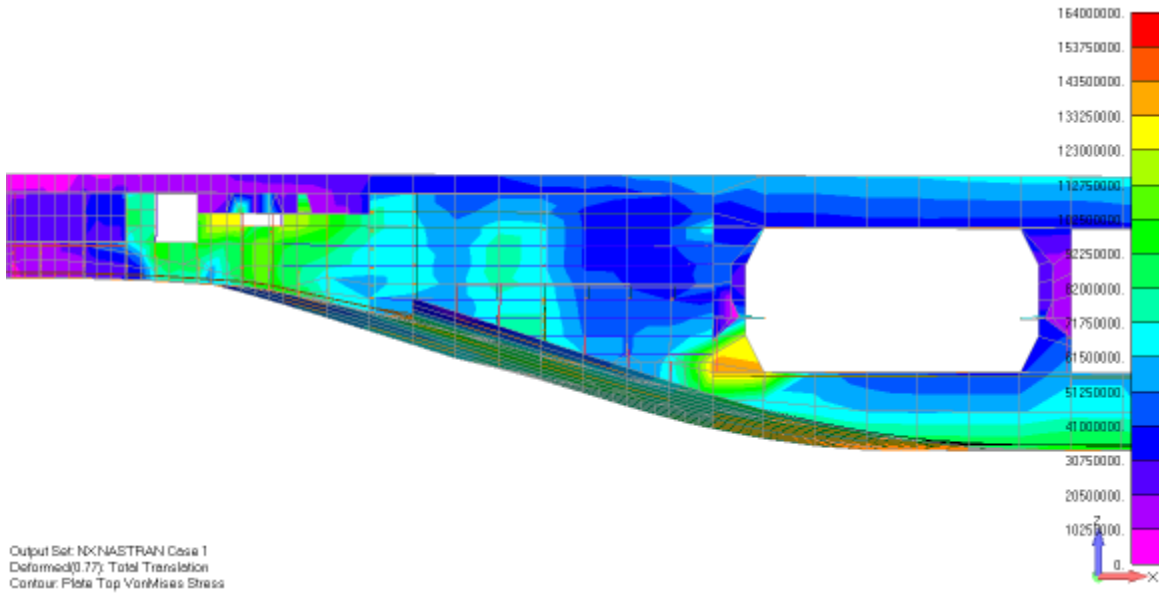
APPENDIX 6
Stress plots of the analysis step hard tank on vessel
with 2 skid beams by uniform loading



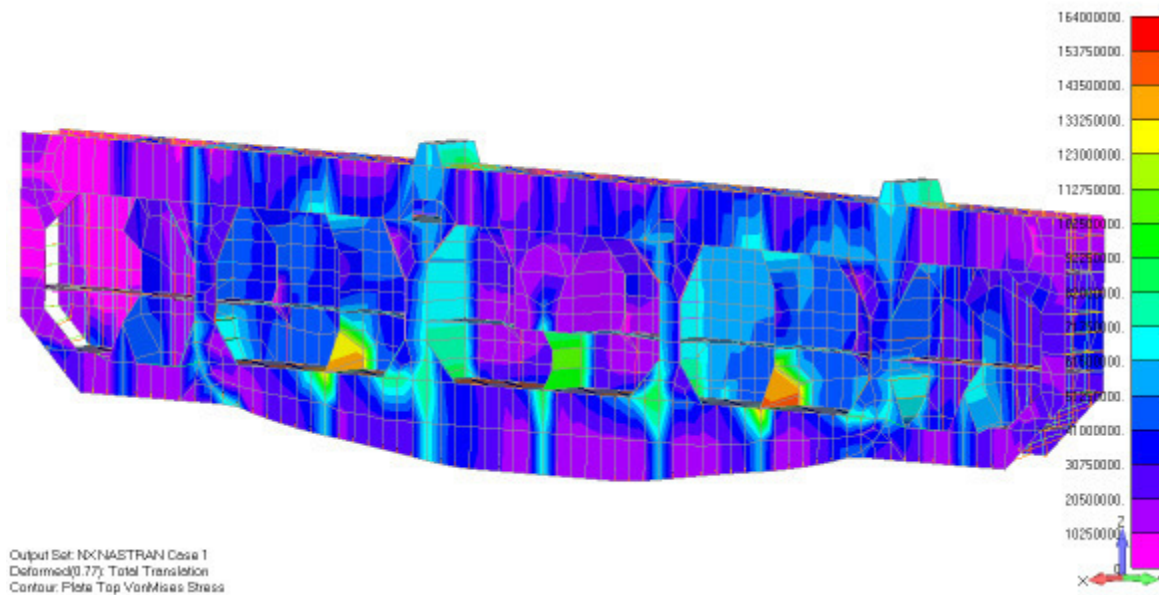
1. Stress components on longitudinal bulkhead under skid beam #2



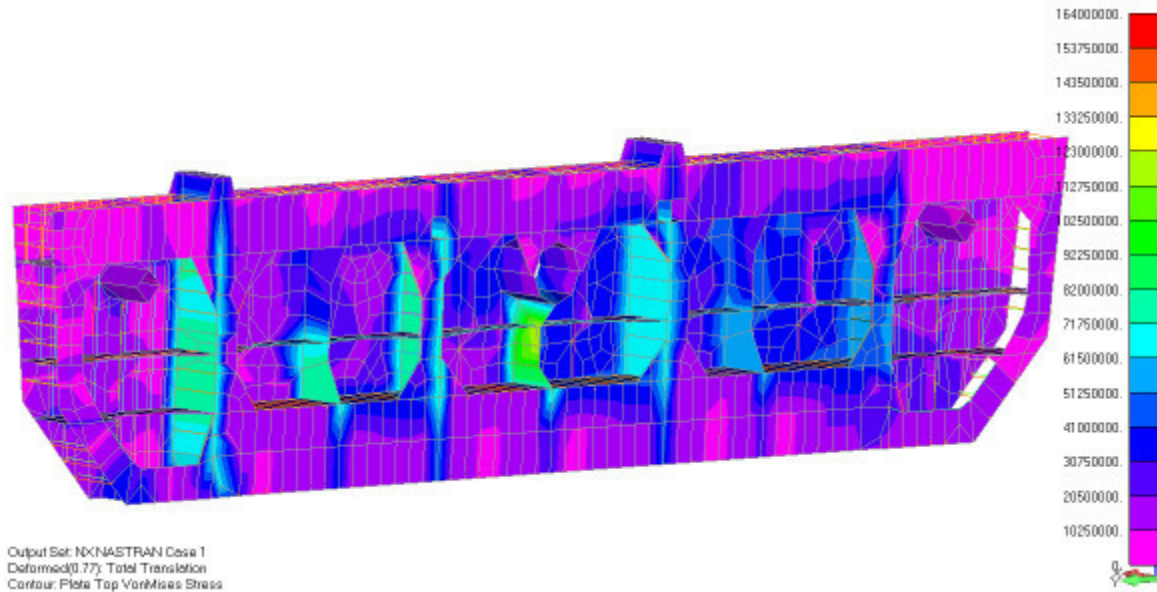
2. Stress components on longitudinal bulkhead under skid beam #3



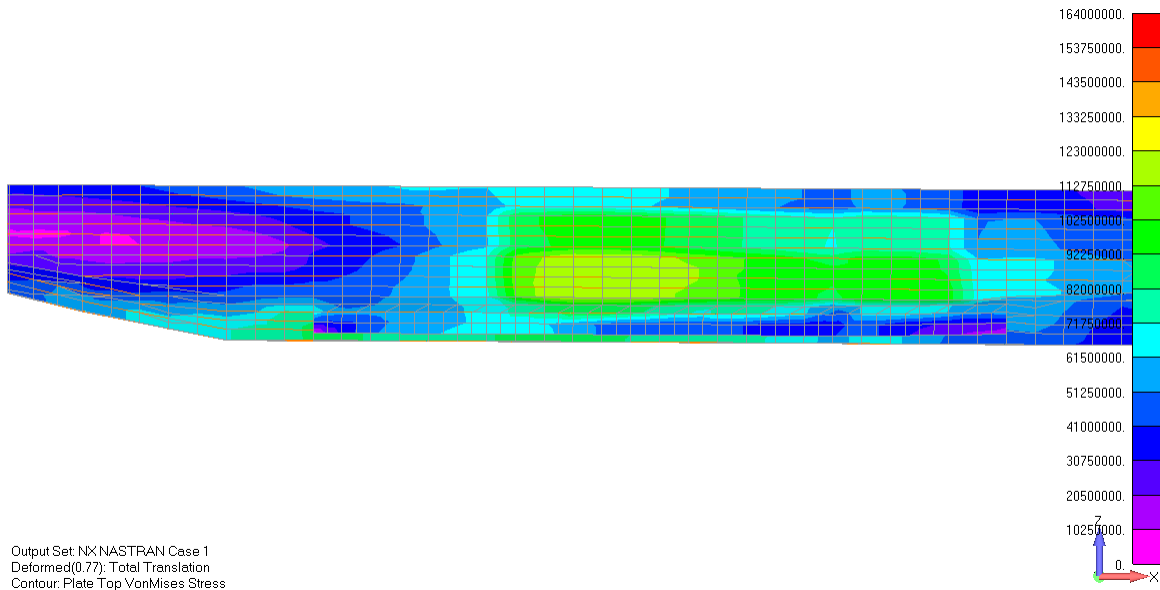
3. Stress components on stern section under skid beam#4



4. Stress components on transverse bulkhead #1 on webframe #46

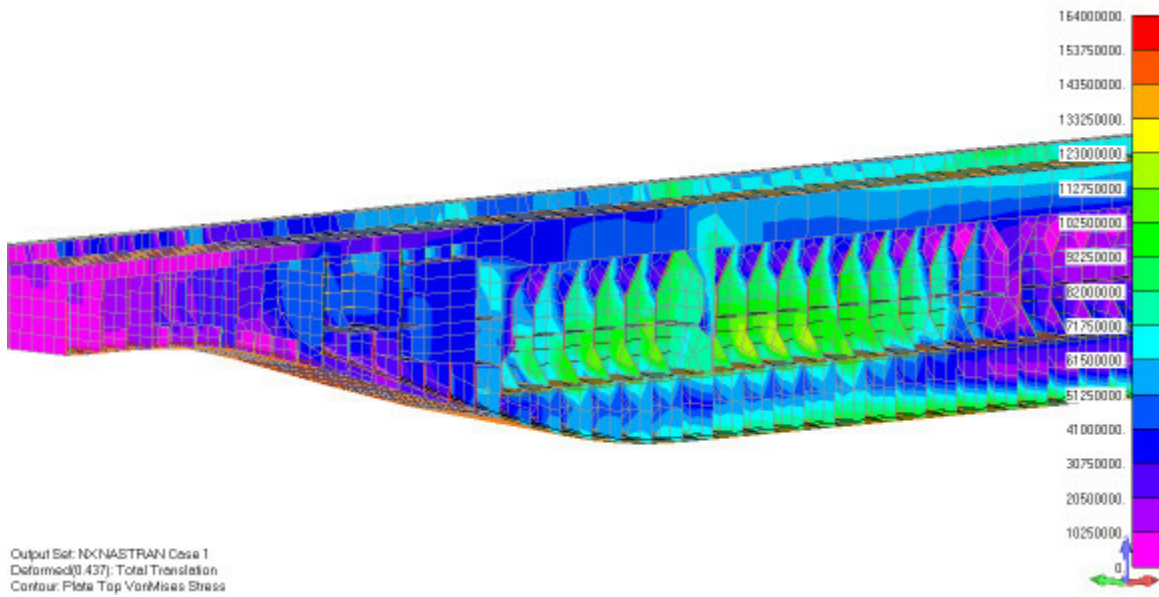


5. Stress components on transverse bulkhead #5 on webframe #83

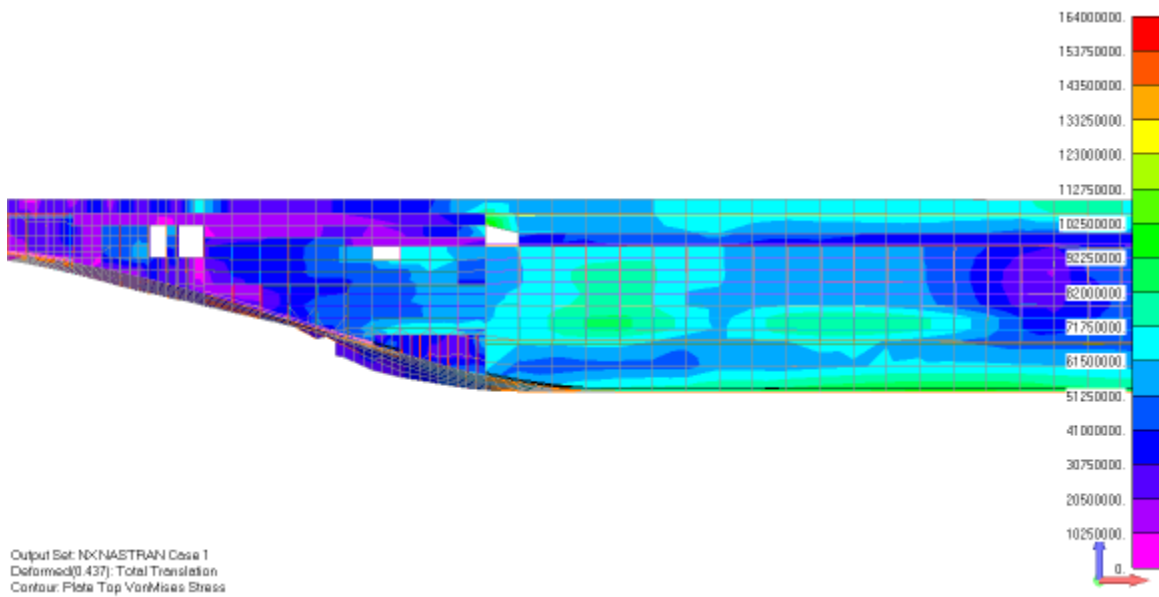


6. Stress components on hull side shell on starboard side

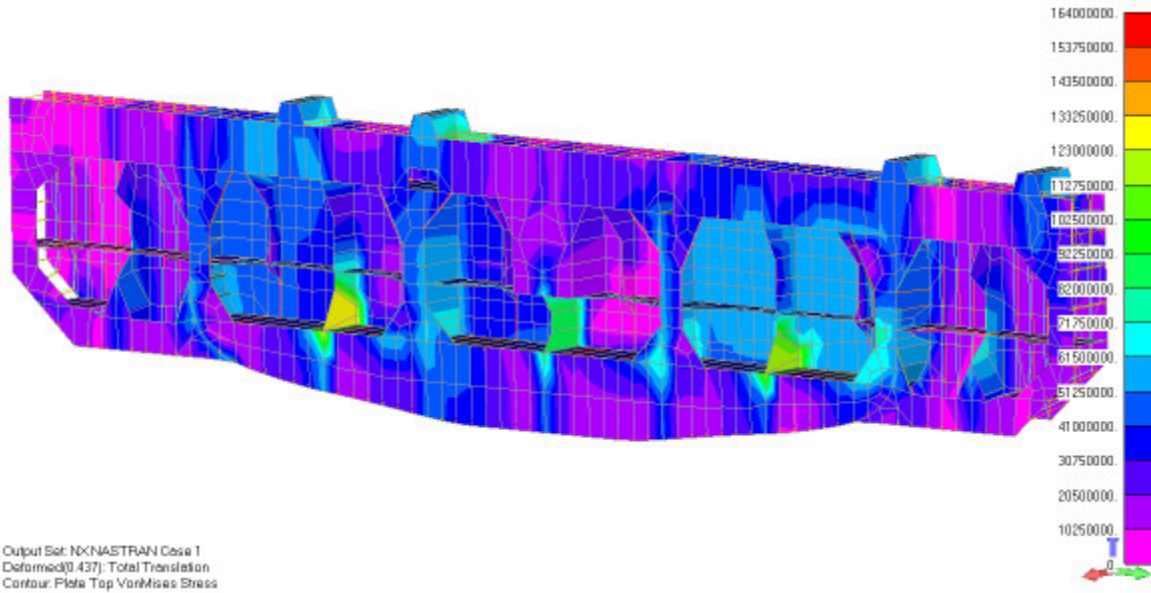
APPENDIX 7
Stress plots of the analysis step hard tank on vessel
with 4 skid beams by SPAR model loading



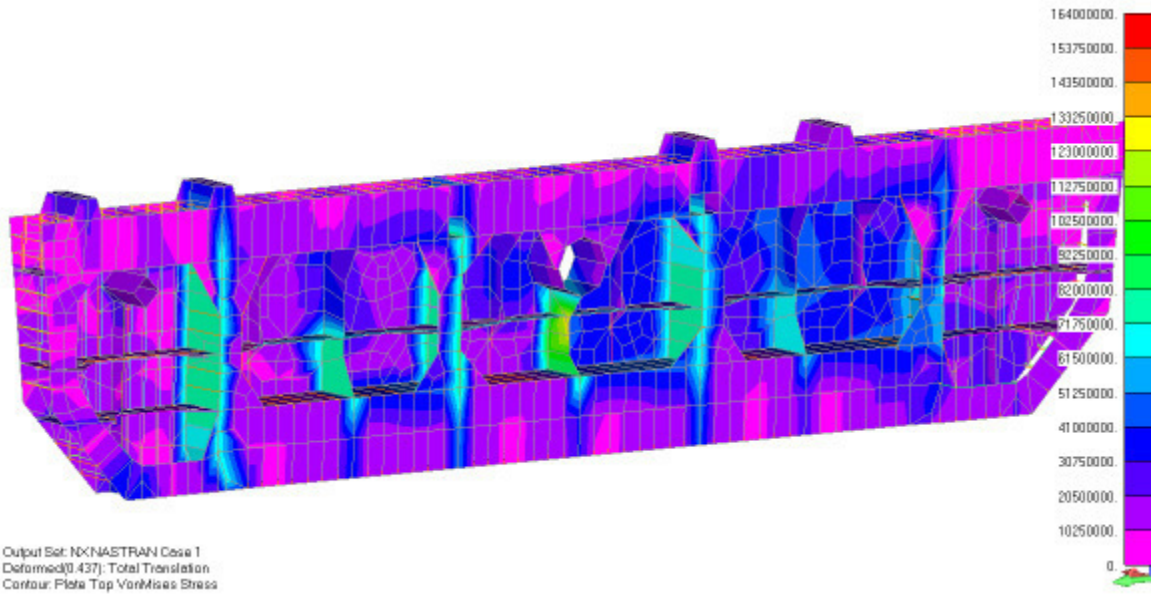
1. Stress components on longitudinal bulkhead under skid beam #2



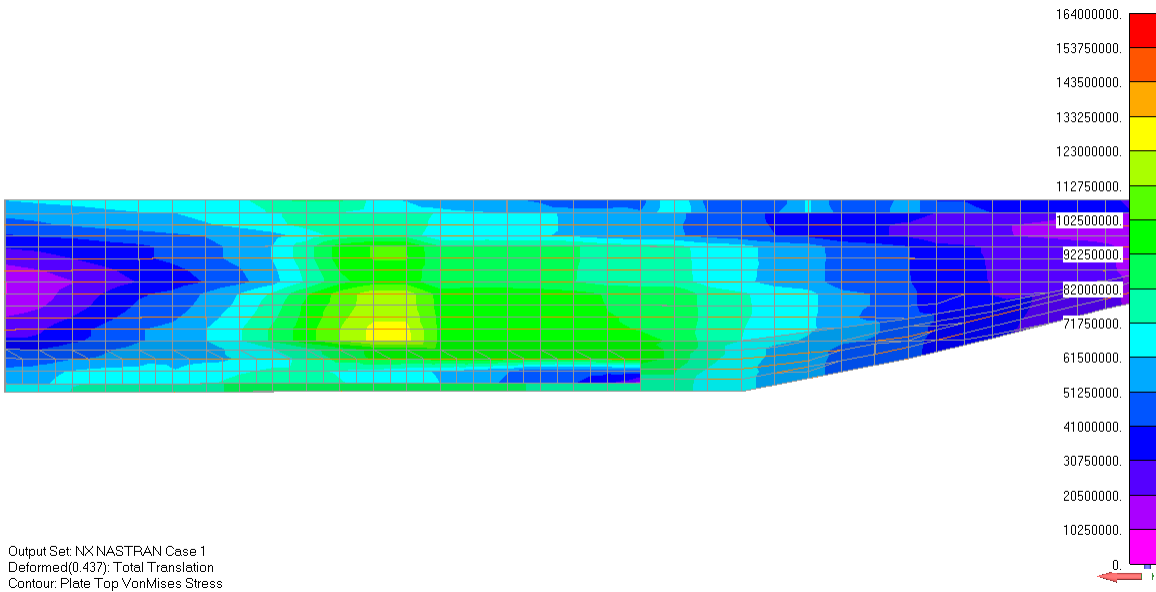
2. Stress components on longitudinal bulkhead under skid beam #3



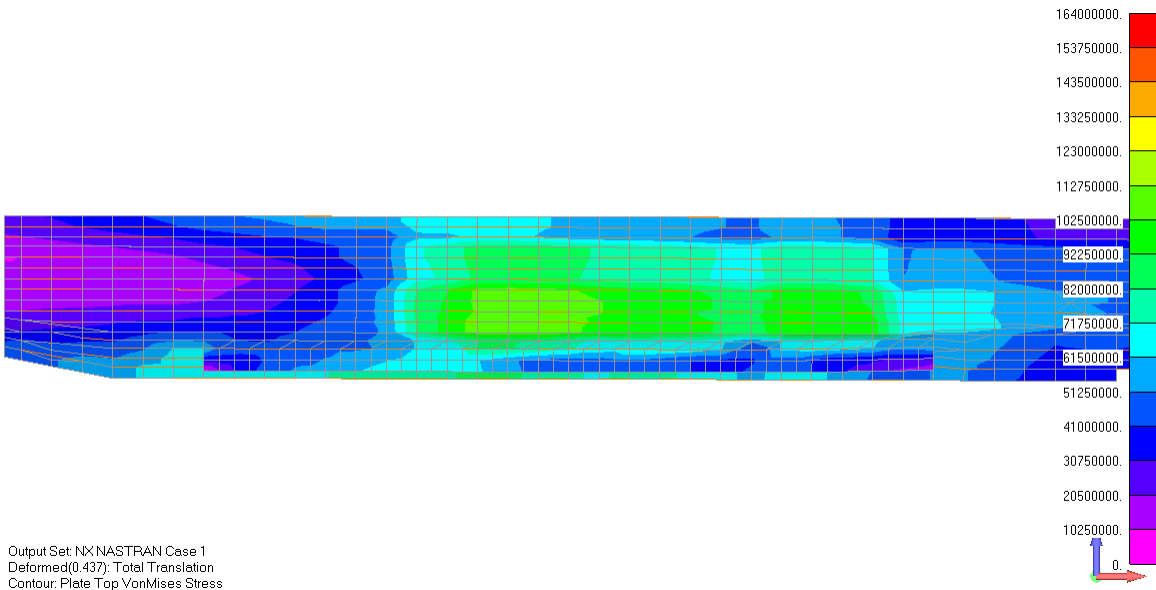
3. Stress components on transverse bulkhead #1 on webframe #46



4. Stress components on transverse bulkhead #5 on webframe #83

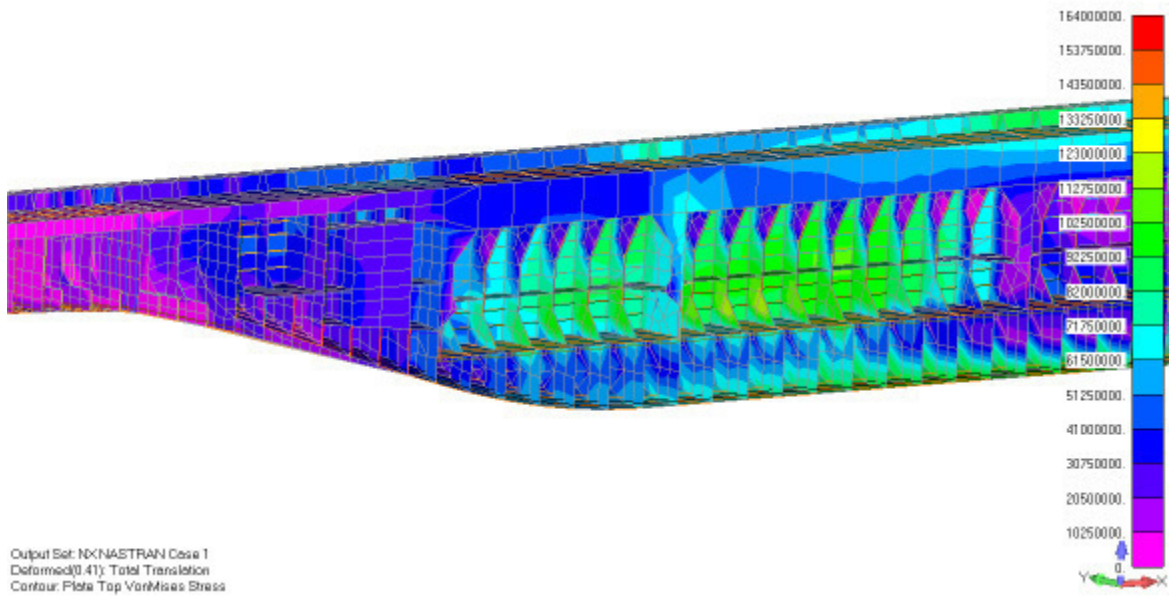


5. Stress components on hull side shell on port side

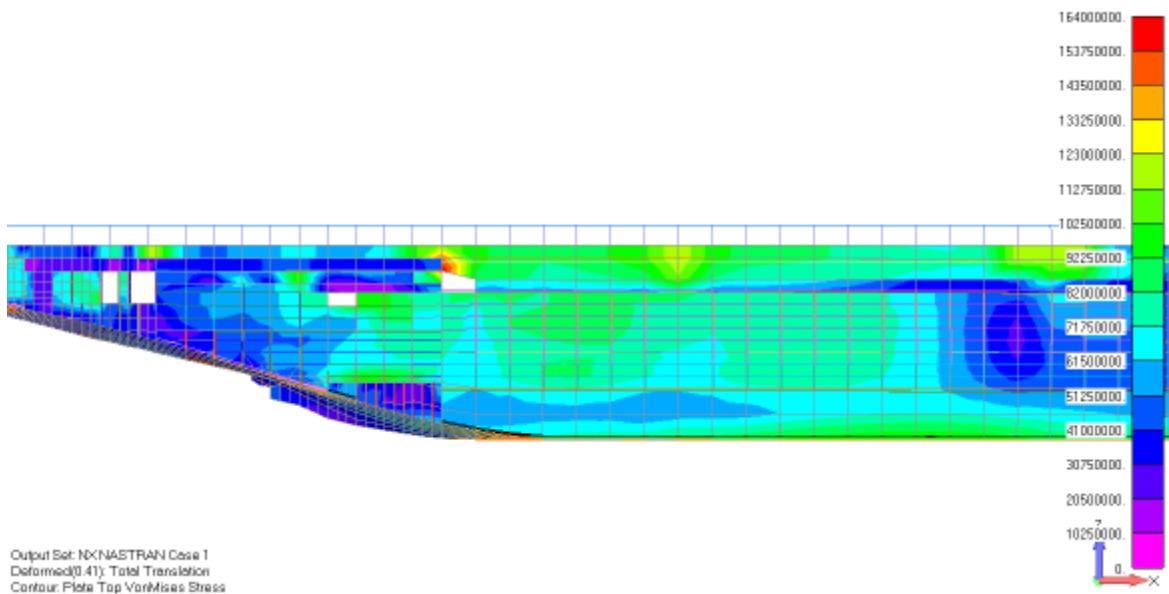


6. Stress components on hull side shell on starboard side

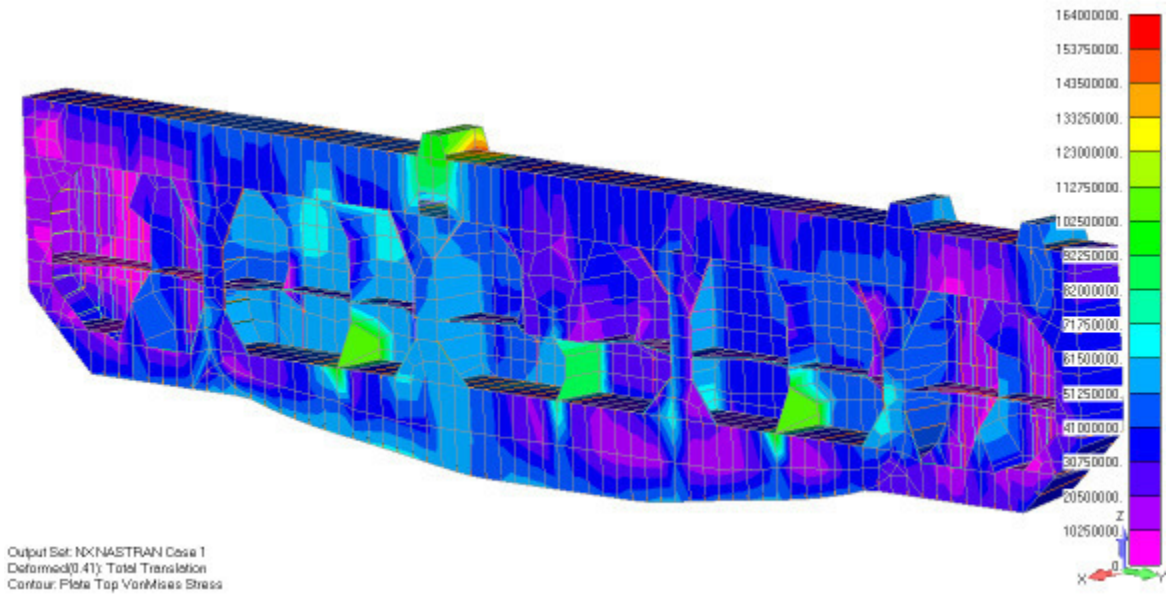
APPENDIX 8
Stress plots of the analysis step hard tank on vessel
with 3 skid beams by SPAR model loading



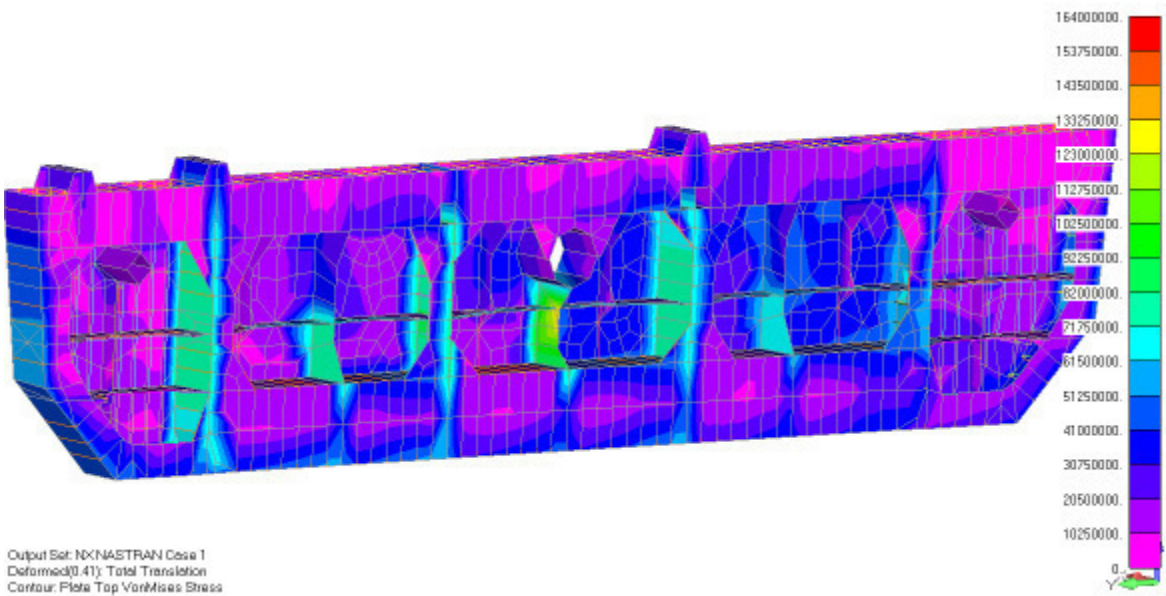
1. Stress components on longitudinal bulkhead under skid beam #2



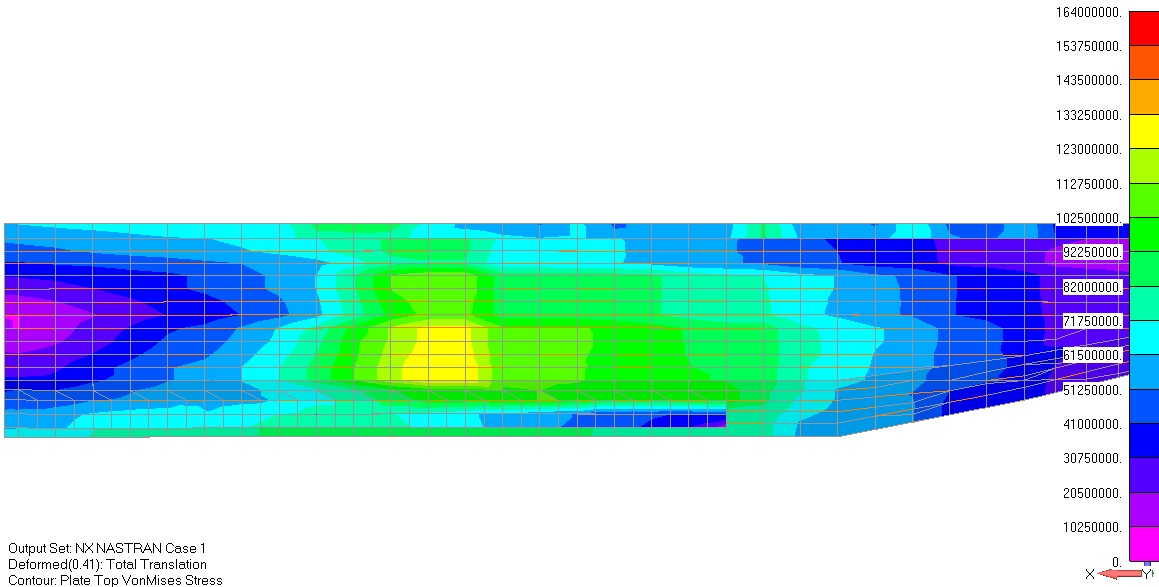
2. Stress components on longitudinal bulkhead under skid beam #3



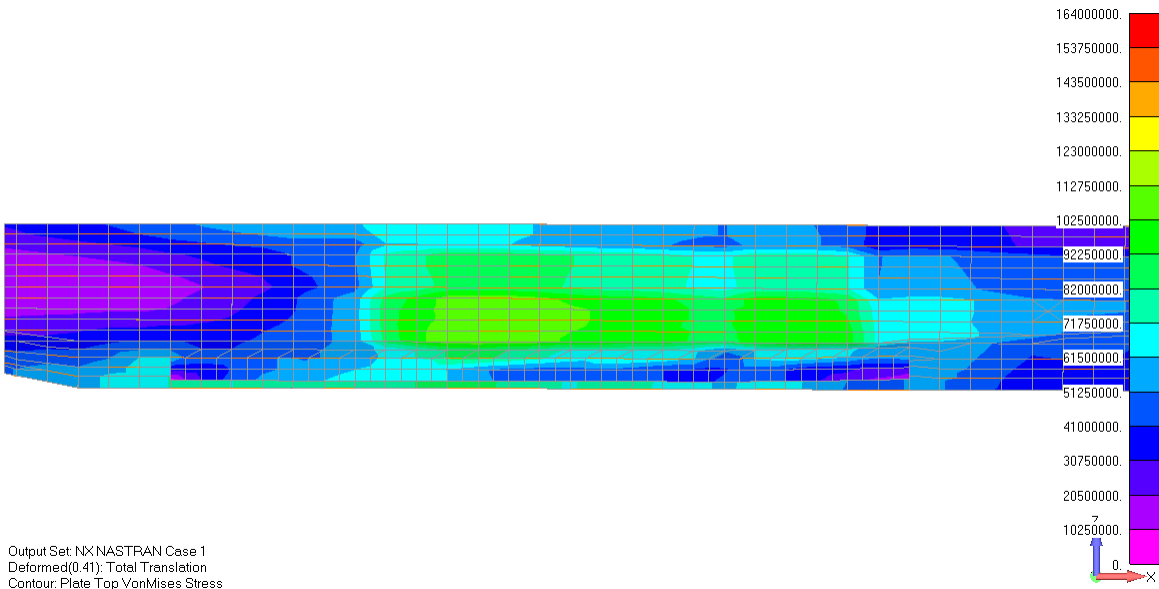
3. Stress components on transverse bulkhead #1 on webframe #46



4. Stress components on transverse bulkhead #5 on webframe #83

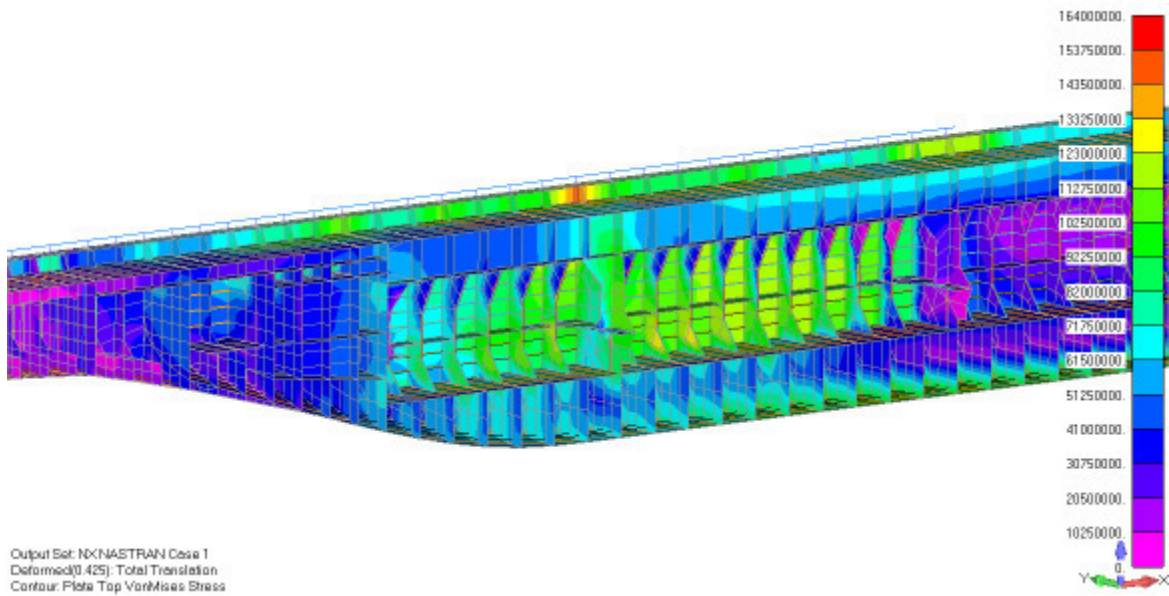


5. Stress components on hull side shell on port side

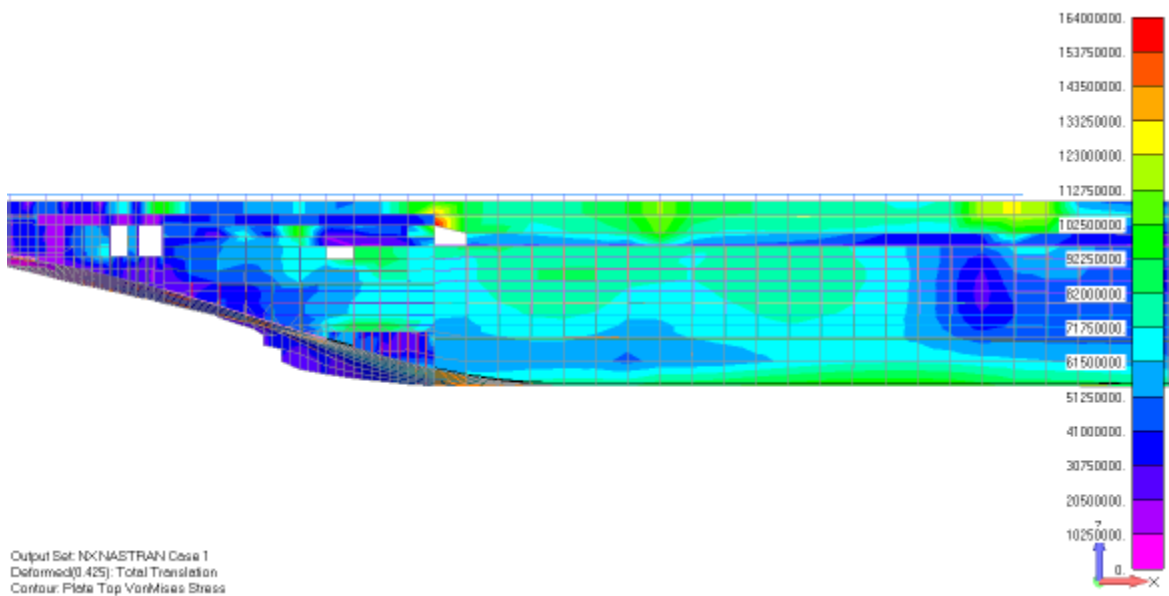


6. Stress components on hull side shell on starboard side

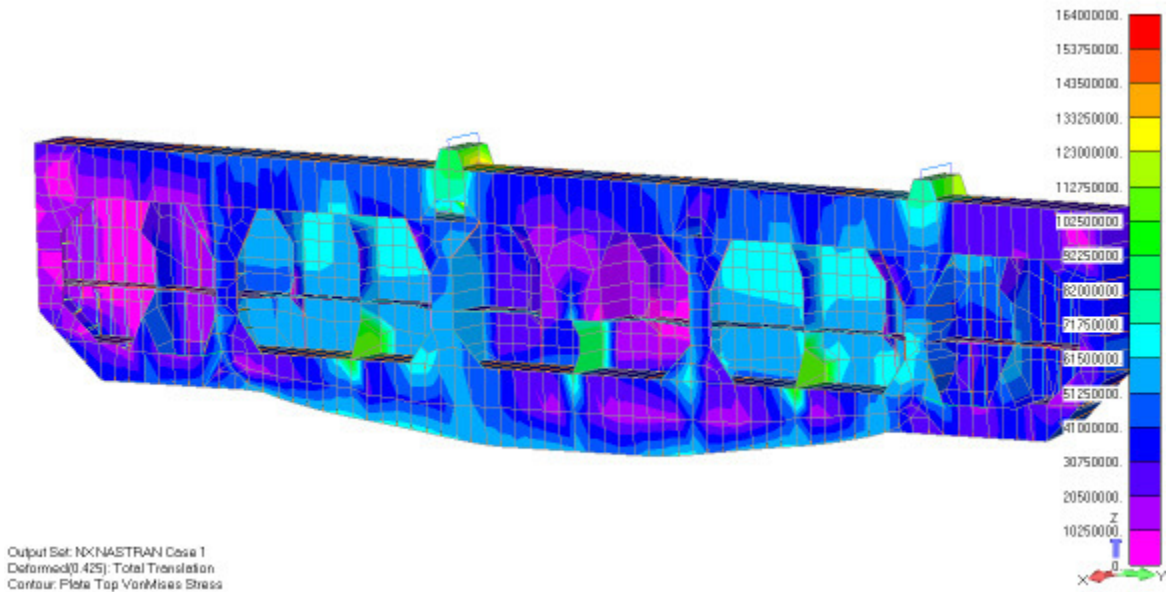
APPENDIX 9
Stress plots of the analysis step hard tank on vessel
with 2 skid beams by SPAR model loading



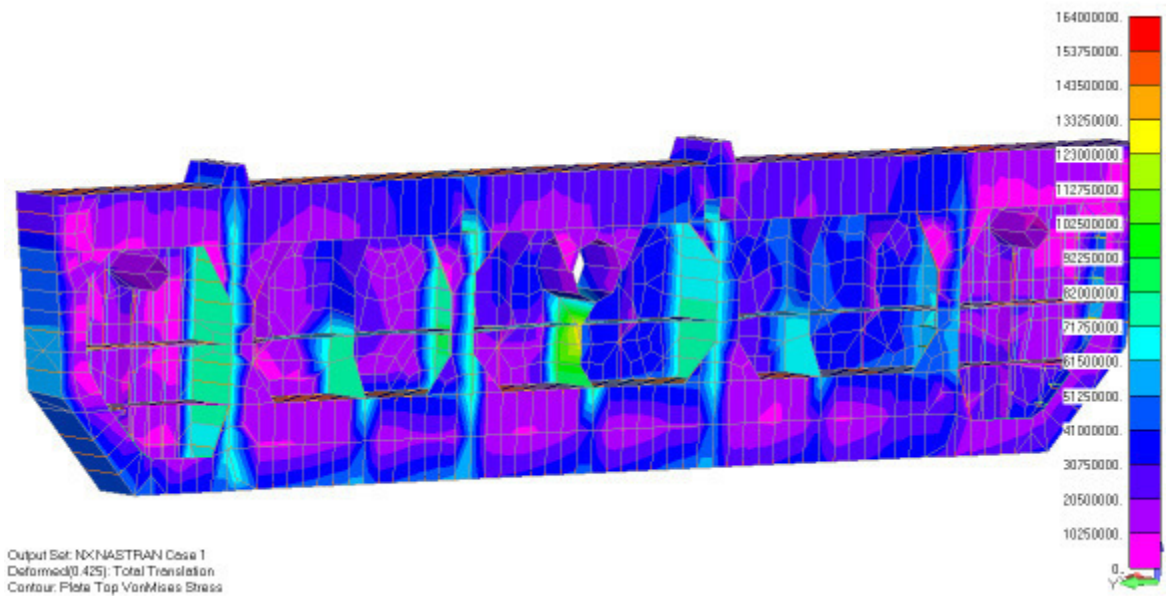
1. Stress components on longitudinal bulkhead under skid beam #2



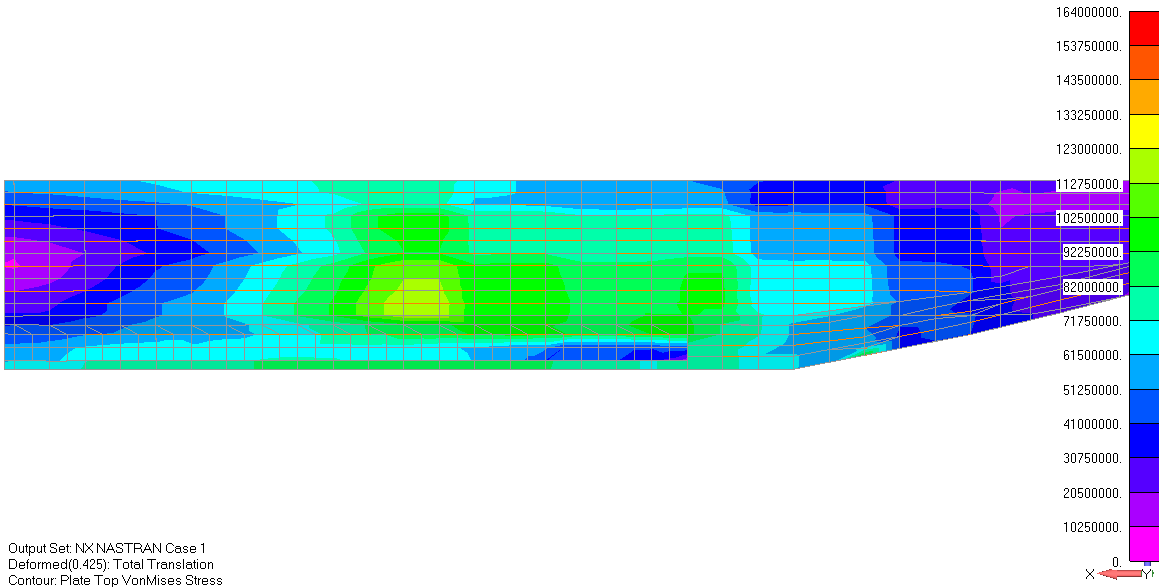
2. Stress components on longitudinal bulkhead under skid beam #3



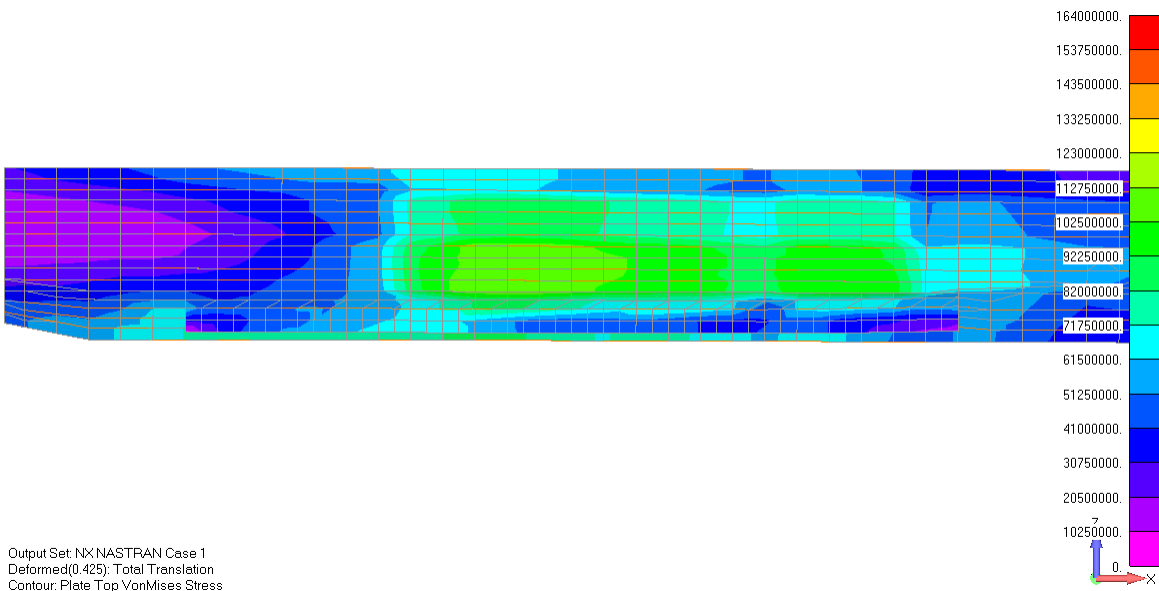
3. Stress components on transverse bulkhead #1 on webframe #46



4. Stress components on transverse bulkhead #5 on webframe #83



5. Stress components on hull side shell on port side



6. Stress components on hull side shell on starboard side

APPENDIX 10
Ballast calculation for the step entire SPAR on vessel

REFERENCE NUMBER : 0611266

MINIMUM DRAFT AT FPP TO AVOID SLAMMING > 8.16M OBTAINED 10.95M
AT A DRAFT OF 10.96M @ APP, THE PROPELLER IMMERSION = 145%

DRAFTS SUMMARY

DRAFT @ PERPENDICULARS	DRAFT @ MARKS
10.95M @ FPP 206.50f FROM APP	10.95M @ BOW 204.50f FROM APP
10.96M @ MID 103.25f FROM APP	10.96M @ MIDSHIPS 103.25f FROM APP
10.96M @ APP 0.00a FROM APP	10.96M @ RUDDER 3.50a FROM APP
	10.95M @ ACCOM.BULKHEAD 174.70f FROM APP
	10.96M @ CASING 10.50f FROM APP

HYDROSTATIC PROPERTIES

Trim: 0.00/206.50, Heel: Stbd 0.07 deg., VCG = 14.963

LCF	Displacement	Buoyancy-Ctr.	Weight/	Moment/
Draft	Weight (MT)	LCB	VCB	cm trim
10.956	113,932.59	99.080f	5.862	121.46
				91.359f
				1764.22
				319.76
				22.777

Distances in METERS.-----Specific Gravity = 1.025.-----Moment in m.-MT.
Trim is per 206.50m.
Draft is from Baseline. Free Surface included. GMT is from RA curve.
Caution: Standard GMT is 22.760

WEIGHT STATUS

Trim: 0.00/206.50, Heel: Stbd 0.07 deg.

Part	Weight (MT)	LCG	TCG	VCG	FSM
Total Fixed	60,139.63	106.017f	3.875p	22.668	
Total Tanks	53,792.91	91.326f	4.396s	6.350	48691.6
Total Weight	113,932.55	99.081f	0.030s	14.963	
Free Surface Adjustment				0.427	
Adjusted CG		99.081f	0.030s	15.391	

Distances in METERS.-----Moments in m.-MT.

DISPLACEMENT STATUS

Baseline draft: 10.955 @ 206.50f, 10.957 @ 0.00

Trim: 0.00/206.50, Heel: Stbd 0.07 deg.

Part	SpGr	Displ (MT)	LCB	TCB	VCB
HULL	1.025	113,932.59	99.080f	0.041s	5.862
PSCASING	1.025	0.00			
Total Displacement	1.025	113,932.59	99.080f	0.041s	5.862

Distances in METERS.-----

WEIGHT STATUS

Part-----	Weight (MT)	LCG	TCG	VCG
LIGHT SHIP+	27,935.69	103.855f	0.255s	9.956
STARBOARD CASING	615.41	0.600f	26.130s	27.040
STARBOARD CASING ADDITION	79.30	3.500f	26.130s	15.800
PORT CASING	0.24	3.150f	26.196p	26.600
PORT CASING ADDITION	0.08	3.150f	26.196p	15.800
CREW AND EFFECTS	5.70	186.600f	0.000	31.910
PROVISIONS	7.69	189.750f	0.000	24.000
STORES FORE	23.45	194.330f	0.000	23.110
STORES AFT	19.19	15.170f	0.000	9.980
SMALL TANK IN E/R (FORE)	52.22	184.720f	0.000	15.410
SMALL TANK IN E/R (AFT)	362.65	22.890f	0.000	6.150
Skid load Hard Tank	25,122.60	128.255f	8.322p	34.250
Skid load UHP	2,958.39	55.961f	8.322p	34.250
Skid load LHP	2,957.01	20.608f	8.322p	34.250
Total Fixed----->	60,139.63	106.017f	3.875p	22.668
Distances in METERS.-----				

TANK STATUS

Trim: 0.00/206.50, Heel: Stbd 0.07 deg.

Part-----	Load	SpGr	Weight (MT)	LCG	TCG	VCG
SEA WATER	0.335	1.025	48,592.13	89.059f	4.807s	6.257
HEAVY FO	0.955	0.991	4,290.77	119.566f	0.543s	6.330
DIESEL OIL	0.980	0.850	308.37	13.694f	14.335p	9.871
LUBE OIL	0.980	0.900	33.69	18.585f	9.907p	6.444
FRESH WATER	1.000	1.000	567.96	118.466f	9.409s	12.569
WATER 1.001	0.000	1.001	0.00			
Total Tanks----->			53,792.92	91.326f	4.396s	6.350
Distances in METERS.-----						

LOAD STATUS

Trim: 0.00/206.50 Heel: Stbd 0.07 deg.

Tank Description-----	Name-----	Contents-----	Load Wt MT--	Load%--	Sounding
1 UPPER C	WBT1U.C	SEA	38.81	6.2	0.071
1 UPPER P	WBT1U.P	SEA	0.00	0.0	0.000
1 UPPER S	WBT1U.S	SEA	0.00	0.0	0.000
2 UPPER C	WBT2U.C	SEA	0.00	0.0	0.000
2 UPPER P	WBT2U.P	SEA	861.43	100.0	15.710
2 UPPER S	WBT2U.S	SEA	839.34	100.0	15.710
3 UPPER C	WBT3U.C	SEA	861.29	100.0	15.710
3 UPPER P	WBT3U.P	SEA	850.38	100.0	15.710
3 UPPER S	WBT3U.S	SEA	861.43	100.0	15.710
4 UPPER C	WBT4U.C	SEA	0.00	0.0	0.000
4 UPPER P	WBT4U.P	SEA	0.00	0.0	0.000
4 UPPER S	WBT4U.S	SEA	0.00	0.0	0.000
5 UPPER C	WBT5U.C	SEA	839.21	97.4	2.347
5 UPPER P	WBT5U.P	SEA	243.85	28.7	0.664
5 UPPER S	WBT5U.S	SEA	254.43	29.5	0.670
6 UPPER C	WBT6U.C	SEA	585.24	100.0	15.710
6 UPPER P	WBT6U.P	SEA	607.42	100.0	15.710
6 UPPER S	WBT6U.S	SEA	585.33	100.0	15.710

LOAD STATUS, continued

Tank Description	Name	Contents	Load Wt MT	Load%	Sounding
1 MIDDLE C	WBT1M.C	SEA	0.00	0.0	0.000
1 MIDDLE P	WBT1M.P	SEA	0.00	0.0	0.000
1 MIDDLE S	WBT1M.S	SEA	0.00	0.0	0.000
1 OUTER WING P	WBT1O.P	SEA	0.00	0.0	0.000
1 OUTER WING S	WBT1O.S	SEA	0.00	0.0	0.000
2 MIDDLE P	WBT2M.P	SEA	432.87	17.4	1.143
2 MIDDLE S	WBT2M.S	SEA	756.07	30.6	2.060
2 OUTER WING P	WBT2O.P	SEA	0.00	0.0	0.000
2 OUTER WING S	WBT2O.S	SEA	0.00	0.0	0.000
3 MIDDLE C	WBT3M.C	SEA	0.00	0.0	0.000
3 MIDDLE P	WBT3M.P	SEA	0.00	0.0	0.000
3 MIDDLE S	WBT3M.S	SEA	0.00	0.0	0.000
3 OUTER WING P	WBT3O.P	SEA	0.00	0.0	0.000
3 OUTER WING S	WBT3O.S	SEA	2,546.81	80.4	10.846
4 MIDDLE C	WBT4M.C	SEA	2,321.52	100.0	22.750
4 MIDDLE P	WBT4M.P	SEA	2,487.61	100.0	22.750
4 MIDDLE S	WBT4M.S	SEA	2,467.71	100.0	22.750
4 OUTER WING P	WBT4O.P	SEA	210.73	6.5	1.050
4 OUTER WING S	WBT4O.S	SEA	2,447.06	75.0	10.099
5 MIDDLE C	WBT5M.C	SEA	0.00	0.0	0.000
5 MIDDLE P	WBT5M.P	SEA	0.00	0.0	0.000
5 MIDDLE S	WBT5M.S	SEA	0.00	0.0	0.000
5 OUTER WING P	WBT5O.P	SEA	2,464.04	75.2	10.126
5 OUTER WING S	WBT5O.S	SEA	3,276.98	100.0	26.510
6 MIDDLE C	WBT6M.C	SEA	1,588.29	100.0	22.750
6 MIDDLE P	WBT6M.P	SEA	1,732.38	100.0	22.750
6 MIDDLE S	WBT6M.S	SEA	1,711.63	100.0	22.750
6 OUTER WING P	WBT6O.P	SEA	0.00	0.0	0.000
6 OUTER WING S	WBT6O.S	SEA	2,126.90	100.0	26.510
7 OUTER WING P	WBT7O.P	SEA	0.00	0.0	0.000
7 OUTER WING S	WBT7O.S	SEA	1,859.96	100.0	24.070
1 LOWER C	WBT1L.C	SEA	1,116.96	100.0	26.510
1 LOWER P	WBT1L.P	SEA	1,214.41	100.0	26.510
1 LOWER S	WBT1L.S	SEA	1,214.41	100.0	26.510
2 LOWER C	WBT2L.C	SEA	1,325.95	100.0	26.510
2 LOWER P	WBT2L.P	SEA	1,307.69	100.0	26.510
2 LOWER S	WBT2L.S	SEA	1,302.22	100.0	26.510
3 LOWER C	WBT3L.C	SEA	1,327.37	100.0	26.510
3 LOWER P	WBT3L.P	SEA	1,304.22	100.0	26.510
3 LOWER S	WBT3L.S	SEA	1,309.48	100.0	26.510
4 LOWER C	WBT4L.C	SEA	0.00	0.0	0.000
4 LOWER P	WBT4L.P	SEA	0.00	0.0	0.000
4 LOWER S	WBT4L.S	SEA	0.00	0.0	0.000
5 LOWER C	WBT5L.C	SEA	0.00	0.0	0.000
5 LOWER P	WBT5L.P	SEA	1,309.43	100.0	26.510
5 LOWER S	WBT5L.S	SEA	0.00	0.0	0.000
6 LOWER C	WBT6L.C	SEA	0.00	0.0	0.000
6 LOWER P	WBT6L.P	SEA	0.00	0.0	0.000
6 LOWER S	WBT6L.S	SEA	0.00	0.0	0.000
FWD LOWER WB P	WBTFL.P	SEA	0.00	0.0	0.000

LOAD STATUS, continued

Tank Description	Name	Contents	Load Wt	MT	Load%	Sounding
FWD LOWER WB S	WBTFL.S	SEA	0.00	0.0	0.000	0.000
FWD UPPER WB P	WBTFU.P	SEA	0.00	0.0	0.000	0.000
FWD UPPER WB S	WBTFU.S	SEA	0.00	0.0	0.000	0.000
AFT WB P	WBTA.P	SEA	0.00	0.0	0.000	0.000
POOP AFT WB S	WBTPA.S	SEA	0.00	0.0	0.000	0.000
POOP FWD WB S	WBTPF.S	SEA	0.00	0.0	0.000	0.000
AFT L BALLAST S	WBTA.LWL.S	SEA	0.00	0.0	0.000	0.000
AFT PEAK C	WBTA.PC.C	SEA	0.00	0.0	0.000	0.000
AFT POOP LOWER WB P	WBTA.PL.P	SEA	0.00	0.0	0.000	0.000
AFT POOP UPPER WB P	WBTA.PU.P	SEA	0.00	0.0	0.000	0.000
ENGINE RM TOP P	WBTERTOP.P	SEA	0.00	0.0	0.000	0.000
ENGINE RM TOP S	WBTERTOP.S	SEA	0.00	0.0	0.000	0.000
LOWER PEAK C	WBTLLOWPEAK.C	SEA	0.00	0.0	0.000	0.000
HIGH PEAK C	WBTHIGHPEAK.C	SEA	0.00	0.0	0.000	0.000
WB OVRFL FWD	WBTOVERFWD.C	SEA	0.00	0.0	0.000	0.000
WATER BAL OFLOW	WBTOVERF.S	SEA	0.00	0.0	0.000	0.000
Total as loaded----->			48,590.86			
Soundings in m.-----						

LONGITUDINAL STRENGTH LIMIT APPLIED: SHELTERED CONDITION
SHELTERED CRITERION LONGITUDINAL STRENGTH SUMMARY at Heel = Stbd 0.07 deg.

Largest Shear: -5,541.6 MT at 91.310f
Largest Bending Moment: -173,974 MT-m. at 125.700f (Sagging)

LONGITUDINAL STRENGTH at Heel = Stbd 0.07 deg.

FRAME	LOCATION	SHEAR FORCE			BENDING MOMENT			LIMIT
		MT	%	MT	MT-m.	%	MT-m.	
Fr.-5	3.500a	181.65	3	6,538.00	628.9	1	119,623.0	
Fr.17	11.900f	-378.00	6	-5,820.00	-511.6	1	-86,500.0	
Fr.29	20.300f	544.66	4	13,275.00	-156.8	0	-186,087.7	
Fr.47	34.700f	278.60	1	18,703.00	8,875.6	3	329,713.2	
Fr.53	49.700f	79.53	1	14,682.00	11,039.7	2	597,778.0	
Fr.60	67.199f	-1,178.19	8	-14,768.00	6,417.6	1	664,318.4	
Fr.63	74.700f	-2,877.91	20	-14,124.00	-8,762.0	1	-709,742.7	
Fr.73	99.700f	-4,062.05	29	-14,124.00	-118,884.6	19	-625,742.0	
Fr.83	124.700f	-306.77	2	-15,272.00	-173,748.8	28	-622,378.4	
Fr.93	149.700f	4,215.20	28	15,134.00	-126,942.0	24	-533,195.0	
Fr.103	174.700f	3,015.24	55	5,491.00	-19,053.1	8	-237,181.0	
Fr.131	194.300f	523.51	12	4,421.00	6,211.9	9	66,269.0	

SHELTERED CRITERION SUMMARY

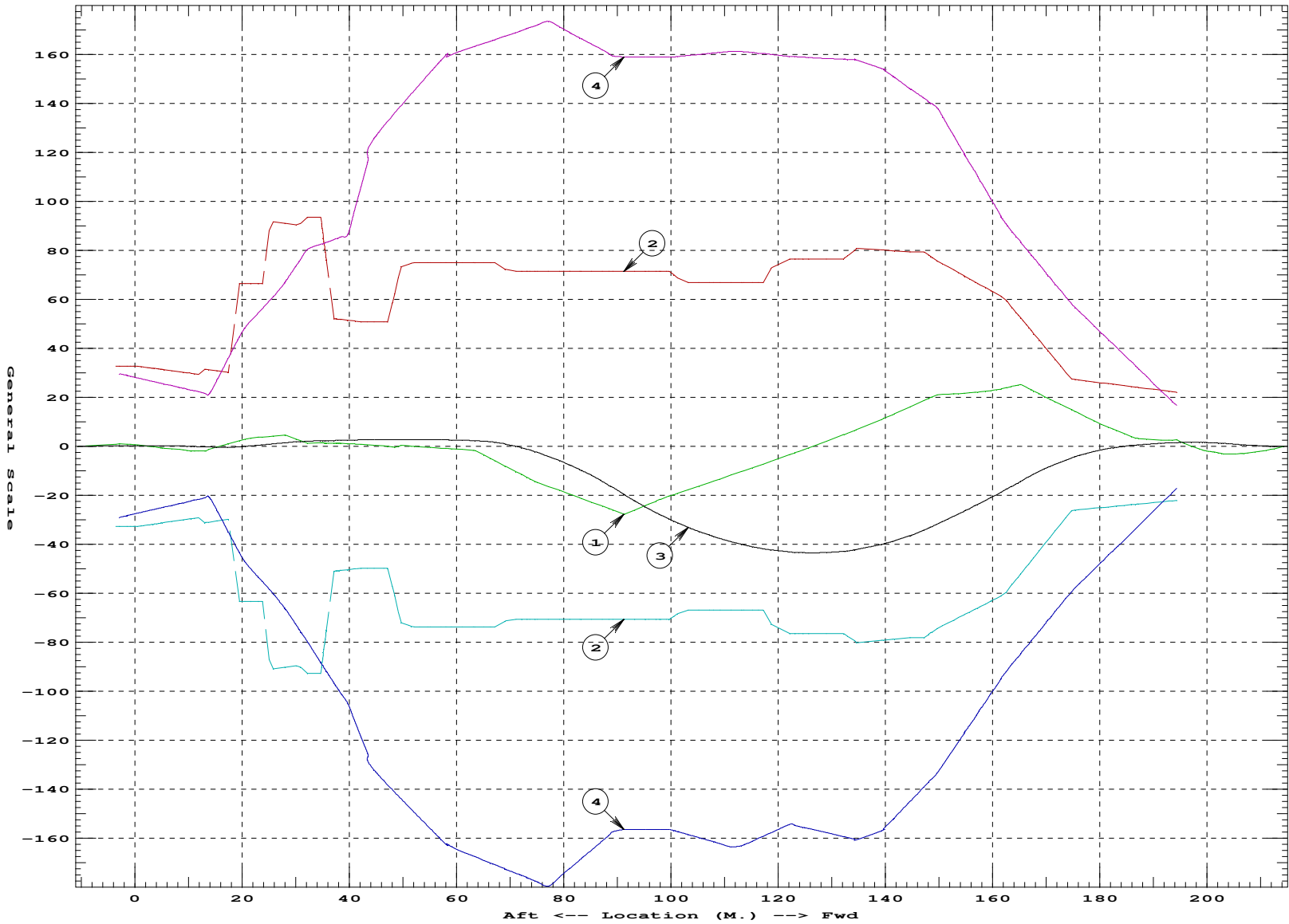
Largest Shear: 54.9% at 174.700f
Largest Bending Moment: -28.0% at 123.100f (Sagging)

SHELTERED criterion LONGITUDINAL STRENGTH at 0.07 degrees STBD HEEL

07/15/08 11:44:48
GHS 10.50

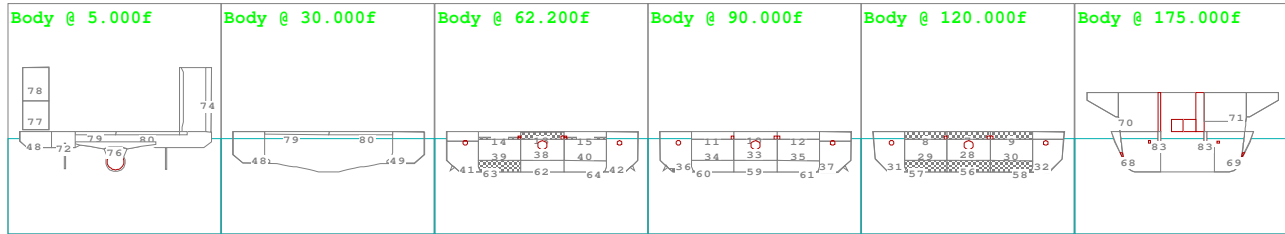
Dockwise Shipping B.V.
BLUE MARLIN
REFERENCE 0611266, STEP 4

Page 28
L004

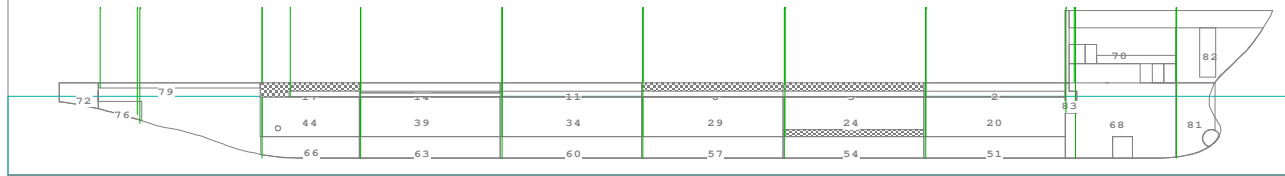


- | | |
|-----------------------|-----------------------------|
| ① Shear 1=200 MT | ③ Bending Mom. 1=4000 MT-M. |
| ② Shear Lim. 1=200 MT | ④ Bending Lim. 1=4000 MT-M. |

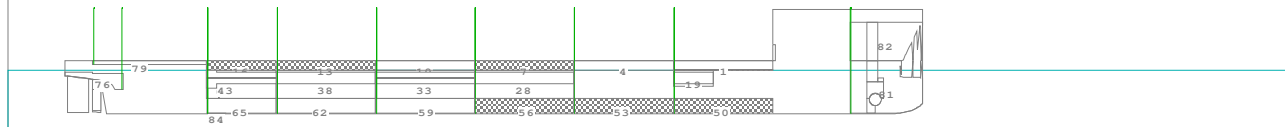
CG - Draft: 10.955 @ 206.500f, 10.957 @ 0.000 Heel: stbd 0.07 deg.



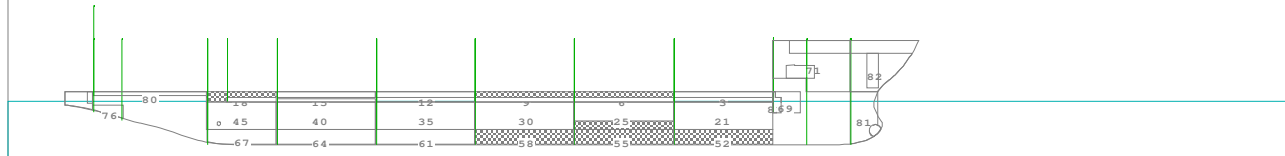
Profile View @ 7.500p



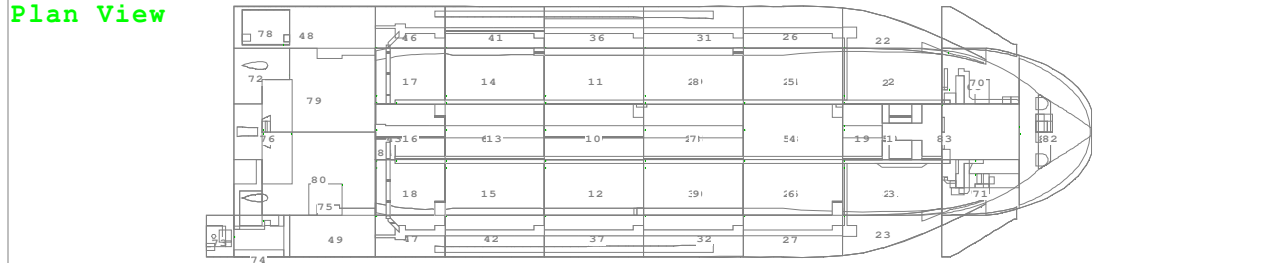
Profile View @ 0.000



Profile View @ 7.500s



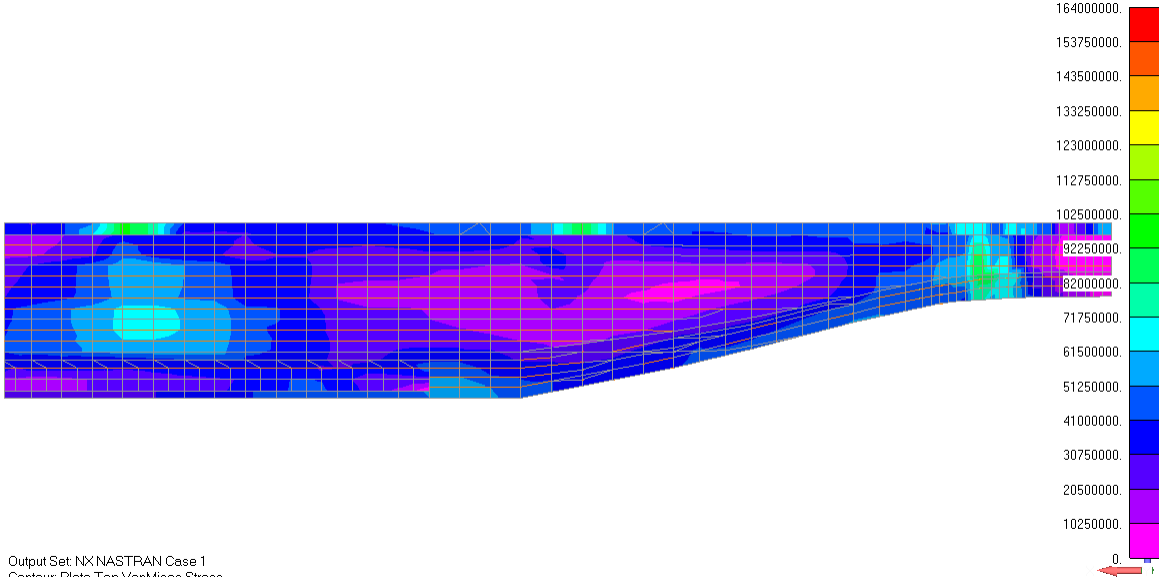
Plan View



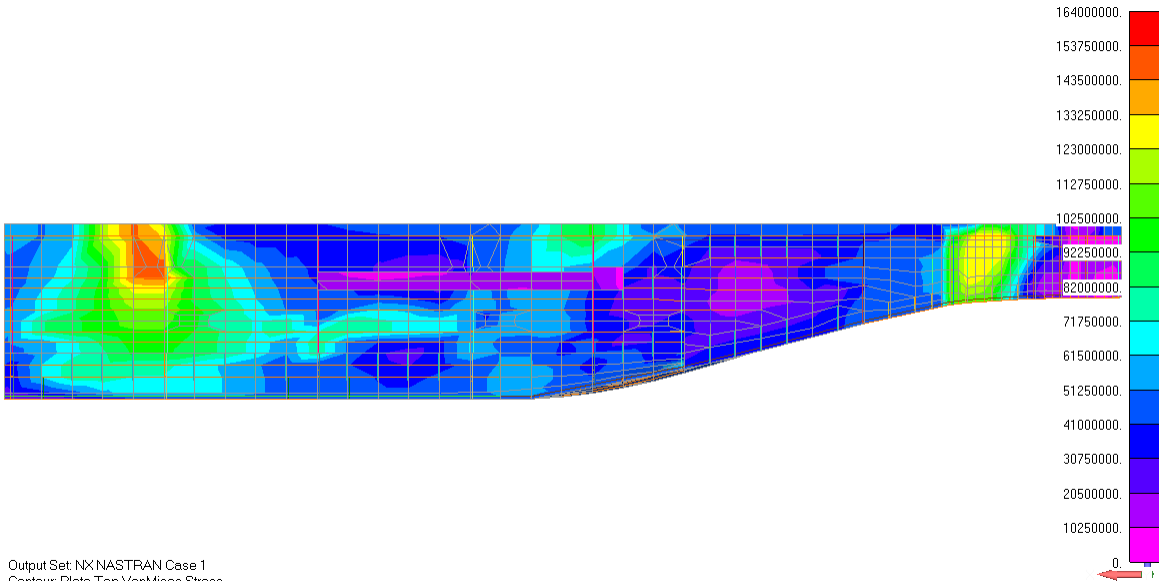
Tanks

1	WBT1U.C.....6%	17	WBT6U.P.....100%	34	WBT4M.P.....100%	51	WBT1L.P.....100%	68	WBTFLL.P.....0%
2	WBT1U.P.....0%	18	WBT6U.S.....100%	35	WBT4M.S.....100%	52	WBT1L.S.....100%	69	WBTFLL.S.....0%
3	WBT1U.S.....0%	19	WBT1M.C.....0%	36	WBT4O.P.....6%	53	WBT2L.C.....100%	70	WBTFU.P.....0%
4	WBT2U.C.....0%	20	WBT1M.P.....0%	37	WBT4O.S.....75%	54	WBT2L.P.....100%	71	WBTFU.S.....0%
5	WBT2U.P.....100%	21	WBT1M.S.....0%	38	WBT5M.C.....0%	55	WBT2L.S.....100%	72	WBTA.P.....0%
6	WBT2U.S.....100%	22	WBT1O.P.....0%	39	WBT5M.P.....0%	56	WBT3L.C.....100%	73	WBTPA.S.....0%
7	WBT3U.C.....100%	23	WBT1O.S.....0%	40	WBT5M.S.....0%	57	WBT3L.P.....100%	74	WBTPF.S.....0%
8	WBT3U.P.....100%	24	WBT2M.P.....17%	41	WBT5O.P.....75%	58	WBT3L.S.....100%	75	WBTAWL.S.....0%
9	WBT3U.S.....100%	25	WBT2M.S.....31%	42	WBT5O.S.....100%	59	WBT4L.C.....0%	76	WBTA.P.C.....0%
10	WBT4U.C.....0%	26	WBT2O.P.....0%	43	WBT6M.C.....100%	60	WBT4L.P.....0%	77	WBTA.P.L.....0%
11	WBT4U.P.....0%	27	WBT2O.S.....0%	44	WBT6M.P.....100%	61	WBT4L.S.....0%	78	WBTA.P.U.P.....0%
12	WBT4U.S.....0%	28	WBT3M.C.....0%	45	WBT6M.S.....100%	62	WBT5L.C.....0%	79	WBTA.P.C.....0%
13	WBT5U.C.....97%	29	WBT3M.P.....0%	46	WBT6O.P.....0%	63	WBT5L.P.....100%	80	WBTA.P.C.....0%
14	WBT5U.P.....29%	30	WBT3M.S.....0%	47	WBT6O.S.....100%	64	WBT5L.S.....0%	81	WBTA.P.C.....0%
15	WBT5U.S.....30%	31	WBT3O.P.....0%	48	WBT7O.P.....0%	65	WBT6L.C.....0%	82	WBTA.P.C.....0%
16	WBT6U.C.....100%	32	WBT3O.S.....80%	49	WBT7O.S.....100%	66	WBT6L.P.....0%	83	WBTA.P.C.....0%
		33	WBT4M.C.....100%	50	WBT1L.C.....100%	67	WBT6L.S.....0%	84	WBTA.P.C.....0%

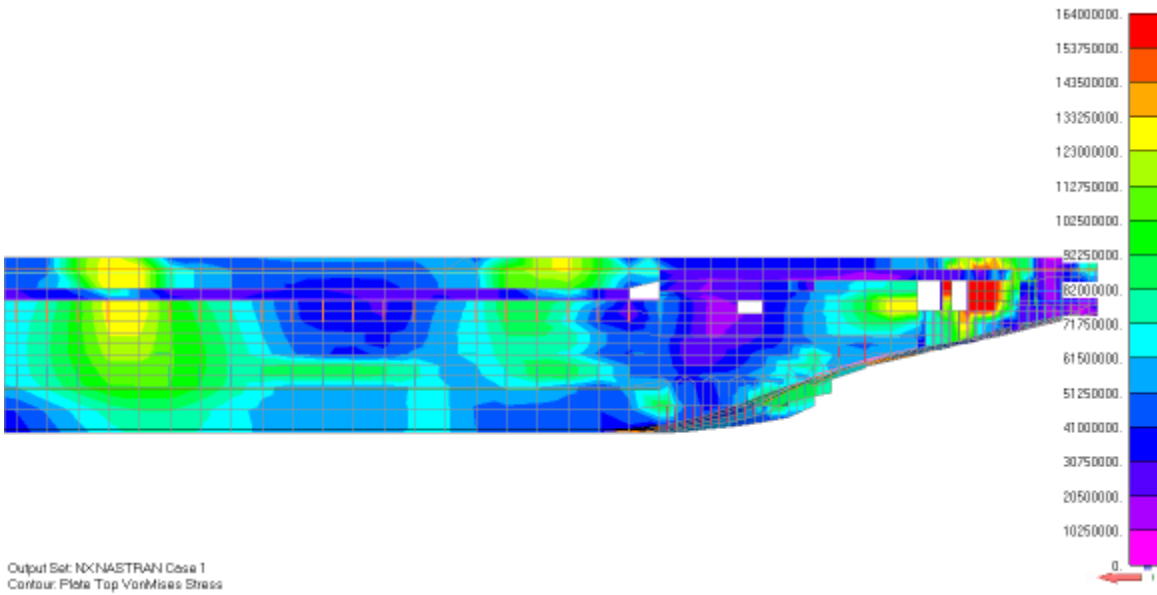
APPENDIX 11
Stress plots of the analysis step entire SPAR on vessel
with 4 skid beams by SPAR model loading



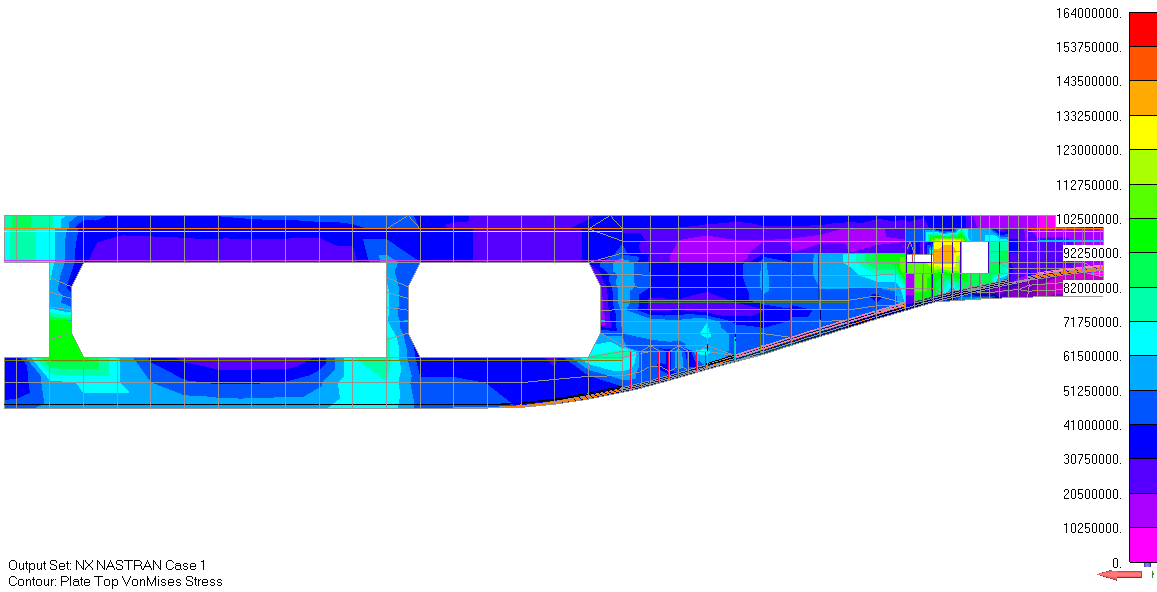
1. Stress components on Hull side shell on port side along the skid beam # 1



2. Stress components on longitudinal bulkhead under skid beam #2

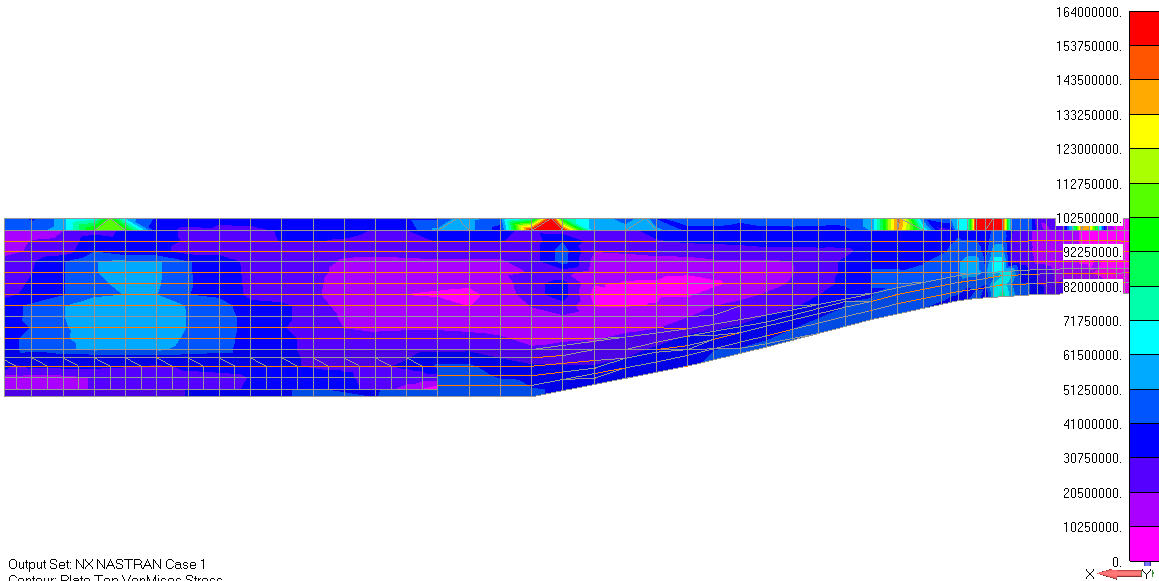


3. stress components on longitudinal bulkhead under skid beam #3

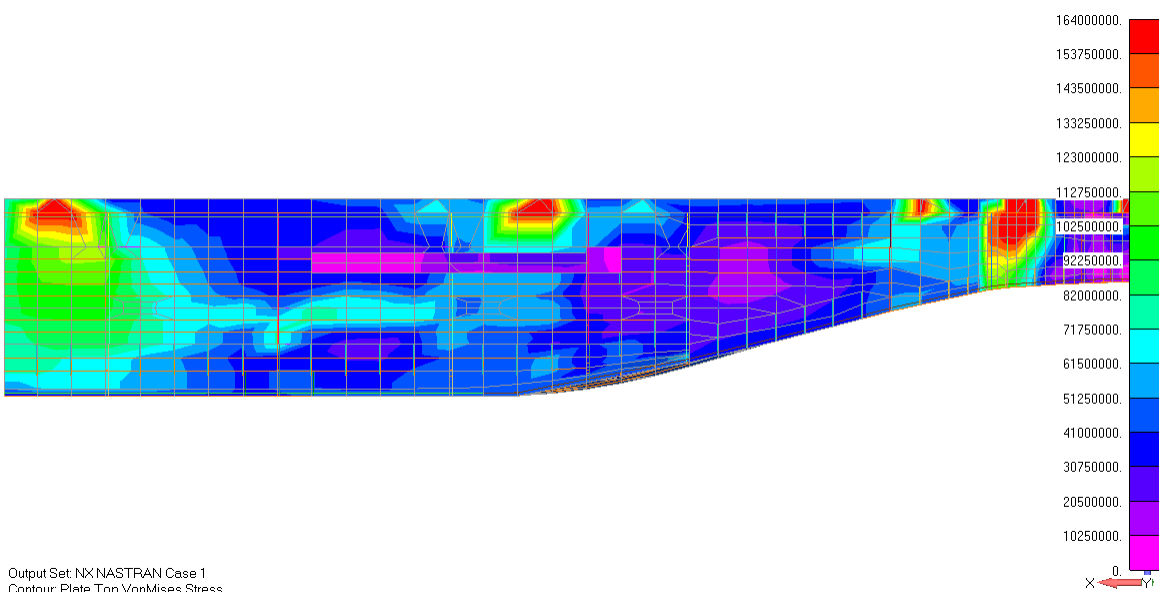


4. stress components on longitudinal sections under skid beam # 4

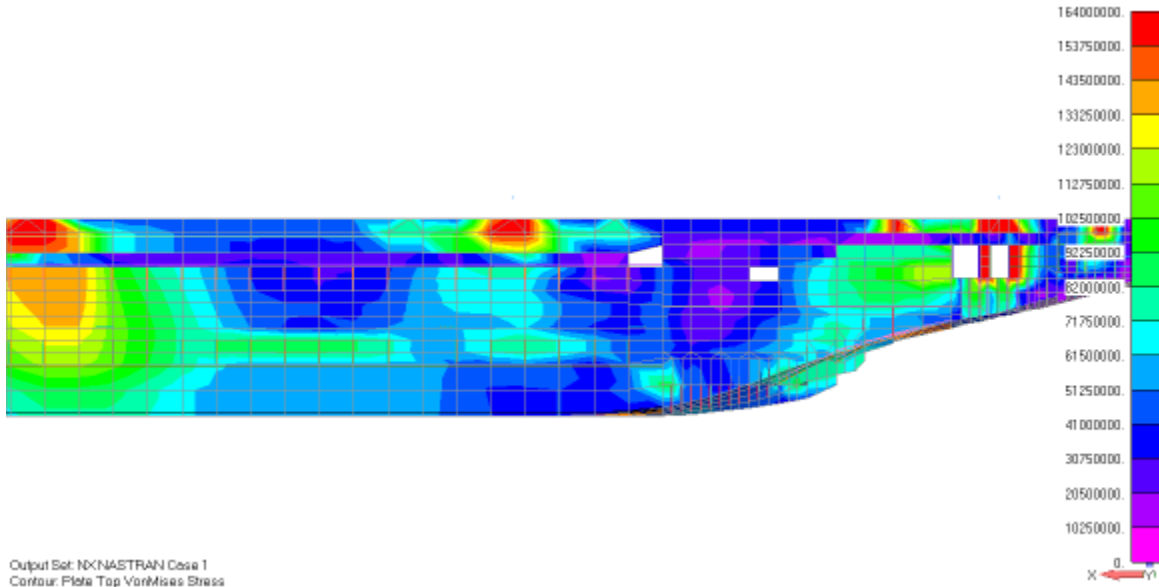
APPENDIX 12
Stress plots of the analysis step entire SPAR on vessel
with 3 skid beams by SPAR model loading



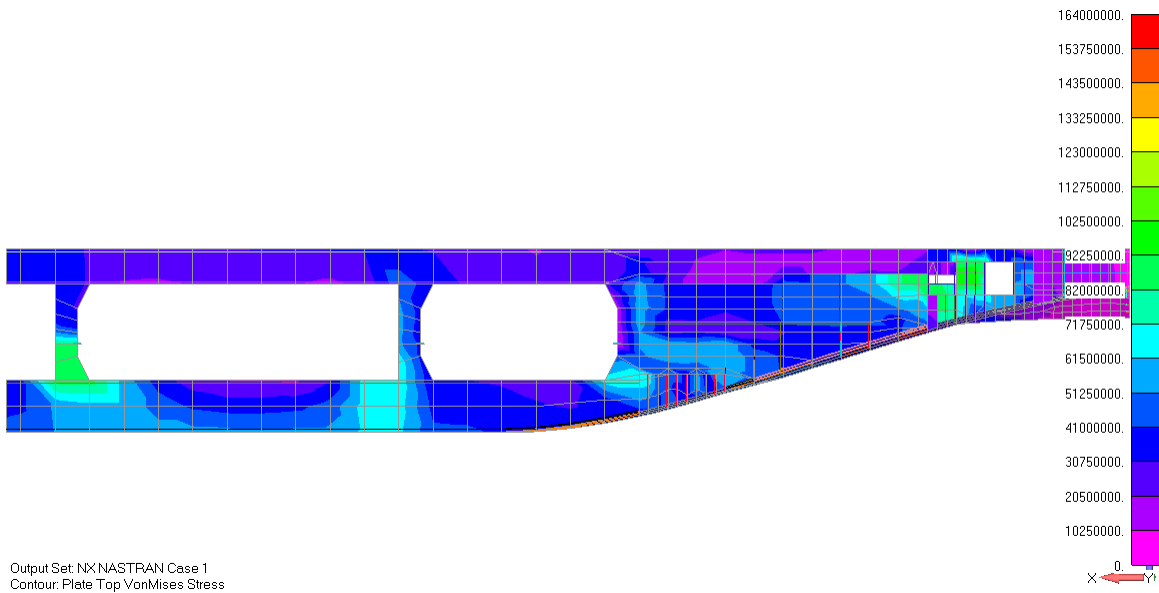
1. Stress components on Hull side shell on port side along the skid beam # 1



2. Stress components on longitudinal bulkhead under skid beam #2

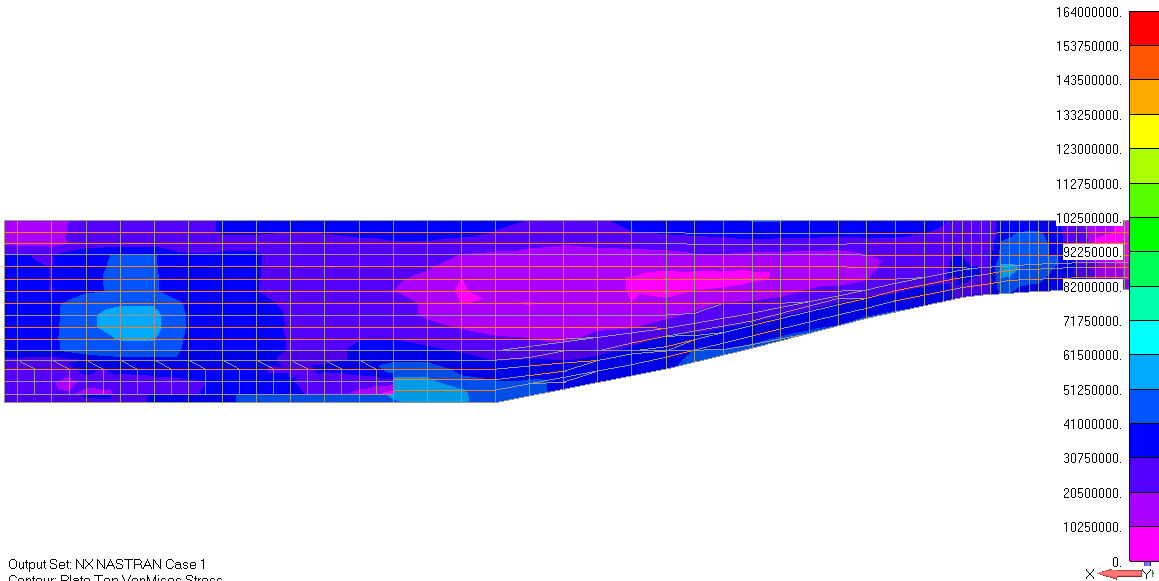


3. stress components on longitudinal bulkhead under skid beam #3

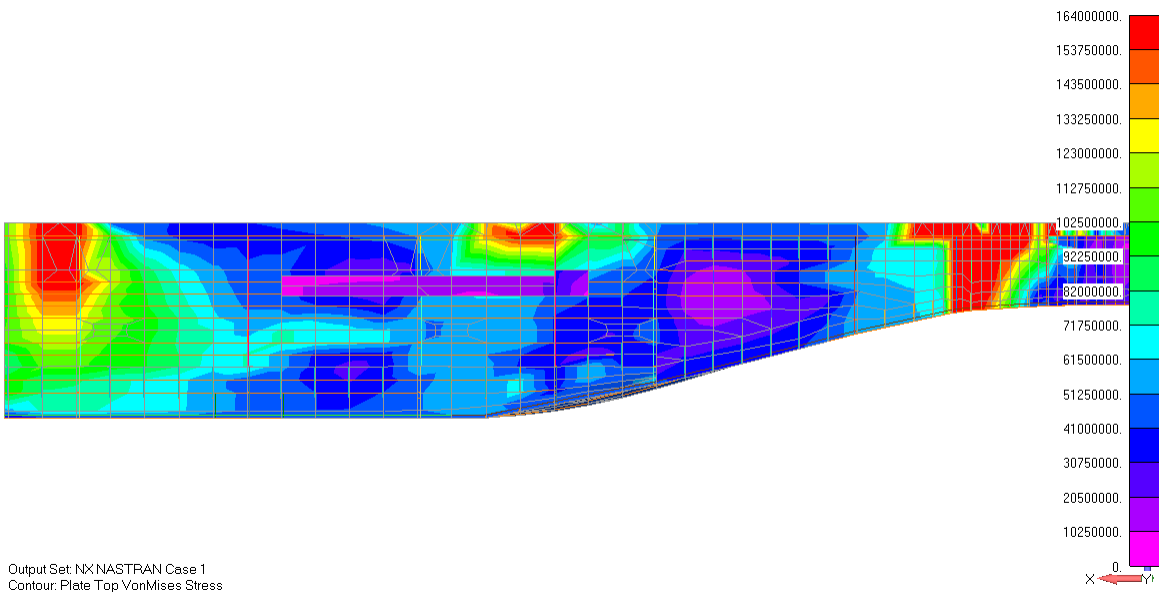


4. stress components on longitudinal sections under skid beam #4

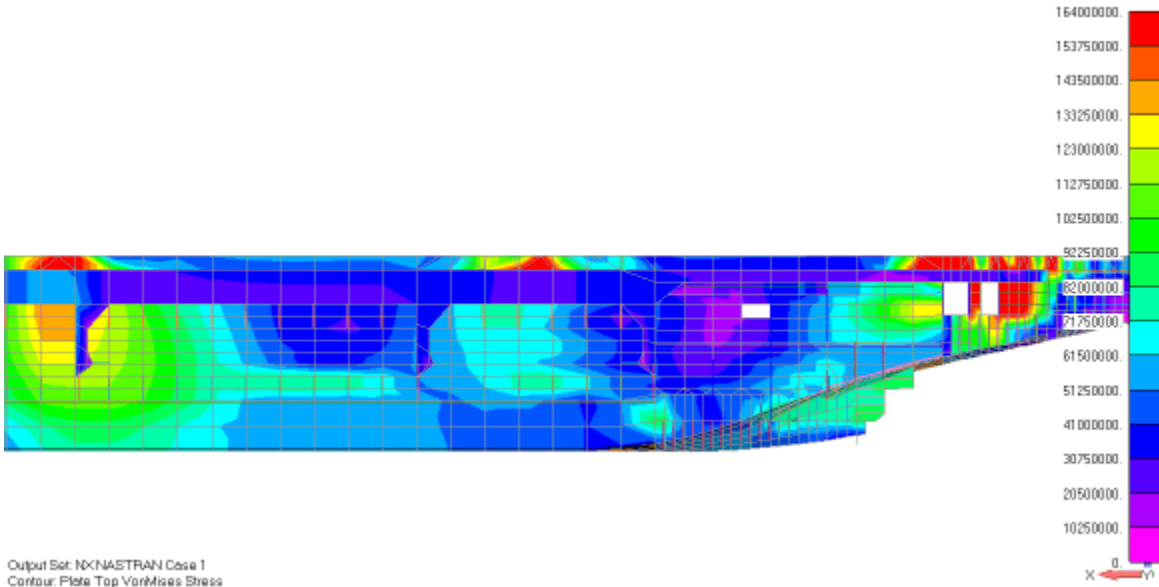
APPENDIX 13
Stress plots of the analysis step entire SPAR on vessel
with 2 skid beams by SPAR model loading



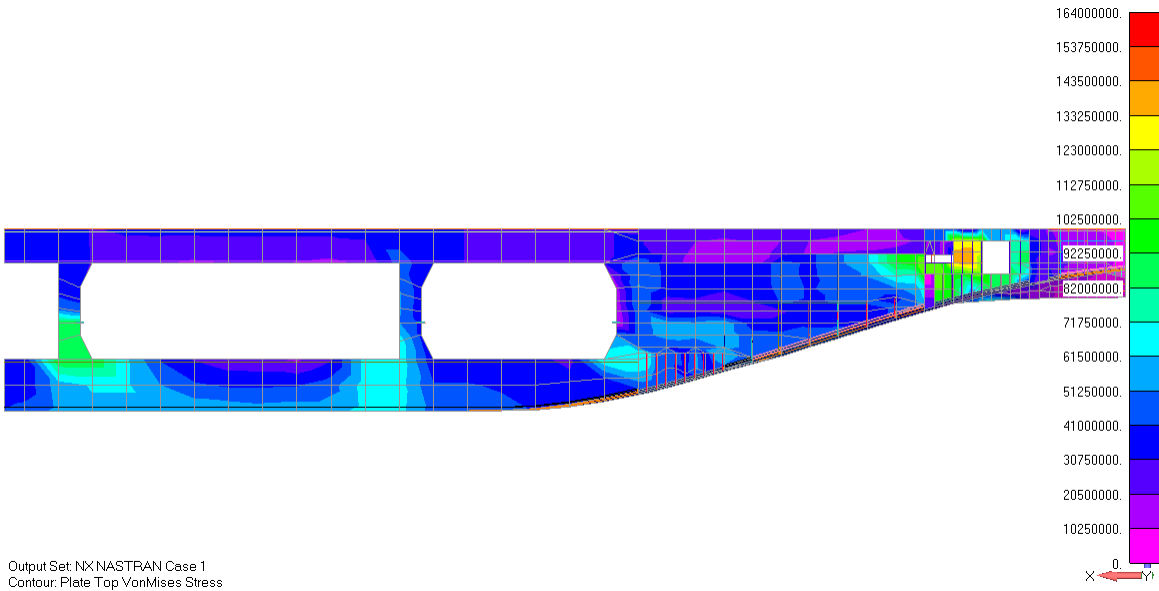
1. Stress components on Hull side shell on port side along the skid beam # 1



2. Stress components on longitudinal bulkhead under skid beam #2

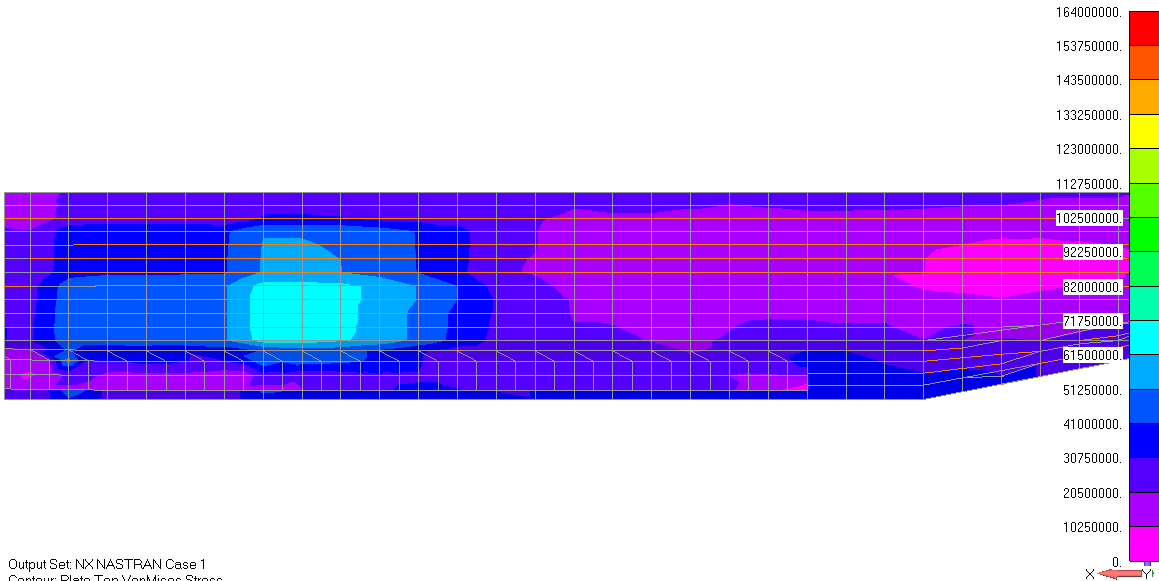


3. stress components on longitudinal bulkhead under skid beam #3

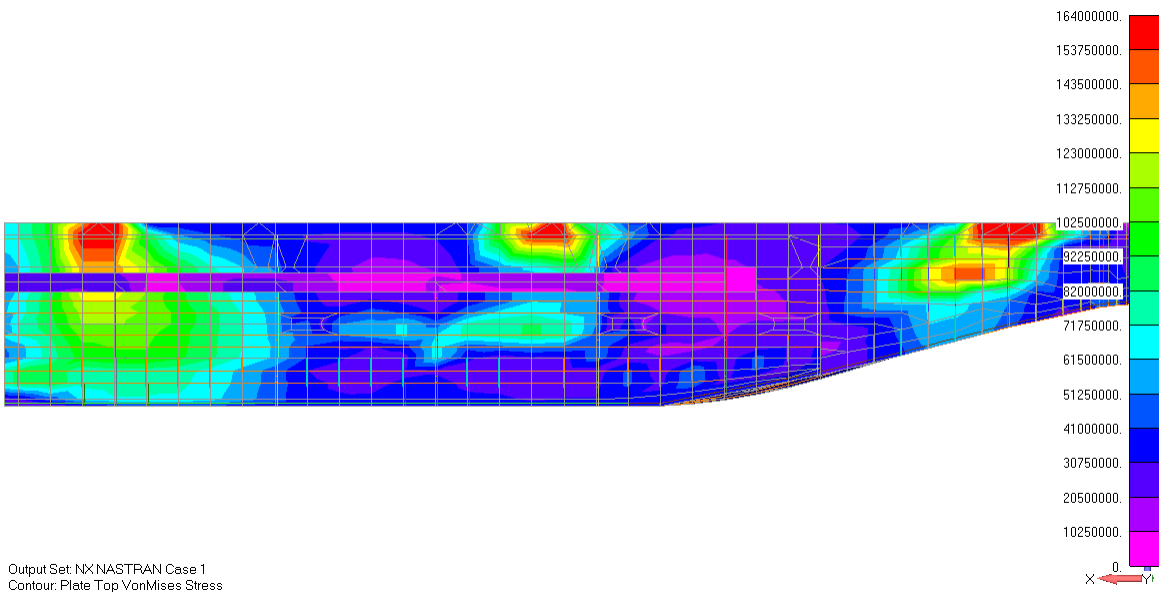


4. stress components on longitudinal sections under skid beam #4

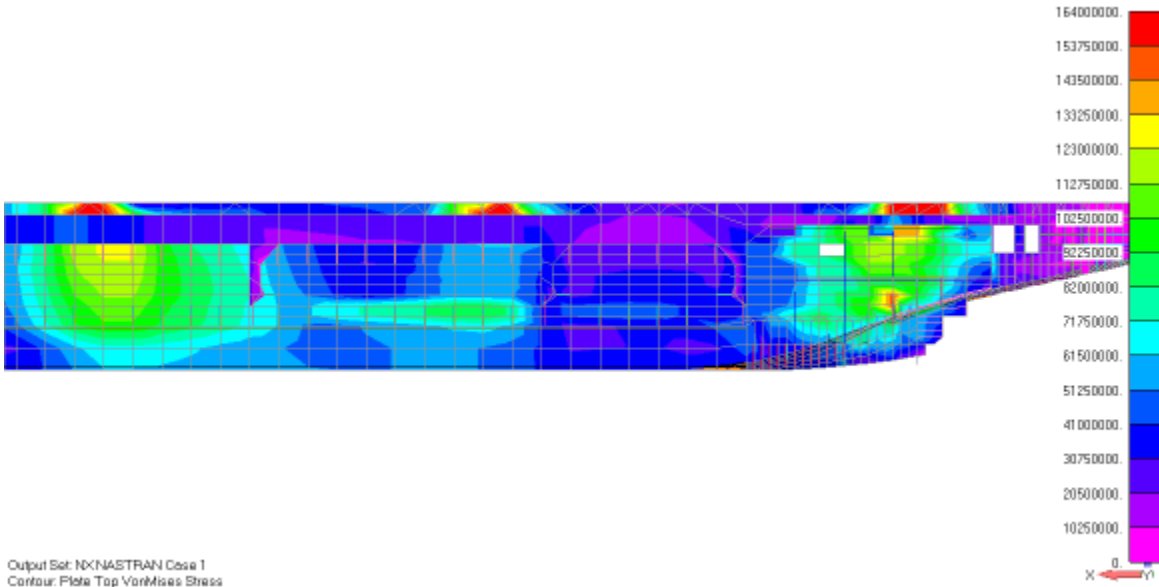
APPENDIX 14
Stress plots of the analysis step final stowage position
of SPAR on vessel with 2 skid beams



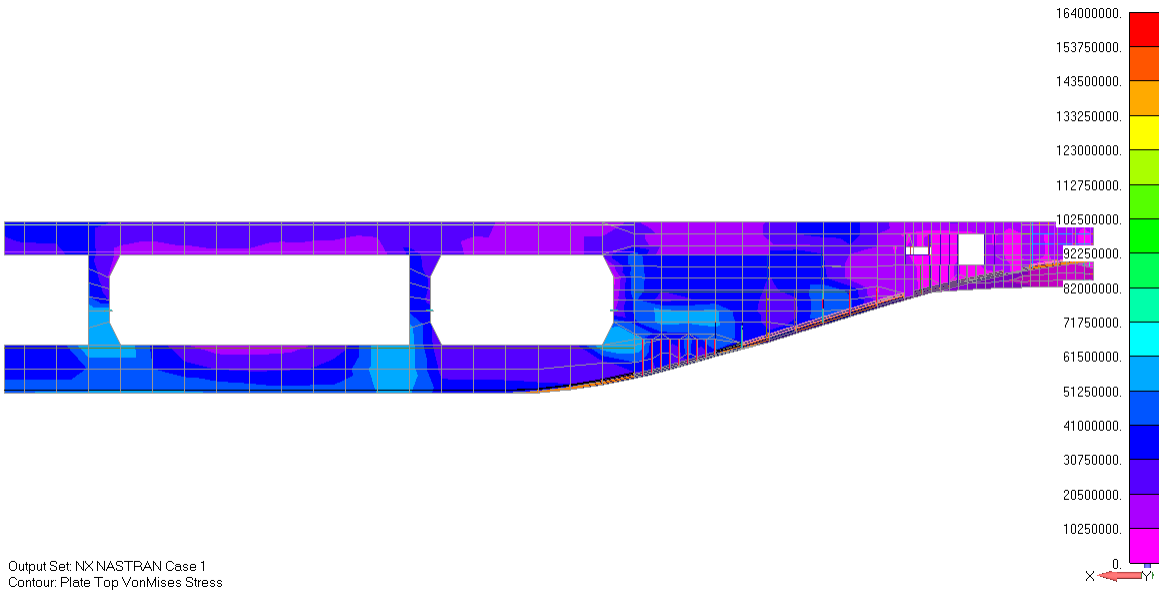
1. Stress components on Hull side shell on port side along the skid beam # 1



2. Stress components on longitudinal bulkhead under skid beam #2



3. stress components on longitudinal bulkhead under skid beam #3



4. stress components on longitudinal sections under skid beam #4

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