# SELF ELEVATING UNIT STRUCTURE GLOBAL FE ANALYSIS

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**Abstract:** *The scope of this document is to present the structural verification for the leg, leg to hull interface as well as the critical area in the hull. The paper describes the strength verification of the jack-house structure, leg well structure and the leg within the guides. The verification is performed for jacking and transit conditions. The platform basically consists of a hull, four circular legs and four hydraulic jacking systems. Prime movers are provided to supply power for propulsion, jacking, crane operations and domestic purposes. The main crane is arranged on a pedestal at the aft of the unit. The pedestal is integrated with the SB aft jack-house. An accommodation deck-house is arranged at the forward end. A helicopter landing deck is provided at the forward end of the hull. Five thrusters are arranged at the aft of the hull to provide propulsion for transit, station keeping and positioning next to a platform or wind turbine location.*

**Keywords:** *strength, finite elements, naval structure*

## 1. Introduction

This document describes the global hull structure analysis for a Windmill Carrier, having the main characteristics presented below. The cvasi-static linear analysis (displacements, reactions, forces, stresses) have been performed. The scope of this document is to present the structural verification for the leg, leg to hull interface as well as the critical area in the hull. The report describes the strength verification of the jack-house structure, leg well structure and the leg within the guides. The verification is performed for jacking and transit conditions.

FEA Solver was NX Nastran for Windows using FEMAP 11 as interactive graphic software tool, pre and post-processor designed for calculation codes using finite elements.

The FE-model consist out of 400000 nodes and elements. In addition, rigid links are used to describe load distribution from crane operation as well as the jacking system behavior. The types of finite elements which have been used to model the structure are:

- Plate elements used for deck plating, longitudinal and transverse bulkheads plates, and primary stiffener webs;
- Bar elements used for the rest of elements (secondary stiffeners);
- Rod elements used for bulb profiles flange;
- Mass elements used for simulating the mass of each equipment.

The mesh size is, generally, one longitudinal frame space (about 500 mm) in longitudinal, transverse and vertical directions. Finer mesh (about 150 mm) has been used in the connection area of the jack house with the hull structure.

The structure was modeled taking into consideration net thickness.

The global view of the models is presented in Fig. 1 for transit condition and 2 for jacking condition.

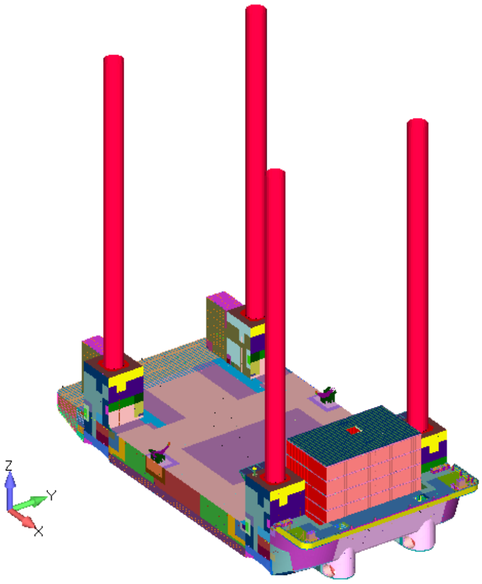


**Figure 1:** *Global FE model for transit condition*

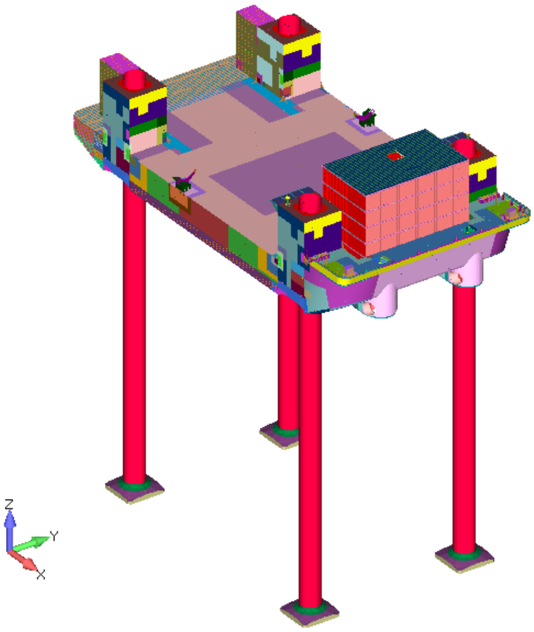


**Figure 2:** *Global FE model for jacking condition*

The leg structure is modeled with thin shell elements. Since the leg part of the model is not connected to the hull, it is not directly restrained. To prevent numerical problems the leg part is restrained with rod elements with a small stiffness.

The jacking system is modeled to transfer only the vertical leg load into the jack-house structure. No moment is dissipated by the jacking system. The vertical leg load is equally divided over and introduced at the jack-house.

For the elevated and transit conditions the vertical leg load is divided over the 4 jacking holes and 8 jacking system cylinders.

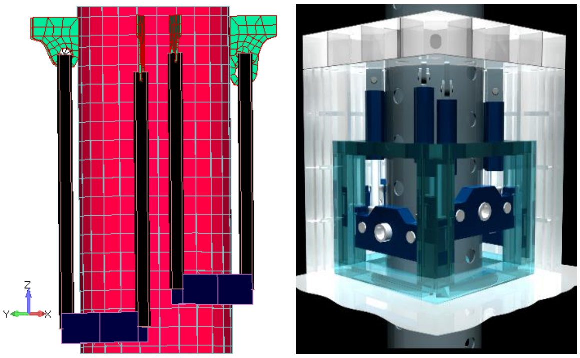


**Figure 3:** *The leg-hull interface system cylinders*

### 1.1 Main Characteristics

**Hull**

Length waterline - 80.0 m;
Width - 40.0 m;
Longitudinal distance between legs - 52 m;
Transversal distance between legs - 32 m;
Depth – 7 m;

**Legs**

Number – 4;
Type – closed circular leg;
Diameter – 4 m;
Length overall – 84 m.

## 2. Boundary conditions

### 2.1 Elevated model constraint

The FE-model is minimally constraint such that the rigid body motions are prevented. At the starboard aft, starboard forward and port side aft legs the model is constraint in vertical direction. At the starboard aft leg the model is constraint in both X and Y horizontal directions and at the port side aft leg the model is constraint in X-direction. On the lower part of the spudcan 0.4412 N/mm$^2$ pressure (reaction of the ground to the spudcan) was applied. Fig. 4 present the constraints applied for the elevated model.

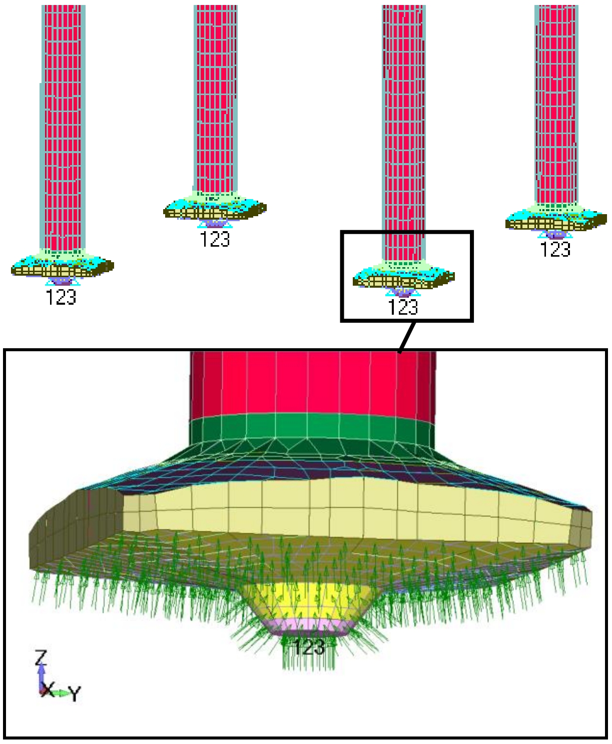


**Figure 4:** *Elevated model restraint*

### 2.2 Transit model constraint

To prevent numerical problems, the FE-model was constraint through rod elements in x, y and z direction (see Fig. 5**Error! Reference source not found.**). The others ends of the rods were fixed (all degree of freedom were restraint).

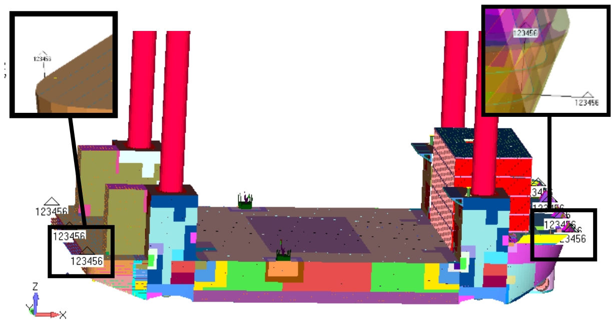


**Figure 5:** *In transit model constraints*

### 3. Loads

The load cases for elevated and transit conditions consist of a combination of the following loads:

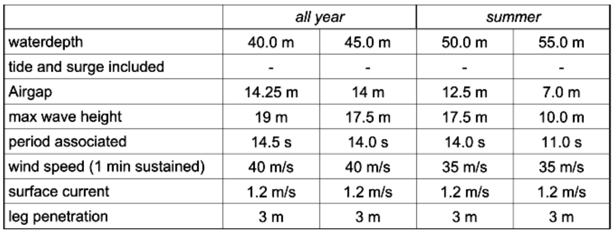
- Weight loads:
  - Light ship weight;
  - Consumables;
  - Pay load.
- Wave and Current Loads;
- Wind loads;
- Ship motion accelerations.

### 3.1 Loads for transit conditions

The load cases for elevated conditions are combinations of:

- Weight loads;
- Wave and Current Loads;
- Wind loads in order to maximize the effect of these at the structure.

The platform is designed to withstand the following combination of conditions:



| | *all year* | | *summer* | |
|---|---|---|---|---|
| waterdepth | 40.0 m | 45.0 m | 50.0 m | 55.0 m |
| tide and surge included | - | - | - | - |
| Airgap | 14.25 m | 14 m | 12.5 m | 7.0 m |
| max wave height | 19 m | 17.5 m | 17.5 m | 10.0 m |
| period associated | 14.5 s | 14.0 s | 14.0 s | 11.0 s |
| wind speed (1 min sustained) | 40 m/s | 40 m/s | 35 m/s | 35 m/s |
| surface current | 1.2 m/s | 1.2 m/s | 1.2 m/s | 1.2 m/s |
| leg penetration | 3 m | 3 m | 3 m | 3 m |

### 3.1.1 Weight loads

The horizontal center of gravity of the elevated weight of 11000 t (including approx. 2850 t variable load) is located within 0.1 m of hull centerline and between 0.1 m aft and 0.1 m forward to the center of the leg pattern.

Generally, the weight is applied to the FE-model in two ways, namely by gravity load on the modeled elements and by applying nodal forces. In this case the weight was applied by gravity load on the modeled elements. Large items, like main crane, with a specific location are modeled with a lumped mass connected to the hull with a constraint element. Structural weight of the construction and small weight items are distributed evenly over the modeled construction with a tuned density to simulated correct weight.

### 3.1.2 Wave and Current Loads

This load case is a development of the sine wave theory for deep water waves and may be used for determining the drag and inertial forces on the underwater portions of offshore unit.

The wave criterion was described by deterministic waves having shape, size and period appropriate to the depth of water in which the unit is to operate. Waves are to be considered as coming from any direction relative to the unit. Consideration is to be given to waves of less than maximum height where due to their period, the effects on various structural elements may be greater.

For structures comprised of slender members who do not significantly alter the incident wave field, semi-empirical formulations such as Morison's equation may be used. For calculations of wave loads on structural configurations which significantly alter the incident wave field, diffraction methods are to be used which account for both the incident wave force (i.e., Froude-Krylov force) and the forces resulting from wave diffraction and radiation.

In general, Morison's equation may be used for structures comprised of slender members the diameters of which are less than 20% of the wave lengths being considered and are small in relation to the distances between structural members subject to wave.

For each combination of wave height, wave period and water depth being considered, a range of wave crest positions relative to the structure is to be investigated to ensure an accurate determination of the maximum wave force on the structure.

The hydrodynamic force acting normal to the axis of a cylindrical member, as given by Morison's equation, is expressed as the sum of the force vectors indicated in the following equation:

$F_W = F_D + F_I$

where:

$F_W$ = hydrodynamic force vector per unit length along the member, acting normal to the axis of the member.

$F_D$ = drag force vector per unit length;

$F_I$ = inertia force vector per unit length;

The drag force vector per unit length for a stationary, rigid member is given by:

$F_D = (C/2) \cdot D \cdot C_D \cdot u_n \cdot |u_n|$ kN/m

where:

C = 1.025 (0.1045, 1.99)

D = projected width, in m, of the member in the direction of the cross-flow component of velocity (in the case of a circular cylinder, D denotes the diameter)

$C_D$ = drag coefficient (dimensionless)

$u_n$ = component of the velocity vector, normal to the axis of the member, in m/s

$|u_n|$ = absolute value of $u_n$, in m/s.

The inertia force vector per unit length for a stationary, rigid member is given by:

$F_I = C\,(\pi D^2/4) \cdot C_M \cdot a_n$ kN/m

where:

$C_M$ = inertia coefficient based on the displaced mass of fluid per unit length (dimensionless);

$a_n$ = component of the fluid acceleration vector normal to the axis of the member, in m/s$^2$.

According to this algorithm, resulted the forces and moments due to waves and tidal applied to the legs. Five different environmental load directions (at 0, 30, 45, 60 and 90°) are included in structural analysis for eight different phases of time, resulting 40 loading cases.

For the following seven cases, the effects of the environmental loads are maximum:

| Direction[°] | 0 | 30 | 45 | 45 | 60 | 90 | 90 |
|---|---|---|---|---|---|---|---|
| Time[s] | 0 | 0 | 0 | T/8 | 0 | 0 | T/8 |

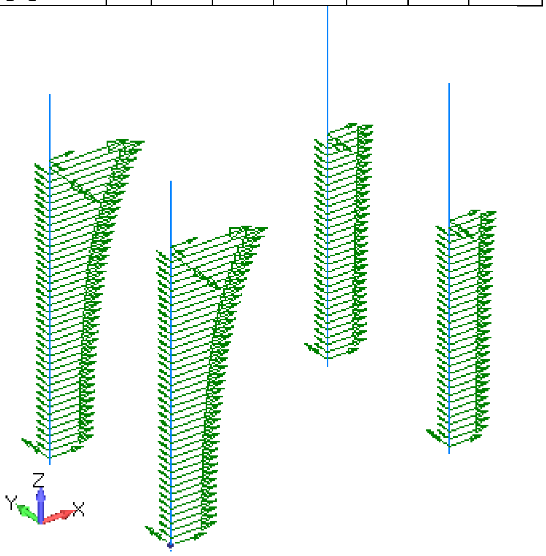


**Figure 6:** *Wave and current load direction for 0°and 30° at t=0s*

### 3.1.3 Wind loads

The wind force, F, is to be calculated in accordance with the following equation for each vertical area and the resultant force and vertical point of application is to be determined.

$F = P \cdot A$

where:

$F$ = force, in N;

$P$ = pressure, in N/m$^2$;

$A$ = projected area, in m$^2$ of all exposed surfaces in either the upright or heeled condition.

In the calculation of wind pressure, P, the following equation is to be used and the vertical height is to be subdivided approximately in accordance with the values listed in **Error! Reference source not found.** Part 3 Ch.1, Sect. 2, Table 1 and 2.

$P = f \cdot V_k^2 \cdot C \cdot C_s$ N/m$^2$

f = 0.611 (0.0623,0.00338);

$V_k$ = wind velocity in m/s;

$C_h$ = height coefficient;

$C_s$ = shape coefficient.

The minimum wind speed was considered Vk = 40 m/s (1 min. sustained), in elevated conditions.

According to "**Error! Reference source not found.**", the following expression can be used for calculation of the mean wind speed U with averaging period T at height z above sea level as

$$U(T,z) = U_{10} \cdot (1 + 0.137 \ln \frac{z}{H} - 0.047 \ln \frac{T}{T_{10}})$$

where H = 10 m and $T_{10}$ = 10 minutes, and where $U_{10}$ is the 10-minute mean wind speed at height H. This expression converts mean wind speeds between different averaging periods.

When $T < T_{10}$, the expression provides the most likely largest mean wind speed over the specified averaging period T, given the original 10-minute averaging period with stationary conditions and given the specified 10-minute mean wind speed $U_{10}$.

The wind forces and moments have been calculated and applied to structure

### 3.2 Loads for transit conditions

The loading conditions are in addition to be defined to cover the full range of still water bending moments and shear forces from maximum sagging to maximum hogging conditions.

Design loads have been determined for loading conditions giving maximum vertical bending moment amidships.

The stillwater bending moment and shear forces shall be combined with the corresponding extreme wave loads such that sets of simultaneously acting loads are obtained.

The hydrodynamic model and the mass model are in proper balance, giving still water shear force distribution with zero value at FP and AP. Any imbalance between the mass model and hydrodynamic model was corrected by modification of the mass model.

The number of elements near the surface is sufficient in order to represent the change of pressure amplitude and phasing of different wave loads.

The load cases for transit conditions consist of a combination of the following loads:

- Inertia loads for both structural and non-structural members;
- External hydro pressure loads;
- Internal pressure loads from ballast;
- Wind loads.

The internal pressure loads may be exchanged with mass of the liquid (with correct center of gravity) provided that this exchange does not significantly change stresses in areas of interest (the mass must be connected to the structural model).

The unit is designed to sail under the following conditions:

- Displacement approx. 13900 t;
- Draft hull (average) 4.7 m.

Legs retracted, spudcans flush with the bottom.

Inertia loads have been applied as acceleration or gravity components. The roll and pitch induced fluctuating gravity component in sway and surge have been included.

Structural weight of the construction and small weight items are distributed evenly over the modeled construction with a tuned density to simulated correct weight.

In stillwater, the weight of the ship (13900 t) is in balance with the external hydrodynamic pressure loads corresponding for an average draft hull of 4.7m.

For hogging condition, the length of wave has been considerate equal with length of ship and the peak amid ship. The maximum heave acceleration $a_{heave} = 0.82\ m/s^2$ has been considerate.

For operating conditions the calculations are performed in three steps:

Step one: the ship model is equilibrate in still water in order to calibrate the model and to obtain a good re-start point for the dynamic loading;

The model was equilibrate for a draft of 4.664 m (see Fig. 7).

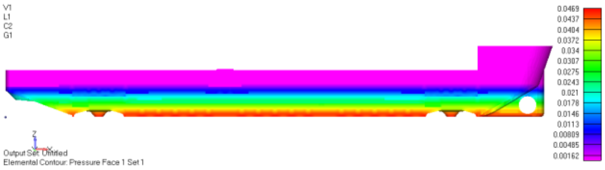


**Figure 7:** *External hydro pressure loads - still water*

Step two: the ship model is loaded with the inertia forces and wave sea pressure, according to "**Error! Reference source not found.**". The significant wave height considered is Hs = 2 m, leading to a maximum wave height of $H_{max} = 1.86 \times 2 = 3.72$ m.

The model was equilibrate for a draft as 3.808 m and a wave with amplitude 1.86 m (see Fig. 8).

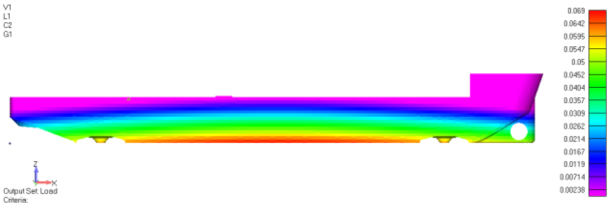


**Figure 8:** *External hydro pressure loads – wave amid ship*

Step three: the ship model is loaded with the inertia forces, head seas and wave sea pressure.

For head seas case the angular pitch acceleration that lead to model equilibrium was found as 0.07 rad/s2.

The trim angle as 4.15°, draft as 3.780 m and a wave with amplitude 1.86 m were considerate (see Fig. 9).

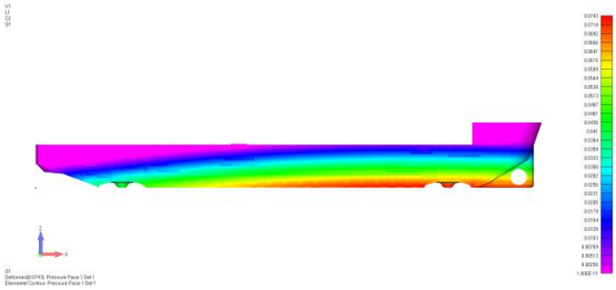


**Figure 9:** *External hydro pressure loads – trim and wave amid ship*

Transit conditions, draft 3.788 m, wave amplitude 1.86 m.

Body acceleration: $-(9.81 + 0.82) = -10.63\ m/s^2$, with vertical acceleration aheave = $0.82\ m/s^2$.

Sinusoidal wave with amplitude of 1.86 m and length equal with the ship length, applied with the crest amidships. This distribution gives minimum buoyancy in aft and fore parts of ship.

The pressure function of the wave is:

$p(x,z) = g \cdot \rho \cdot (T + h_{wave} \cdot \sin(x/L) - z)\ \ N/mm^2$

where:

$g = 9810\ mm/s^2$;

$\rho = 1.025e\text{-}9\ kg/mm^3$;

T = 3788 mm – draft;

hwave = 1860 mm – wave amplitude;

L = 81000 mm – ship length.

O(0,0,0) is situated at intersection between aft perpendicular, base line and center line.

The pressure function applied to this model is:

$p(x,z) = 9810 \cdot 1.025e\text{-}9 \cdot (3788 + 1860 \cdot \sin(x/81000) - z)\ \ N/mm^2$.

## 4. Results

According to "**Error! Reference source not found.**" Part 3 Ch. 2 Sec. 1, for plated structures, members may be designed according to the Von Mises equivalent stress criterion, where the equivalent stress is not exceed $F_y/F.S.$

|  | $F_y$ [N/mm$^2$] | $\sigma_{allowable}$ [N/mm$^2$] |
|---|---|---|
| H36 | 355 | 322 |
| EQ70 | 690 | 627 |

F.S. = 1.1 - factor of safety.

The following sections show the occurring plate stress distribution within the global model for transit and jacking conditions. Due to a high number of analyzed load combinations, only the governing load combination results are shown for all two condition types.

For each shown load combination a plot of the global model with its applied loads and masses is shown. In addition a global plot of the Von Mises stress results is given.

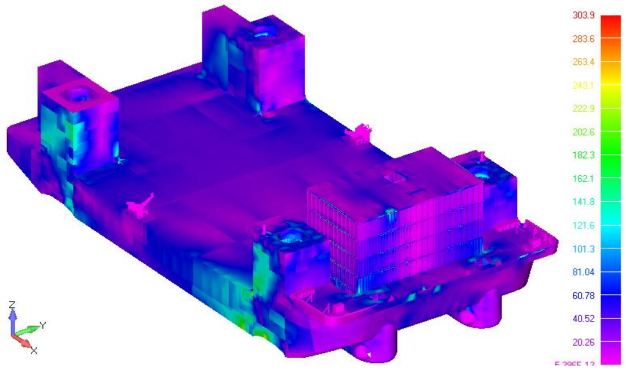


**Figure 10:** *Von Mises stress for global model (elevated condition)*

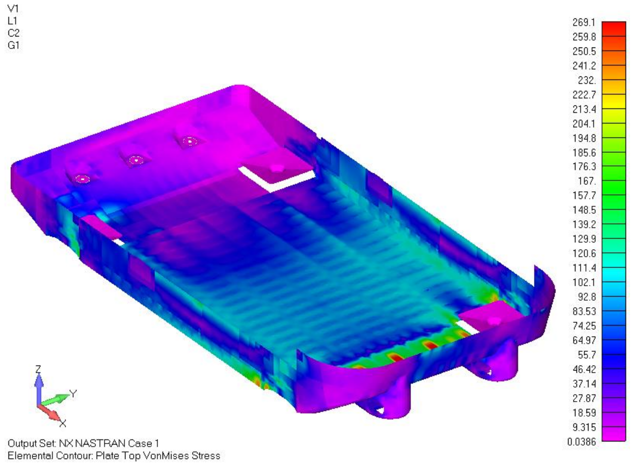


**Figure 11:** *Von Mises stress for shell (elevated condition)*

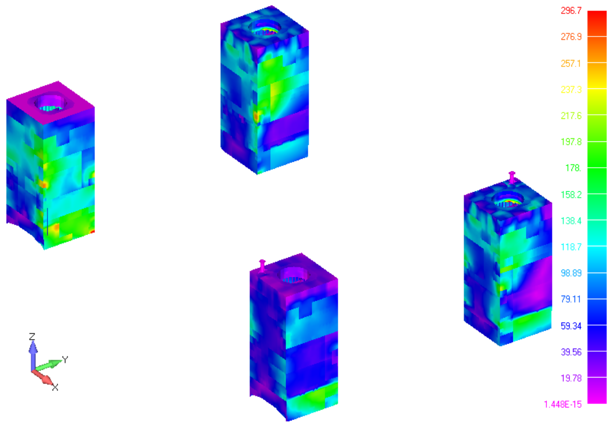


**Figure 12:** *Von Mises stress for shell (elevated condition)*

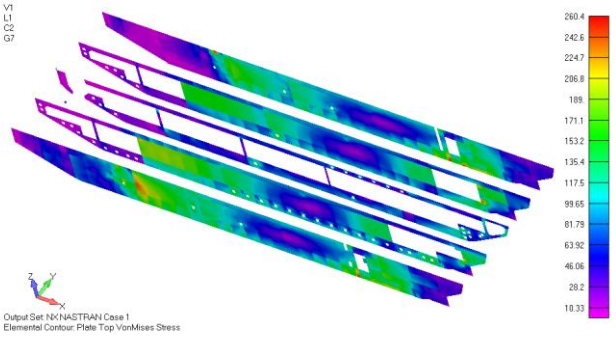


**Figure 13:** *Von Mises stress for longitudinal bulkhead (transit condition)*

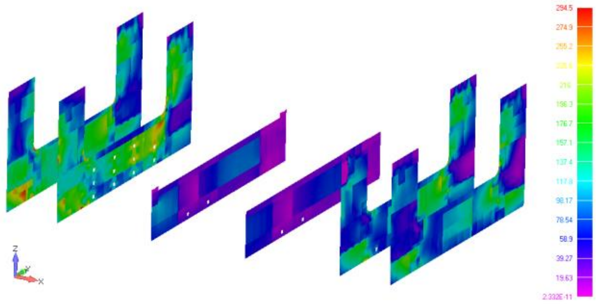


**Figure 14:** *Von Mises stress for transversal bulkhead (elevated condition)*

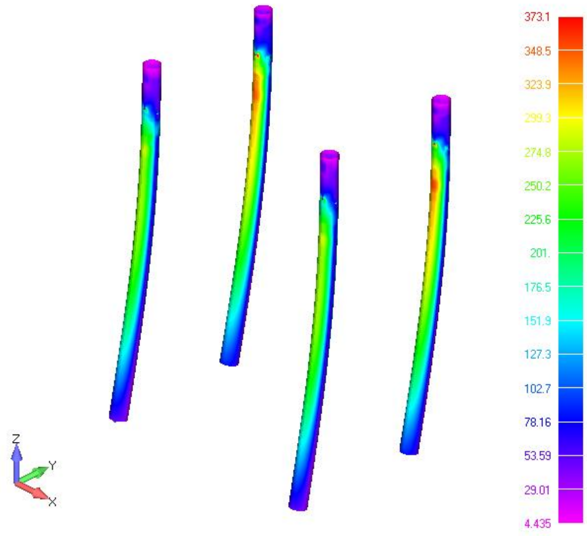


**Figure 15:** *Mises stress for legs (elevated condition)*

**Figure 16:** *Von Mises stress for spudcan for LC2 (elevated condition)*

## 5. Conclusions

The structural strength of the normal jack-houses, leg wells and leg structures have been verified to comply with the ABS regulations.

The stresses determined using Femap 11.0 have been compared with the allowable values presented in this report. The scantlings of the structure have been iteratively modified so that the yielding acceptance criteria to be satisfied.

The presented analysis leads to the conclusion that the overall yield strength of the jack-house, leg well and leg structure is sufficient.

## References

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