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GLOBAL STRENGTH ANALYSIS IN HEAD WAVES OF AN FSO UNIT, BASED ON USER SUBROUTINES TECHNIQUE

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ABSTRACT

For the analysis of the FSO global strength, the modern approaches are based on FEM models developed over the ship length with equivalent wave loads. This paper presents the global strength analysis in head waves of an FSO unit for oil storage and off-loading. The head wave and FSO ship system equilibrium is obtained by own user subroutines, package Eq_Trim, implemented as API codes in the Femap program. The numerical results are assessed by the yielding stress ratio criterion, pointing out the structural parts that have to be improved in the design process.

Keywords: FSO global strength, 3D-FEM, equivalent head wave loads, FSO unit.

1. INTRODUCTION

The FSO global strength based on 3D-FEM models, with equivalent head wave loads, requires iterative procedures [8],[9] applied directly on the 3D structural model.

Previous implementations [4] were done using procedures such as macro-command files implemented in the SW Cosmos/M [10] program. Because of geometric non-linearities of the external shell and the interpreter programming language technique used before, the iterative procedure on 3D-FEM models has required a significant amount of simulation time.

The iterative algorithm for the head waves and FSO ship system equilibrium can be improved in terms of simulation time by implementing the numerical procedures [4] as user subroutines using the API programming language from Femap [7],[3].

Figure 1 presents the main flowchart of the algorithm for the ship - head wave equilibrium computation, implemented in the own *Eq_Trim* package [3] as API user-subroutines in the Femap [7] program.

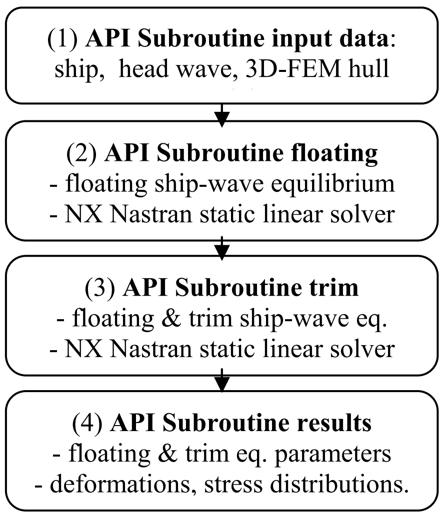

Fig.1 The main flowchart for ship-wave equilibrium, head wave condition, based on *Eq_Trim* API user subroutines in Femap [7].

The own iterative algorithm for ship-head wave equilibrium includes four main parts:
(1) Subroutine input data. The following data are selected: the ship displacement and length, still water plane centre longitudinal

position, draught minimum, maximum and step values; head wave height; water density and gravity acceleration; longitudinal trim step value; the FSO 3D-FEM model developed by the Femap [7] program, extended on one side; the reference aft and fore master nodes.

(2) Subroutine floating. The iterations on the draught parameter are included in this subroutine. On each iteration, the NX Nastran [7] linear static solver is used for the objective function representing the sum of the two vertical reaction forces at the aft and fore master nodes. The convergence is obtained when the objective function becomes close to the zero value.

(3) *Subroutine trim.* The iterations on the longitudinal trim parameter are included in this subroutine. On each iteration, by NX Nastran [7] solver, the vertical reaction forces at the two master nodes are computed. The convergence is reached when both reaction forces become close to the zero value.

(4) *Subroutine results*. Based on the last iteration results on the 3D-FEM model, the deformations and the stress distributions are obtained over the hull structure, which are assessed according to the classification rules for offshore floating units [1].

The structural elements strength is assessed by the *YR* yielding stress ratio criterion defined according to the Bureau Veritas rules [1], implemented in the user subroutine module 4, with the following expression:

$$YR = \sigma_{vM} / \sigma_{rule} \tag{1}$$

$$\sigma_{rule} = \sigma_y / (\gamma_m \cdot \gamma_R) \tag{2}$$

where σ_{vM} is the equivalent von Mises stress in the assessed element; σ_y is the material yielding stress; γ_m =1.02 and γ_R =1.02÷1.20 are the material and resistance factors according to the element type.

More details concerning the theoretical basis of the own iterative algorithm (Fig.1) see references [3],[4].

As study case, the numerical analysis is carried out on an FSO [5] floating unit for oil storage and off-loading (section 2), considering two loading cases and the equivalent head wave on sagging and hogging conditions.

2. THE 3D-FEM FSO NUMERICAL MODEL AND THE LOADING CASES

In Table 1 there are the FSO unit [6] main characteristics included in this study.

Table 1. FSO main characteristics

Length between perpendiculars	*LBP*	237 *m*
Breadth	*B*	40 *m*
Depth	*D*	24 *m*
Maximum draft	T_{max}	16 *m*
Minimum draft	T_{min}	9 *m*

According to the BV Rules [1], two loading cases are considered for the FSO unit: full load condition and ballast condition. Fig.2 presents the lightship mass distribution. Figs. 3,4 present the onboard tanks filling for the full loading case (aft and cargo tanks) and ballast case (sides, bottom, aft and fore tanks).

Table 2 presents the FSO steel material characteristics [1]. The main deck panel is made of high tensile steel (HTS32) and the rest of the structure is made of mild steel grade A.

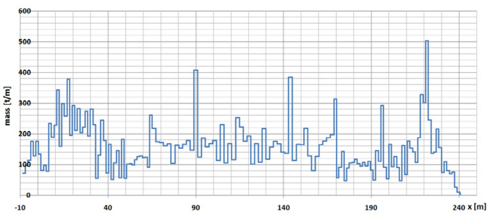

Fig.2 FSO mass [t/m] lightship distribution

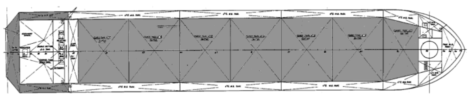

Fig.3 FSO tanks filling for the full load case

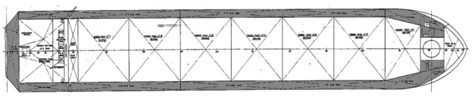

Fig.4 FSO tanks filling for the ballast case

Table 2. FSO steel material characteristics

Young's modulus	*E*	206000 MPa
Poisson's ratio	ν	0.3
Density	ρ	7.85 t/m^3
Yield stress (mild steel)	σ_Y	235 MPa
Yield stress (HTS32)	σ_Y	315 MPa

The 3D-FEM FSO hull model is developed by the Femap [7] program, one side due to the centre plane symmetry and head wave external loading condition. The mesh density and the type of elements, membranes-plates and beams [4] are according to CSR-IACS [2] rules. The superstructures on the main deck are also included in the numerical 3D-FEM model.

Figs.5÷11 present the details of the FSO 3D-FEM hull structural model.

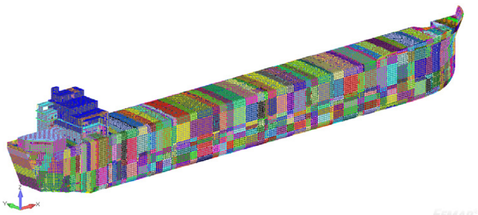

Fig.5 FSO 3D-FEM model - general view

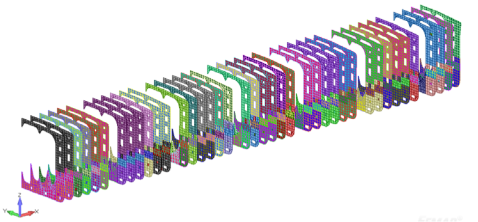

Fig.6 FSO 3D-FEM model – transversal web frames in the cargo holds part

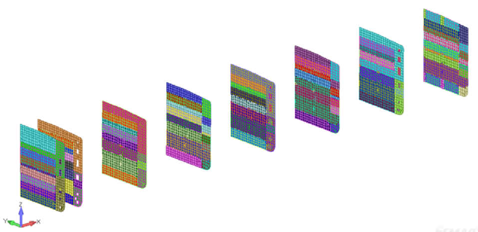

Fig.7 FSO 3D-FEM model - transversal bulkhead TBHD in the cargo holds part

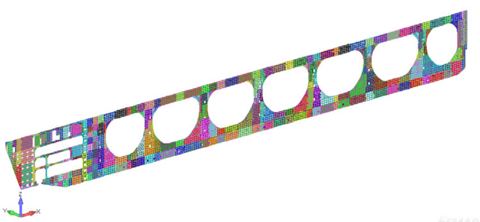

Fig.8 FSO-3D FEM model – centre line web

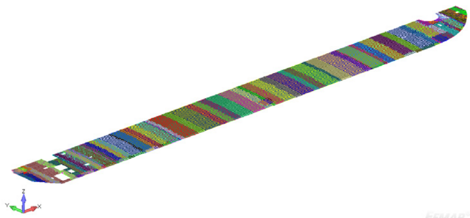

Fig.9 FSO 3D-FEM model–main deck shell

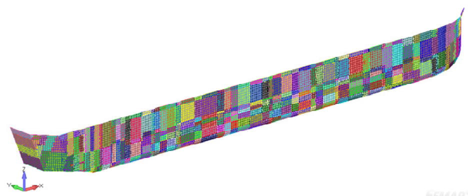

Fig.10 FSO 3D-FEM model – side shell

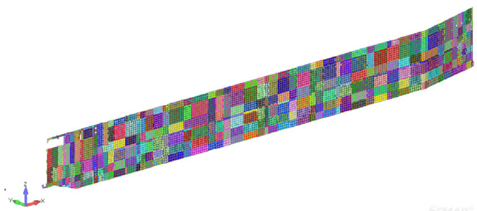

Fig.11 FSO 3D-FEM model–inner hull shell

The boundary conditions applied on the FSO 3D-FEM hull model are shown in Figs.12,13 and Table 3. The symmetry centre-plane boundary conditions are considered (Fig.12), with transversal displacement and rotation around the restrained longitudinal axis. Moreover, at the aft and fore (Fig.13) master nodes, placed in the centre plane and the main deck plane, at both ship extremities, the vertical displacements are restrained, those reaction forces being used for the convergence tests of the iterative algorithm (Fig.1). At aft node the longitudinal displacement is also restrained.

Table 3. FSO 3D-FEM boundary conditions

Nodes	*Degree of freedom on nodes*					
	TX	*TY*	*TZ*	*RX*	*RY*	*RZ*
CL sym		X		X		
ND 1 aft	X	X	X	X		
ND 2 fore		X	X	X		

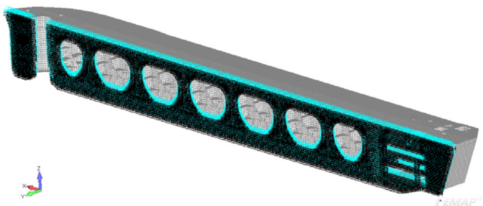

Fig.12 FSO 3D-FEM symmetry boundary conditions in the centre plane

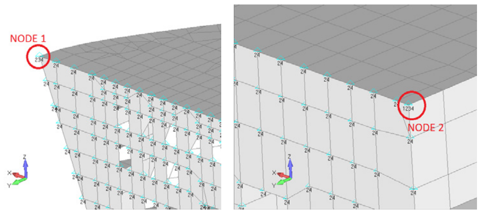

Fig.13 FSO 3D-FEM boundary conditions at aft ND 1 and fore ND 2 master nodes

3. THE NUMERICAL ANALYSIS OF FSO UNIT GLOBAL STRENGTH IN HEAD WAVE EQUIVALENT LOADS

According to the Bureau Veritas Rules [1], the design equivalent wave is H_w=10.25m. In order to cover the whole wave height range, the numerical strength analyses are carried out for wave height H_w=0÷12 m, with the step of 2 m. On both loading cases, the sagging and hogging head equivalent wave conditions are considered.

The FSO still water equilibrium conditions, T_{aft} and T_{fore} draughts, for the two loading cases are shown in the following table.

Table 4. The FSO still water eq. conditions

Load case	T_{aft} [m]	T_{fore} [m]	*Trim* [deg]
Full cargo	15.908	14.324	0.383
Ballast	9.844	11.604	-0.425

Fig.14 presents the head equivalent wave pressure applied on the FSO external shell, full load case, H_w=10.25m, sagging condition.

Figs. 15÷18 present the *YR* yielding stress ration distribution (1), for the full loading case, head equivalent wave on sagging condition, with height H_w=0÷12 m, based on the own iterative algorithm (Fig.1).

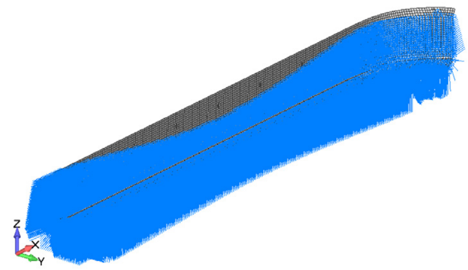

Fig.14 FSO full load case, equivalent wave pressure on the 3D-FEM model external shell, H_w = 10.25 m, wave sagging condition.

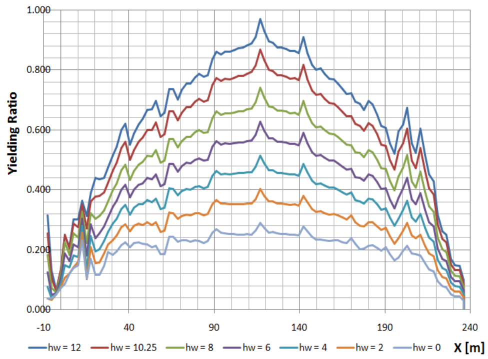

Fig.15 FSO 3D-FEM, main deck *YR* yielding stress ratio, full load case, H_w=0÷12 m, wave sagging condition

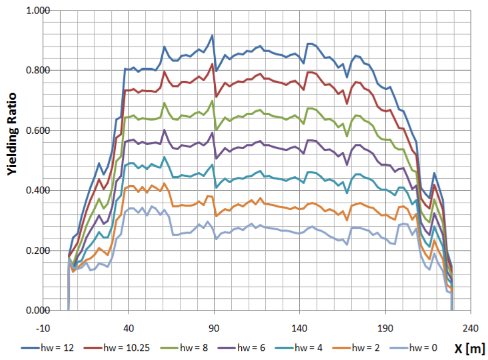

Fig.16 FSO 3D-FEM, longitudinal bulkhead *YR* yielding stress ratio, full load case, H_w=0÷12 m, wave sagging condition

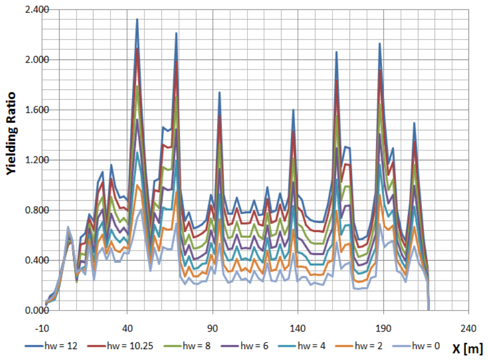

Fig.17 FSO 3D-FEM, centre line web *YR* yielding stress ratio, full load case, H_w= 0÷ 12 m, wave sagging condition

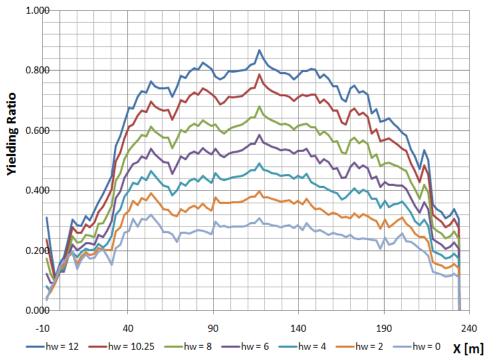

Fig.18 FSO 3D-FEM, side shell *YR* yielding stress ratio, full load case, H_w=0÷12 m, wave sagging condition

Fig.19 presents the head equivalent wave pressure applied on the FSO external shell, ballast case, H_w=10.25m, hogging condition.

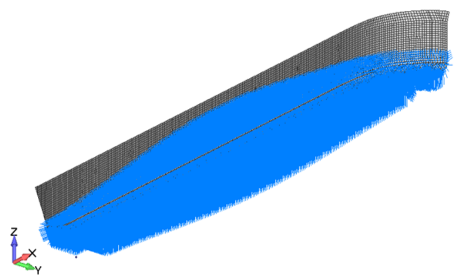

Fig.19 FSO ballast case, equivalent wave pressure on the 3D-FEM model external shell, H_w = 10.25 m, wave hogging condition.

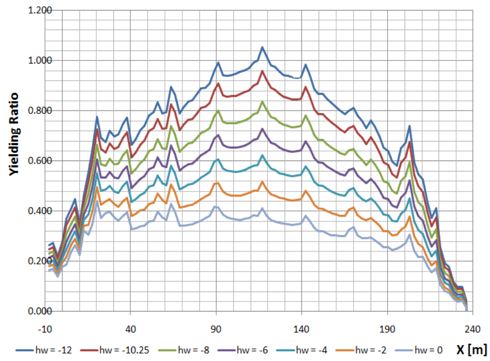

Fig.20 FSO 3D-FEM, main deck *YR* yielding stress ratio, ballast case, H_w=0÷12 m, wave hogging condition

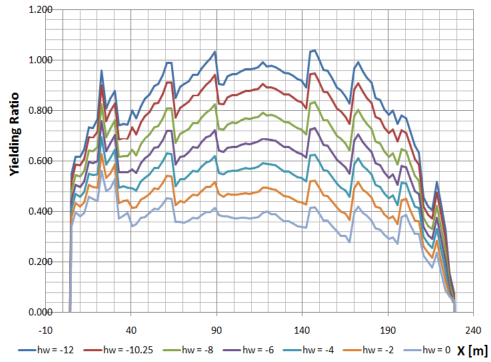

Fig.21 FSO 3D-FEM, longitudinal bulkhead *YR* yielding stress ratio, ballast case, H_w=0÷12 m, wave hogging condition

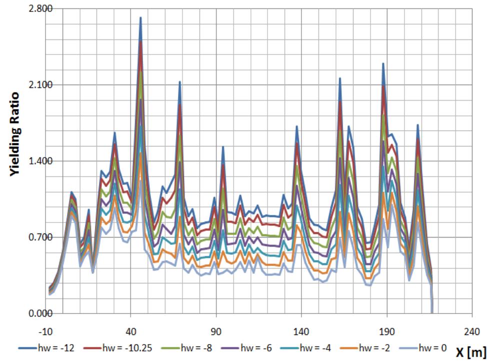

Fig.22 FSO 3D-FEM, centre line web *YR* yielding stress ratio, ballast case, H_w=0÷12m, wave hogging condition

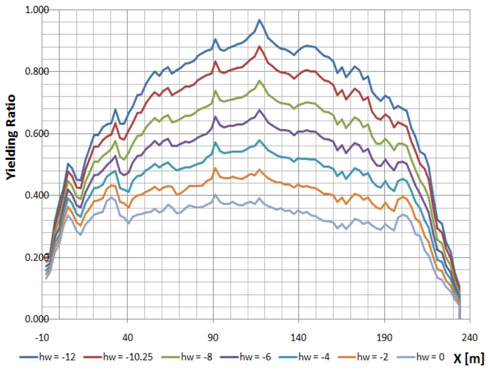

Fig.23 FSO 3D-FEM, side shell *YR* yielding stress ratio, ballast case, H_w=0÷12 m, wave hogging condition

Figs. 20÷23 present the *YR* yielding stress ration (1) distribution, for the ballast case, head equivalent wave on hogging condition, with height H_w=0÷12 m, based on the own iterative algorithm (Fig.1).

For the equivalent wave design height H_w=10.25 m, the yielding stress ratio *YR* distribution over the FSO 3D-FEM model is presented in Figures 24÷29 for full cargo case and in Figures 30-36 for ballast case.

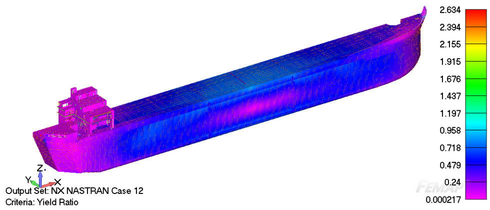

Fig.24 FSO 3D-FEM model, yielding ration *YR*, full load case, H_w = 10.25m, sagging

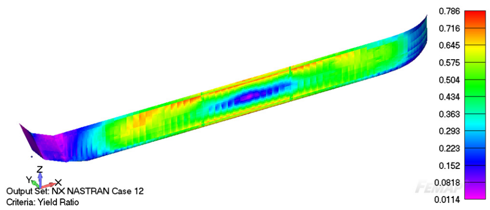

Fig.25 FSO 3D-FEM shell, yielding ratio *YR*, full load case, H_w = 10.25m, sagging

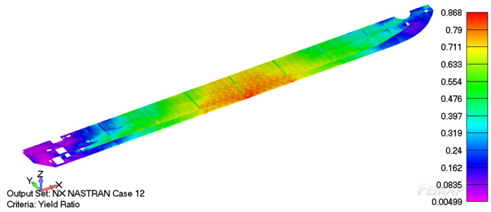

Fig.26 FSO 3D-FEM main deck, yielding ratio*YR*, full load case, H_w = 10.25m, sagging

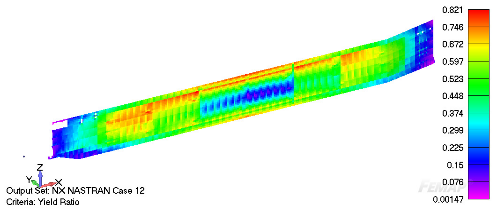

Fig.27 FSO 3D-FEM LBHD, yielding ratio *YR*, full load case, H_w = 10.25m, sagging

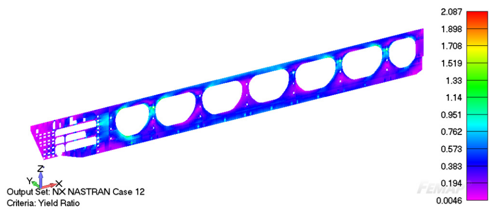

Fig.28 FSO 3D-FEM centre line web, *YR*, full load case, H_w = 10.25m, sagging

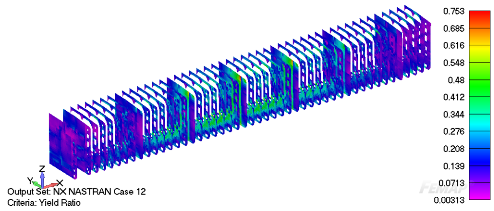

Fig.29 FSO 3D-FEM frames, yielding ratio *YR*, full load case, H_w = 10.25m, sagging

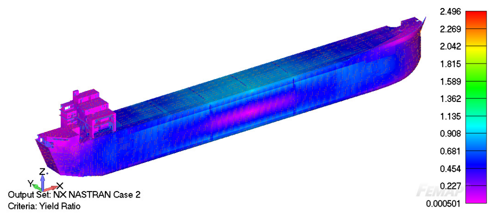

Fig.30 FSO 3D-FEM model, yielding ratio *YR*, ballast case, H_w = 10.25m, hogging

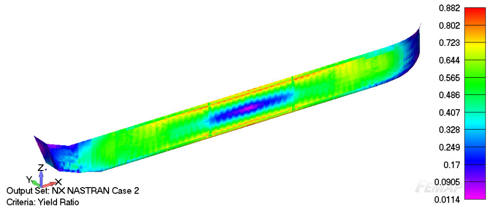

Fig.31 FSO 3D-FEM shell, yielding ratio *YR*, ballast case, H_w = 10.25m, hogging

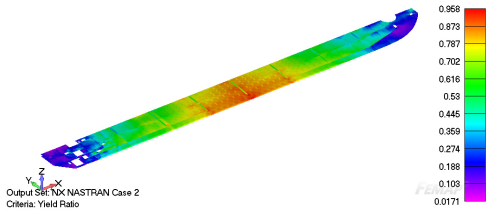

Fig.32 FSO 3D-FEM main deck, yielding ratio*YR*, ballast case, H_w = 10.25m, hogging

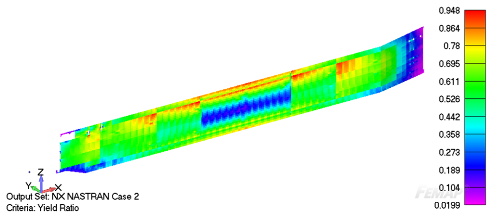

Fig.33 FSO 3D-FEM LBHD, yielding ratio *YR,* ballast case, H_w=10.25m, hogging

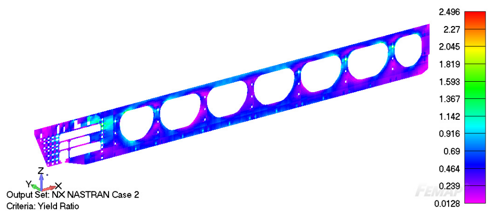

Fig.34 FSO 3D-FEM centre line web, *YR*, ballast case, H_w = 10.25m, hogging

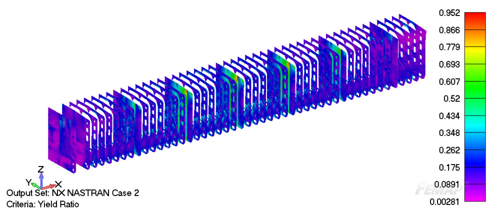

Fig.35 FSO 3D-FEM frames, yielding ratio *YR*, ballast case, H_w = 10.25m, hogging

4. CONCLUSIONS

Table 5 includes the maximum *YR* yielding stress ratios obtained from FSO global strength analysis, for the design wave height H_w=10.25 m (Figs.24÷35).

Table 5 The *YR* yielding stress ratio maximum values for wave reference H_w=10.25 m

Element	*YR full load*	*YR ballast*
Model	2.634	2.496
Shell	0.786	0.882
Main deck	0.868	0.958
LBHD	0.821	0.948
CL web	2.087	2.496
Frames	0.753	0.952

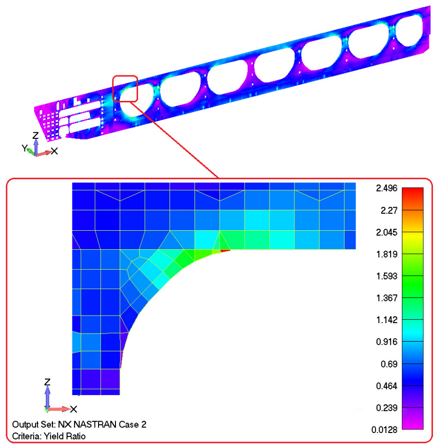

Fig.36 FSO 3D-FEM centre line web, stress hot spot, ballast case, H_w = 10.25m, hogging

To sum up, based on the *YR* yielding stress ration values from section 3 and Table 5 for the FSO offshore unit (section 2), the following conclusions result from the global strength analysis :

1. The yielding stress ratio *YR* has larger values in the case of ballast than in the case of full load for the most part of the hull structure elements (Table 5).
2. At the centre line web, significant yielding stress ratios are recorded, 2.087 for full load case and 2.496 for ballast case, due to the

structural stress hot spots (Fig.36). The hot spot regions have to be analyzed besides the local detailed FEM models, in order to consider the exact geometry of the bracket joint elements.

3. Overall, the yielding stress ratio *YR* >1 is larger than 1, pointing out the existence of several structural hot spots areas that require further detailed FEM analyses.

4. The details that do not meet the yielding stress criterion have to be improved in the design process, by modifying their geometry, thickness and even by changing the material to higher tensile steel.

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