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FACTOR OF SAFETY IN OFFSHORE STRUCTURES DESIGN ACCORDING TO ENVIRONMENTAL LOADS

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Abstract:*Factor of safety in offshore structures will be analyzed in models using Solidworks Simulation Xpress on a specific build model according to shipyard specifications according to environmental loads. The Fos is used in all project and is a way to enrich the structural capacity of the structure in order to carry loads higher than normal use. The factor of safety for offshore structures is determined according to design and material strength, and the value commonly used is between 1.2and 2. According to results is recommended to use a highet value than 2.1 for the models used.*

Key-words: *factor of safety, calculus using solid works software, offshore structures, jacket FoS.*

1. FACTOR OF SAFETY (**FoS**), also known as (and used interchangeably with) **safety factor** (**SF**), is a term describing the structural capacity of a system beyond the expected loads or actual loads. Essentially, how much stronger the system is than it usually needs to be for an intended load. Safety factors are often calculated using detailed analysis because comprehensive testing is impractical on many offshore projects, such as jackets and semisubmersible platforms, but the structure's ability to carry load must be determined to a reasonable accuracy.

All offshore structures are purposefully built much stronger than needed for normal usage to allow for emergency situations, unexpected loads, misuse, or degradation.

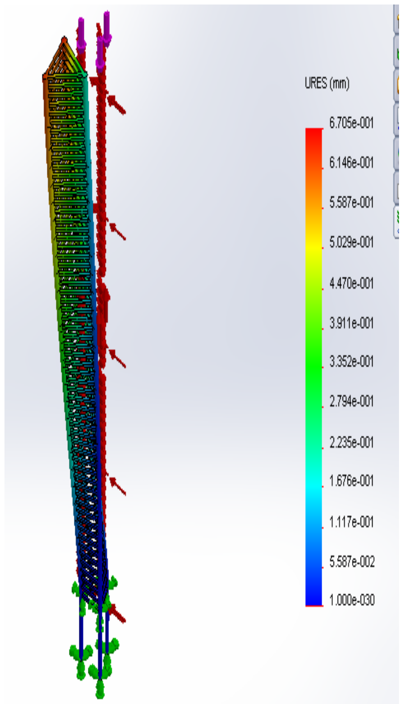

Fig. 1 Jack-up Leg displacement Solidworks SimulationXpress Study

There are two distinct uses of the factor of safety:

- One as a ratio of absolute strength (structural capacity) to actual applied load, this is a measure of the reliability of a particular design.
- The other use of FoS is a constant value imposed by law, standard, specification, contract or custom to which a structure must conform or exceed.

The first use (a calculated value) is generally referred to as a factor of safety or, to be explicit, a realized factor of safety. The second use (a required value) as a design factor, design factor of safety or required factor of safety. However, between various industries and engineering groups usage is inconsistent and confusing, it is important to be aware of which definition are being used. The cause of much confusion is that various reference books and standards agencies use the factor of safety definitions and terms differently. Design codes and structural and mechanical engineering textbooks often use "Factor of Safety" to mean the fraction of total structural capability over that needed.

According to MOBILE OFFSHIRE DRILLING UNITS 2012 (Part 3 Hull construction and equipments, Chapter 2 Hull structures and arrangements, Section 1 Structural Analisis) the FoS is used with this values:

For individual stresses $F = \frac{F_y}{FoS}$

F_y–minimum yield point or yield stress as defined in Chapter 1 of the ABS Rules for materials and welding part 2

FoS – Factor of Safety:is used for combined loadings: FoS=1,25 for axial or bending stress and FoS=1,88 pentru solicitarea de forfecare (for shear stress)

Members subjected to combined axial load and bending

When $\frac{f_a}{F_a} \leq 0{,}15 \left(\frac{f_a}{F_a}\right) + \left(\frac{f_b}{F_b}\right) \leq 1$

When $\frac{f_a}{F_a} > 0,15 \left(\frac{f_a}{F_a}\right) + \frac{C_m f_b}{\left(1-\frac{f_a}{F_e'}\right)F_b} \leq 1$

Buckling consideration

Where buckling of a structural element due to compressive or shear stresses, or both, is a consideration, thecompressive or shear stress is not to exceed the corresponding allowable stress, F, as obtained from the following equation:

$$F = \frac{F_{cr}}{FoS}$$

F_{cr} –critical compressive or shear bucklingstress of the structural element, appropriate toits dimensional configuration, boundary conditions, loading pattern, material, etc.

FoS –factor of safety

FoS=1,67 for static loadings

FoS=1,25 for combined loadings

Column buckling stress

$$F_{cr} = \left(F_y - \frac{F_y^2}{4\pi^2 E}\right)\left(\frac{kl}{r}\right)^2 \text{ when } \left(\frac{kl}{r}\right)^2 < \sqrt{\frac{2\pi^2 E}{F_y}}$$

$$F_{cr} = \frac{\pi^2 E}{\left(\frac{Kl}{r}\right)^2} \text{ when } \left(\frac{kl}{r}\right)^2 \geq \sqrt{\frac{2\pi^2 E}{F_y}}$$

F_{cr}–critical overall buckling stress

F_y –minimum yield point or yield strenght

E –modulus of elasticity

l –unsuported length of collumn

k –effective length factor which accounts for support conditions at ends oflength l. For cases where lateral deflection of end supports may exist, K isnot to be considered less than 1.0.)

$$FoS = 1,25\left(1 + 0,15\frac{\frac{kl}{r}}{\sqrt{\frac{2\pi^2 E}{F_y}}}\right) \text{ when } \frac{kl}{r} < \sqrt{\frac{2\pi^2 E}{F_y}}$$

FoS=1,44 when $\frac{kl}{r} \geq \sqrt{\frac{2\pi^2 E}{F_y}}$ (r –radius of giration)

- Chord

$$\frac{kl}{r} = \frac{1\times 3,658}{0,308} = 11,877 \qquad \sqrt{\frac{2\pi^2 E}{F_y}} = \sqrt{\frac{2\pi^2 \times 21000}{44,85}} = 96,138$$

$$F_{cr} = 44,85 - \frac{44,85^2}{4\pi^2 \times 21000}\left(\frac{1\times 3,658}{0,308}\right)^2 = 44,85 - 0,342 = 44,508$$

$$FoS = 1,25\left(1 + 0,15\frac{\frac{kl}{r}}{\sqrt{\frac{2\pi^2 E}{F_y}}}\right) = 1,25\left(1 + 0,15\frac{11,877}{96,138}\right) = 1,,273$$

- Horizontal

$$\frac{kl}{r} = \frac{1\times(2,692-0,457)}{0,1146} = 19,503 \qquad \sqrt{\frac{2\pi^2 E}{F_y}} = \sqrt{\frac{2\pi^2\, 21000}{70}} = 76,953$$

$$F_{cr} = 70 - \frac{70^2}{4\pi^2 \times 21000}\left(\frac{1\times 2,235}{0,1146}\right)^2 = 70 - 2,248 = 67,752$$

$$FoS = 1,25\left(1 + 0,15\frac{19,503}{76,953}\right) = 1,298$$

- Diagonal

$$\frac{kl}{r} = \frac{1\times 3,826}{0,0924} = 41,407 \qquad \sqrt{\frac{2\pi^2 E}{F_y}} = \sqrt{\frac{2\pi^2\, 21000}{70}} = 76,953$$

$$F_{cr} = 70 - \frac{70^2}{4\pi^2 \times 21000}\left(\frac{1 \times 3{,}826}{0{,}0924}\right)^2 = 70 - 10{,}134 = 59{,}866 \quad \left[\frac{N}{mm^2}\right]$$

$$FoS = 1{,}25\left(1 + 0{,}15\frac{41{,}407}{52{,}217}\right) = 1{,}399$$

2. MODEL DESCRIPTION

This model was built using this specifications:

- Structure length 65 m
- Steel cylinders diameter 0.6 m
- Triangle sides are build from bars 4.6X0.3X0.3
- The distance between bars planes is reduced to 0.7 m
- Mass:854994 kg
- Volume:111.038 m^3
- Density:7700 kg/m^3
- Weight:8.37894e+006 N

This model is compared to two other different four sided structures with the same dimensions.

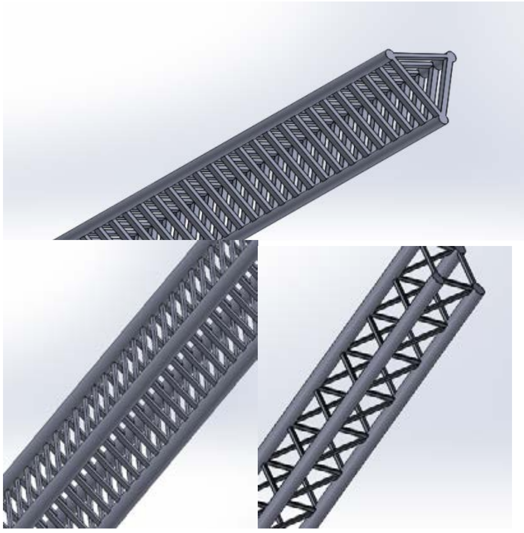

Fig. 2 Models of jacket used in Solidworks SimulationXpress

Table 1 Material used to analyse the model

Name:	Alloy Steel
Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	6.20422e+008 N/m^2
Tensile strength:	7.23826e+008 N/m^2

ANSYS Fluent pressure calculus

The static calculus requires pressures and forces that are acting on this surface. The analysis used the k-epsilon model, and the near wall treatment will be done with standard wall functions.

As seen in fig.3. pressure loads according to envirnement loads, are calculated with Ansys Fluent, can be used to simulate the model static response.

Colors used by the Solidworks software, as seen in fig.3, are:

- green for fixed parts
- red for pressure loads
- violet for forces

Replacing the distributed pressures over the offshore structure with a constant known force acting in the center of pressure will show us the behavior of the model and the places where the factor of safety is low.

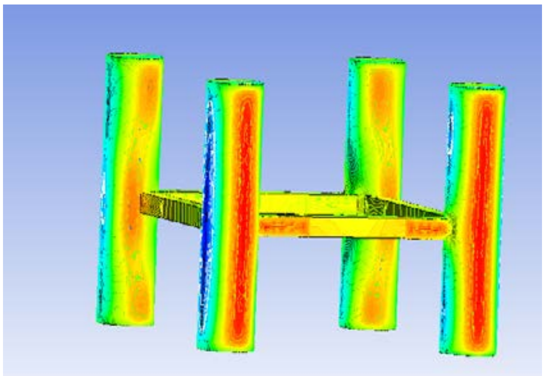

Fig. 3 Pressure values from Ansys Fluent

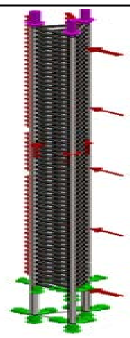

Fig. 4 Mechanical loads used to simulate environment

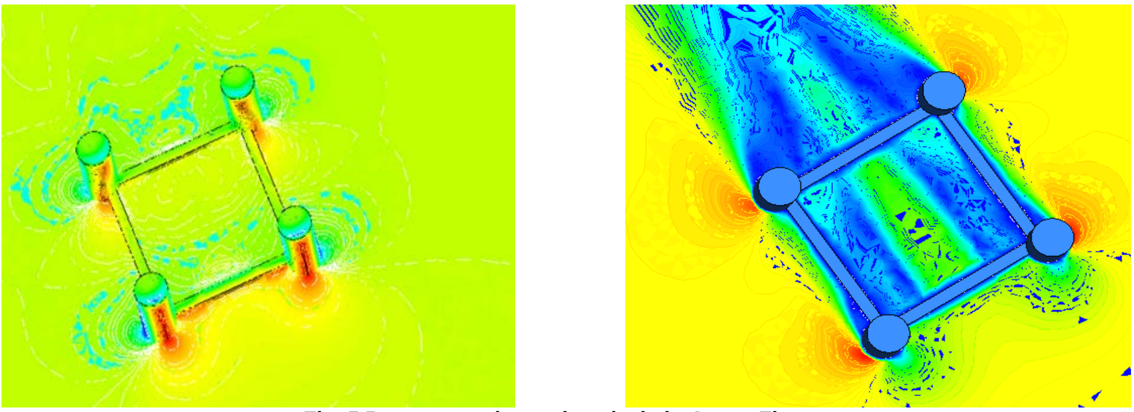

Fig. 5 Pressure and speed analysis in Ansys Fluent

3. CALCULATION OF FOS

There are several ways to compare the factor of safety for structures. All the different calculations fundamentally measure the same thing: how much extra load beyond what is intended a structure will actually take (or be required to withstand).

In this paper I will use tree different structures with the same value loads.

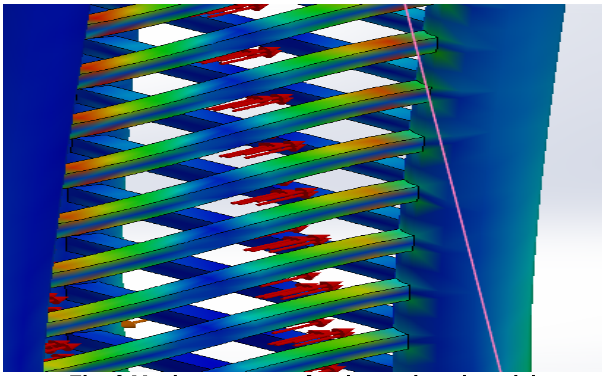

Fig. 6 Maximum stress for the analysed model

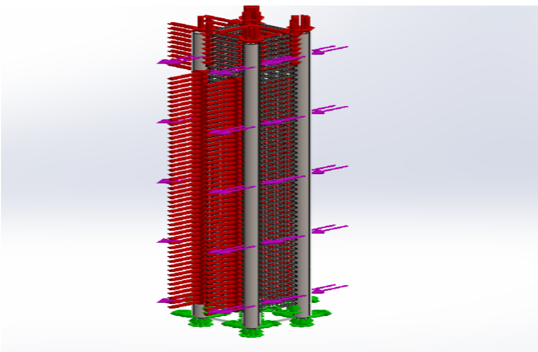

Fig. 7 Loads used to simulate environment

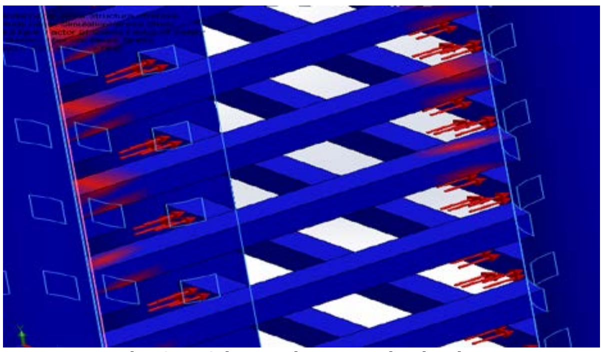

Fig. 8 FoS lower than standard value

The difference between the methods is the way in which the values are calculated and compared. Safety factor values can be thought of as a standardized way for comparing strength and reliability between systems.

The use of a factor of safety does not imply that an item, structure, or design is "safe". Many quality assurance, engineering design, manufacturing, installation, and end-use factors may influence whether or not something is safe in any particular situation.

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4. DESIGN FACTOR AND SAFETY FACTOR

The difference between the safety factor and design factor (design safety factor) is as follows: The safety factor is how much the designed part actually will be able to withstand (first "use" from above). The design factor is what the item is required to be able to withstand (second "use"). The design factor is defined for an application (generally provided in advance and often set by regulatory code or policy) and is not an actual calculation, the safety factor is a ratio of maximum strength to intended load for the actual item that was designed.

$$\text{Factor of Safety} = \frac{\text{Material Strength}}{\text{Design Load}}$$

- Design load being the maximum load the part should ever see in service.

By this definition, a structure with a FOS of exactly 1 will support only the design load and no more. Any additional load will cause the structure to fail. A structure with a FOS of 2 will fail at twice the design load.

Many government agencies and industries (such as ABS- American Bureau of Shipping) require the use of a **margin of safety** to describe the ratio of the strength of the structure to the requirements. There are two separate definitions for the margin of safety so care is needed to determine which is being used for a given application. One usage of M.S. is as a measure of capacity like FoS. The other usage of M.S. is as a measure of satisfying design requirements (requirement verification). Margin of safety can be conceptualized (along with the reserve factor explained below) to represent how much of the structure's total capacity is held "in reserve" during loading.

M.S. as a measure of structural capacity: This definition of margin of safety commonly seen in textbooks basically says that if the part is loaded to the maximum load it should ever see in service, how many more loads of the same force can it withstand before failing. In effect, this is a measure of excess capacity. If the margin is 0, the part will not take any additional load before it fails, if it is negative the part will fail before reaching its design load in service. If the margin is 1, it can withstand one additional load of equal force to the maximum load it was designed to support (i.e. twice the design load).

For ductile materials (as used in this paper Alloy Steel), it is often required that the factor of safety be checked against both yield and ultimate strengths. The yield calculation will determine the safety factor until the part starts to plastically deform. The ultimate calculation will determine the safety factor until failure. On brittle materials these values are often so close as to be indistinguishable, so is it usually acceptable to only calculate the ultimate safety factor.

5. CHOOSING DESIGN FACTORS

Appropriate design factors are based on several considerations, such as the accuracy of predictions on the imposed loads, strength, wear estimates, and the environmental effects to which the product will be exposed in service; the consequences of engineering failure; and the cost of over-engineering the component to achieve that factor of safety. For example, components whose failure could result in substantial financial loss, serious injury, or death may use a safety factor of four or higher (often ten). Non-critical components generally might have a design factor of two. Risk analysis, failure mode and effects analysis, and other tools are commonly used. Design factors for specific applications are often mandated by law, policy, or industry standards.

Buildings commonly use a factor of safety of 2.0 for each structural member. The value for buildings is relatively low because the loads are well understood and most structures are redundant. Pressure vessels and offshore structures use 3.5 to 4.0, automobiles use 3.0, and aircraft and spacecraft use 1.2 to 3.0 depending on the application and materials. Ductile, metallic materials tend to use the lower value while brittle materials use the higher values. The field of aerospace engineering uses generally lower design factors because the costs associated with structural weight are high (i.e. an aircraft with an overall safety factor of 5 would probably be too heavy to get off the ground). This low design factor is why aerospace parts and materials are subject to very stringent quality control and strict preventative maintenance schedules to help ensure reliability. A usually applied Safety Factor is 1.5, but for pressurized fuselage it is 2.0, and for main landing gear structures it is often 1.25.

In some cases it is impractical or impossible for a part to meet the "standard" design factor. Loads that are cyclical or repetitive, as waves are, it is important to consider the possibility of metal fatigue choosing factor of safety. A cyclic load well below a material's yield strength can cause failure if it is repeated through enough cycles.

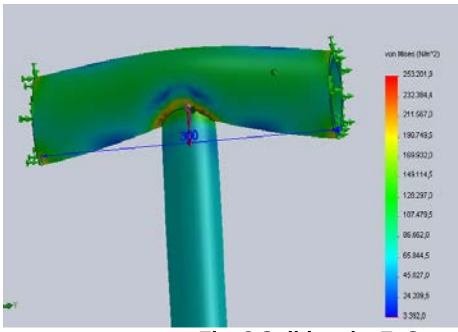
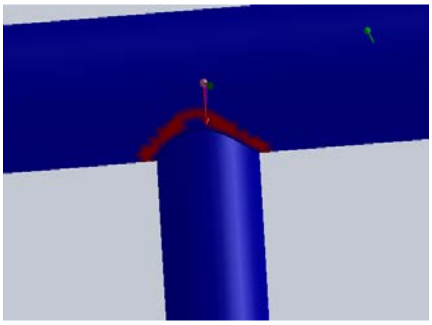

Fig. 8 Solidworks FoS analysis for weldings in offshore structures

Table 2. Recommended values for FoS for environement loads:

No.	Structure tipe:	Recommended Fos:
1.	General used value	**1,5**
2.	Offshore jackets with 3 sides (analyzed in SimulationXpress)	**2.1**

3.	Offshore jackets with 4 sides (analyzed in SimulationXpress)	**2.52**
4.	Semisubmersible platforms	**3.1-4.0**
5.	Tension leg platforms	**1.5-2.2**

6. CONCLUSION

Design of offshore structures requires a good knowledge of the factor of safety applied to the field and a specific value commonly used for the specific type of structures. Some structures will become too heavy using a higher FoS in the initial design, and a further analysis of specific values is needed. Using the highest values from centenary wind speed and current speed, we tested the designed structures with similar forces and pressures and the result on the 3 or 4 sides structure was similar to other studies from references. The FoS used in designing offshore structures should be minimal 2.1 for Offshore jackets with 3 sides and 2.52 for Offshore jackets with 4 sides. This higher FoS factor will cause a higher resistance to harsh variable loads from the environment.

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