EXTREME AND FATIGUE ANALYSES OF A DYNAMIC FIBER OPTIC RISER

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Abstract: This paper presents extreme and fatigue analyses of a newly developed Dynamic Fiber Optic (FO) Riser, which is designed with the aim of long fatigue life even in extreme environments. The riser consists of four layers of steel armor wires and 18 helical stranded steel tubes composing the FO package. The harsh Norwegian Sea environment and the deep-water West African Sea have been chosen as locations for the analyses. The FO riser has been modeled and analyzed based on its dynamic configuration, global loads, vessel's motion characteristic and attached accessories, e.g. bend stiffener, buoyancy module and tether clamp, by using a well-known software Orcaflex. This study shows that the FO riser satisfies the acceptance criteria for both extreme and fatigue.

1. INTRODUCTION

Future growth for liquid hydrocarbons demand will be based mainly on deepwater shelf production. Currently, 27% of shelf production is at a depth of 300 m and more [1]. Moreover, through today technology, producers are able to drill at depths that exceed 3000 m.

The fast growing of advanced sensing and communication in offshore industry requires a reliable, flexible, robust and separate dynamic fiber optic riser design which can stand against extreme environment and at the same time has a long fatigue life [2].

2. DYNAMIC FIBER OPTIC RISER

The latest innovation of a Nexans's Dynamic FO Riser has 18 stranded helical steel tubes covered with four layers steel armors, filled and sheathed with polyethylene (HDPE) resulting a total outside diameter of 64 mm and weight of 145 N/m in air. Each steel tube is designed to host 12 optical fibers, i.e. 216 fibers in total. This new design of the FO riser is intended to withstand any robust and extreme environments.

2.1. Mechanical Properties

Figure 1 shows the cross section drawing of the FO riser.

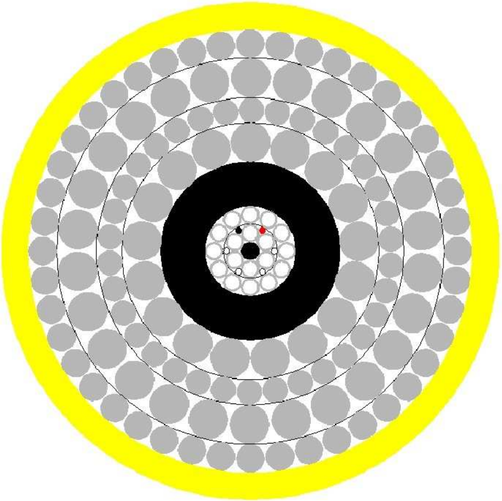


Figure 1 Cross section drawing of the Dynamic FO Riser.

The cross section analysis, which is a terminology that refers to an analysis finding the mechanical properties of a cable, has been carried out to establish the cable's stiffnesses (axial, bending and torsion), capacity curve in means of allowable tension-curvature combinations and stress coefficients for fatigue analysis. The stiffnesses are used as dynamic analysis input while the capacity curve describes the tension-curvature combination criteria for the extreme analysis, see Figure 2. The stress coefficients are on the other hand applied in the fatigue damage analysis enabling us to model the stress-curvature hysteresis of helix cable elements.

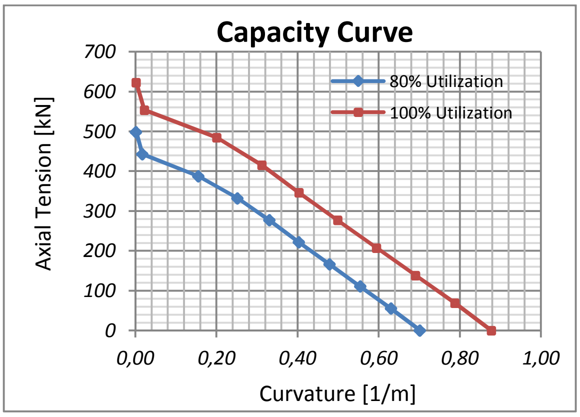


Figure 2 Capacity curve of the Dynamic FO Riser.

2.2. Fatigue Curve

During the FO riser's operation period, it will experience load cycles and local stress variations, which are characterized by a fatigue curve, called the S-N curve, and has a general expression as

$$log(N) = log(a) - m \cdot log(\Delta\sigma)$$

Where N is the number of cycles, $\Delta\sigma$ is the stress range and a and m are the scale and slope factors determined from tests.

The following associated S-N curve parameters are adopted from [3].

Element	S-N curve parameters
FO Tube	log a = 17.446, m = 4.7
Steel Armor	$N \leq 10^6$: log a=14.917, m= 4.0 $N > 10^6$: log a=17.146, m=5.0

Table 1 Fatigue S-N curve parameters.

3. EXTREME AND FATIGUE ANALYSES

These analyses investigate responds of the FO riser due to a dynamic environment. The key inputs to these analyses are the dynamic configuration, vessel RAOs, attached accessories (bending stiffener, buoyancy module, seabed anchoring, etc) and global loads induced by waves and currents.

In this study, two different locations have been chosen for the analysis, the harsh North Sea (Norwegian Sea) environment and the deep-water West African Sea (Gulf of Guinea). The Norwegian Sea represents the harsh sea with maximum wave height up to 31.4 m (100 years extreme wave data) with a water depth of 317 m. In contrary the Gulf of Guinea has a maximum wave height of 7.8 m with a water depth of 1300 m.

The extreme analysis has been performed initially with regular waves, modeled using Stokes's 5th order theory. In addition, the irregular waves, e.g. Gaussian Swell and JONSWAP spectrum theory, have been applied as sensitivity to the most critical load cases. The omni-directional waves and current parameters have been considered in the extreme analysis from 8 directions.

The wave fatigue analysis applies the annual waves scatter table of significant wave height (Hs) and spectral wave period (Tp). Based on this scatter table, load cases have been generated for each bin and modeled in 1 hour simulation time.

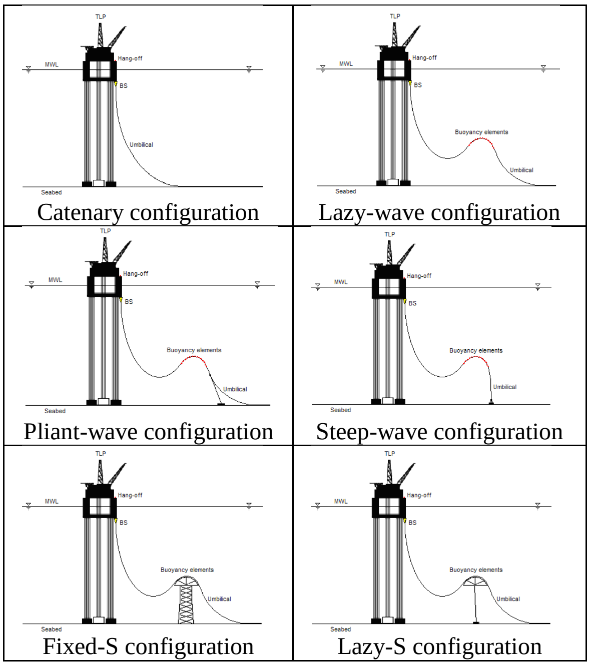
The curvature and tension from each load case is saved in a time domain format. Furthermore, these curvature and tension time series are transformed into hysteretic stress time series by using Uflexfilter software. Finally, the stress time series are used to calculate the fatigue damage of the cable by using Rainflow cycle counting method and the Miner-Palmgren summation of fatigue damage. The Miner-Palmgren fatigue damage summation is given as follow [5]:

$$D_{fat} = \sum \frac{n_i}{N_i} \leq \eta$$

Where D_{fat} is the accumulated fatigue damage, η is the allowable damage ratio, n_i is number of cycles in stress range block i in and N_i is the number of cycles to failure corresponding to the stress range.

3.1. Riser/Cable Configuration

The following figure shows common riser configurations.



Catenary configuration
Lazy-wave configuration
Pliant-wave configuration
Steep-wave configuration
Fixed-S configuration
Lazy-S configuration

Figure 3 Common riser configurations.

At the North Sea location, the FO riser has been suspended from a FPSO in a pliant wave (tethered) configuration with 0 degree departure angle from the vertical, whilst at the Gulf of Guinea the FO riser is configured in a lazy wave configuration with 8 degrees departure angle.

3.2. Environmental Loads

As mentioned earlier, one of the key inputs for the analyses is the meteorological and oceanographic (metocean) data providing waves and current properties.

Based on [4], the extreme and fatigue analyses shall be performed by applying combinations of waves and currents. In this analysis, combinations of 100 years return period of waves and 10 years return period of currents, and vice versa have been considered.

3.3. Vessel Motion

The vessel motion is characterized by a set of displacement RAOs (response amplitude operators). This displacement RAOs characterizes the 1st order vessel motion in response to waves of given period and amplitude in each of the 6 motions directions as shown in Figure 4.

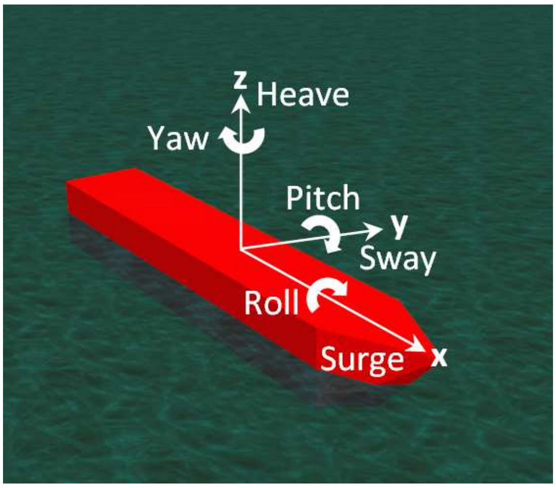


Figure 4 Six degrees of vessel motion.

In addition to the displacement RAOs, vessel offsets have also been included. Offset is defined as a static displacement of the vessel due to waves, current, wind and/or vessel relocation etc.

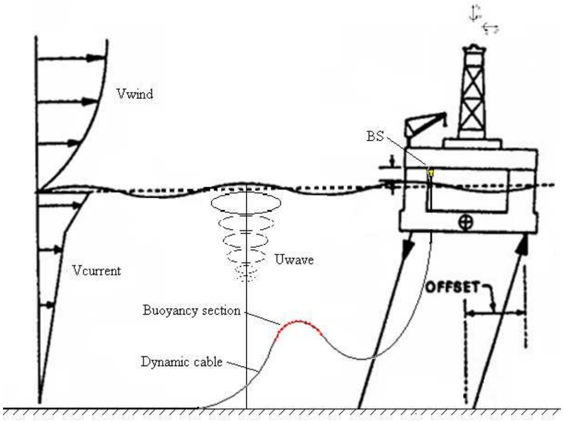


Figure 5 Vessel offset description.

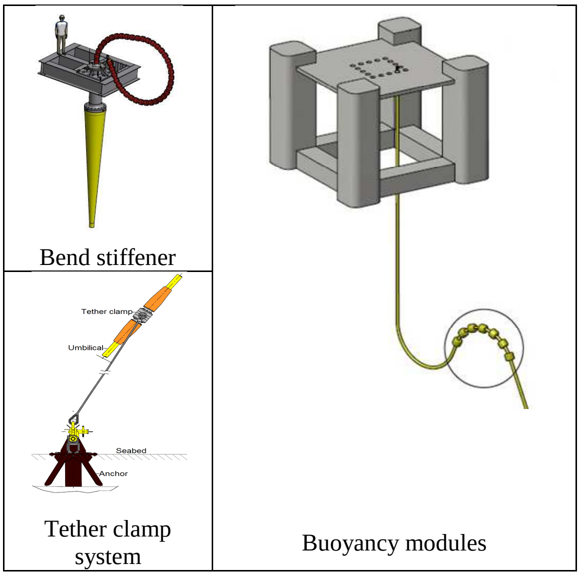
3.4. Attached Accessories

Accessories are required to build desired configuration, e.g. bend stiffener (BS), buoyancy modules (BM), weight elements, clamps, tethers, etc.

Commonly, the FO riser is pulled through a bend stiffener which is connected to an I-tube. The bend stiffener is designed to protect the cable from over bending at hang-off and at the same time to distribute the curvature and thereby the fatigue damage over its length.

Buoyancy modules are used to give uplift in cable sections to achieve the preferred configuration. Different number and properties of the buoyancy modules have been used for both locations. The amounts, properties and dimensions of the buoyancy module have been calculated prior to the analyses.

At the North Sea location, a tether clamp is applied to the configuration to restrict the cable displacement. The tether clamp has been modeled with one small bend stiffener (1.7 m in length) attached on each side of the clamp.



Bend stiffener

Tether clamp system

Buoyancy modules

Figure 6 Drawings of the accessories.

3.5. Analysis Criteria

The analyses criteria in this study are mainly based on the cable strength and fatigue damage.

For the extreme analysis, the maximum yield utilization of the cable strength members, which is based on von Mises's yield criterion, is 80% during normal operation. It means that the applied axial tension and bending radius have to be lower than the 80% capacity curve given in Figure 2.

In this study no compression force is allowed anywhere in the FO riser, due to its complexity.

For the fatigue analysis the maximum damage is Miner sum of 10%. The 10% Miner sum corresponds to a safety factor of 10, according to [3] and [4], or a minimum 250 years fatigue life given that the design life is 25 years.

4. ANALYSIS RESULTS

4.1. Extreme Analysis

The acting tensions and curvatures along the FO riser, as the result of the extreme analysis, is stored in time series and plotted against the capacity curve of the FO riser in order to visually check the criteria.

The tension vs. curvature plots of all extreme load cases at interesting regions at the North Sea location are presented in Figure 8 through Figure 11. The description of the interesting region is given in Figure 7.

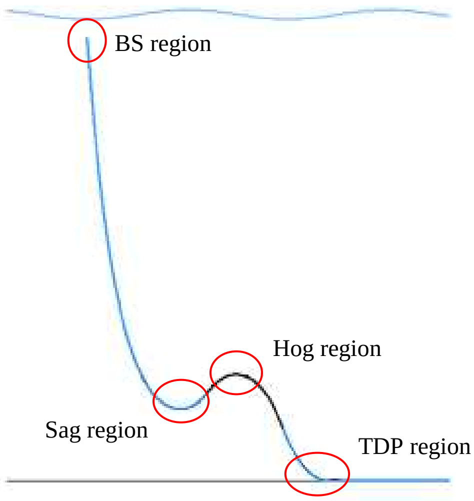


Figure 7 Interesting region along the line.

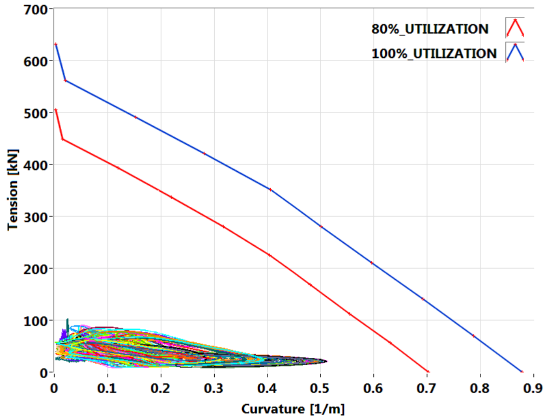


Figure 8 Tension vs. Curvature plots in the BS region at the North Sea location.

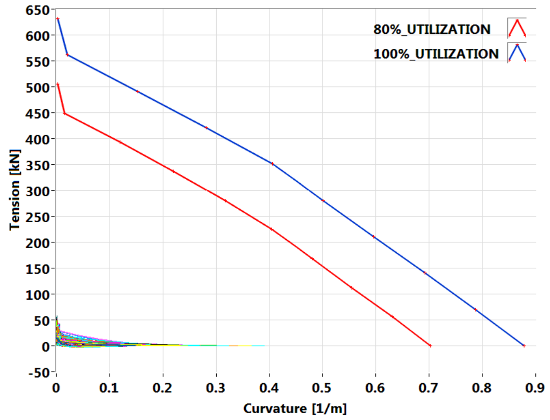


Figure 9 Tension vs. Curvature plots in the sag region at the North Sea location.

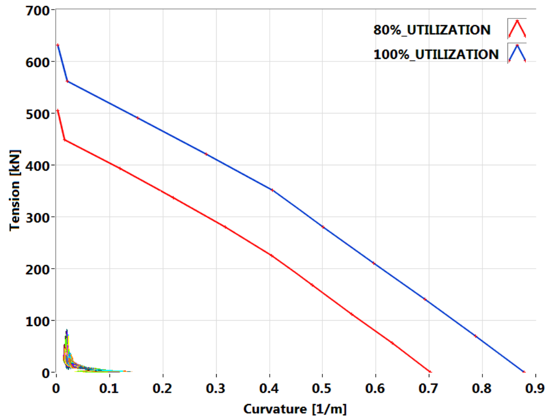


Figure 10 Tension vs. Curvature plots in the hog region at the North Sea location.

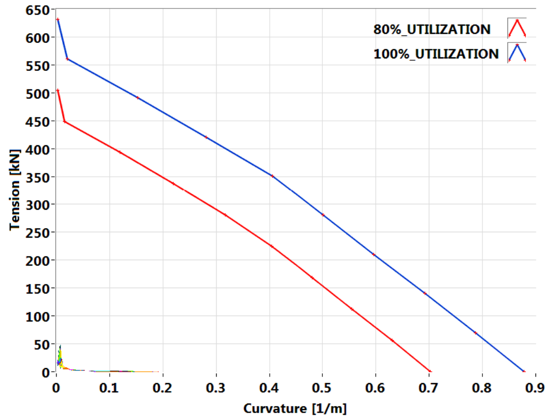


Figure 11 Tension vs. Curvature plots in the TDP region at the North Sea location.

As mentioned previously, the extreme analysis has been initially performed with regular waves. Furthermore, sensitivity analyses have been performed for the most critical load cases; 1) wave period variation and 2) irregular wave analysis.

For the wave period sensitivity, the most critical load cases have been re-run with +/- 1 second period. Whilst the irregular wave sensitivity has been performed by applying irregular wave theory. The results from both sensitivity analyses show minor change compare to initial results.

In the load cases that report compression it takes place in the sag area. The largest compression found is -5.38 kN. No further work has been carried out in this study to minimize the compression. However, it is plausible to reduce the compression by optimizing the configuration and/or attach weight elements in the upper catenary length to the cable.

The final results from the most extreme load cases are presented in Table 2.

Load Case Description	Tmax [kN]	Tmin [kN]	Cmax [1/m]	Region
Max tension	**70.06**	29.97	0.10	BS
Max curvature	57.68	20.66	**0.34**	BS
Max Compression	29.52	**-2.70**	0.23	Sag

Table 2 Extreme analysis result at the North Sea location.

Figure 12 through Figure 15 shows the extreme analysis results at the Gulf of Guinea. Generally, the results are well within the capacity curve and satisfy the criteria.

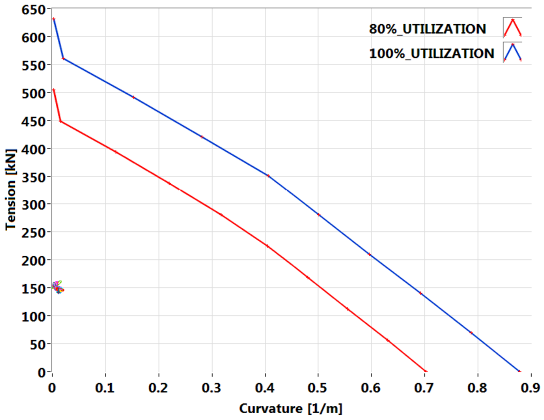


Figure 12 Tension vs. Curvature plots in the BS region at the Gulf of Guinea location.

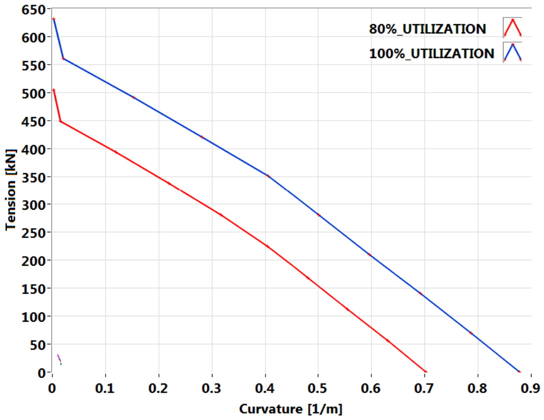


Figure 13 Tension vs. Curvature plots in the sag region at the Gulf of Guinea location.

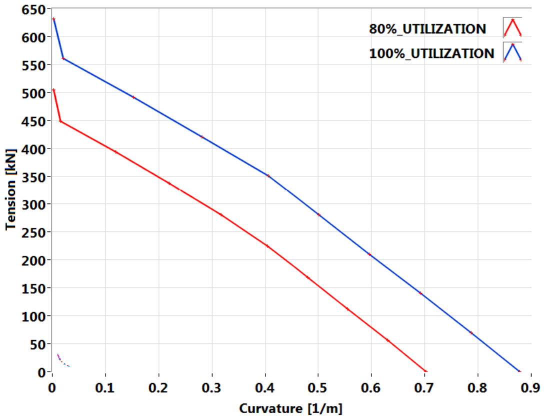


Figure 14 Tension vs. Curvature plots in the hog region at the Gulf of Guinea location.

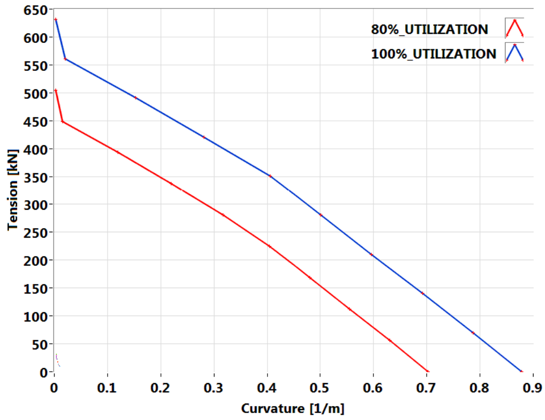


Figure 15 Tension vs. Curvature plots in the TDP region at the Gulf of Guinea location.

Similar sensitivity analyses have been performed for the Gulf of Guinea location. The results of the sensitivity analyses did not introduce any significant change and results remain well within the capacity curve.

The final results from the most extreme load cases are presented in Table 3.

Load Case #	Tmax [kN]	Tmin [kN]	Cmax [1/m]	Region
Max tension	**176.76**	137.45	0.028	BS
Max curvature	17.66	9.60	**0.034**	Hog
Max Comp.	11.82	**9.39**	0.011	TDP

Table 3 Extreme analysis results at the Gulf of Guinea location.

4.2. Wave Fatigue Analysis

As mentioned previously, the wave fatigue damage has been performed based on load cases given by an annual scatter diagram (combination of Hs and Tp).

The following tables present the result of the wave fatigue damage and fatigue life of the FO riser for both locations.

Element	Annual Damage	Fatigue Life [years]	Fatigue Location
FO Tube 1	1.3×10^{-6}	7.8×10^{5}	BS
FO Tube 2	6.3×10^{-7}	1.6×10^{6}	BS
Armor 1	$\mathbf{4.4 \times 10^{-4}}$	$\mathbf{2.3 \times 10^{3}}$	**BS**
Armor 2	6.5×10^{-5}	1.5×10^{4}	BS
Armor 3	1.4×10^{-4}	7.4×10^{3}	BS
Armor 4	2.7×10^{-5}	3.7×10^{4}	BS

Table 4 Fatigue damage at the North Sea location.

Element	Annual Damage	Fatigue Life [years]	Fatigue Location
FO Tube 1	1.1×10^{-8}	9.0×10^{7}	BS
FO Tube 2	9.0×10^{-9}	1.1×10^{8}	BS
Armor 1	1.9×10^{-5}	5.2×10^{4}	BS
Armor 2	$\mathbf{2.1 \times 10^{-5}}$	$\mathbf{4.7 \times 10^{4}}$	**BS**
Armor 3	1.4×10^{-6}	7.2×10^{5}	BS
Armor 4	6.6×10^{-8}	1.5×10^{7}	BS

Table 5 Fatigue damage at the Gulf of Guinea location.

Based on Table 4 and Table 5, the FO riser fulfilled the fatigue criteria, i.e. minimum fatigue life of 250 years (correspond to 25 years design life with safety factor of 10). The most critical element is 1st and 2nd layer armor (from center of the cable) with the shortest expected fatigue live of 2270 years and 47000 years respectively.

5. CONCLUSION AND FUTURE WORK

5.1. Conclusion

The extreme and wave fatigue analyses shows that the FO riser, in a pliant wave and lazy wave configuration, installed at the North Sea and the Gulf of Guinea, satisfies the acceptance criteria for both extreme and fatigue damage.

However, the compression found in the North Sea location is not acceptable without any further verification, i.e. laboratory tests of the actual riser are needed to find the allowable static/cyclic compression level(s). It should be noted that the compression can be reduced by optimizing the configuration and/or attach weight elements in the upper catenary length to the cable.

The results from the fatigue analysis, applying DNV-RP-C203 S-N curves, show the minimum fatigue life of 2270 years and 47000 years at the North Sea and the Gulf of Guinea respectively.

5.2. Future Work

Subsequent to the extreme and wave fatigue analyses, a dynamic flex test has been initiated in order to verify that the FO riser and designed bend stiffener is capable of withstanding the fatigue loads during its fatigue life.

The dynamic flex test is still in progress while this paper is being written.

6. REFERENCES

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