PARAMETRIC ANALYSIS OF STEEL LAZY-WAVE RISERS

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Abstract. *With the intention of automating parametric analyses of steel lazy-wave risers under different environmental conditions a methodology was developed. This methodology builds different configurations of cables according to a pre-defined range of parameters as segment lengths and floaters data. Each configuration is then analyzed for a set of load cases. Five types of analyses are done, to say: Neutral, Static, Dynamic, Internal Stress and Fatigue.*
The methodology was implemented in order to verify which the best configurations are as quick as possible. Therefore, some simplifications in the models were done to make all the analyses feasible in the early stages of the riser design.
The focus of this paper is the influence of the flotation in lazy-wave configurations of steel risers. In other words, considering given a set of environmental conditions, the parameters related to the floaters, such as diameter, length and pitch, and the position of the floating segment will be changed to verify their effects on results.
The results of a real case are discussed, improving the knowledge about lazy-wave, since that configuration appears as a possible solution for ultra deepwater oil fields.

Keywords: *Steel risers, Lazy-wave configurations, Parametric analysis*

1. Introduction

The unquestionable importance of oil comes from the fact that it is used to produce more than six thousand products, such as, fuel, lubricant, plastics, synthetic fabrics and electric power, having significant influence on the world economy.

The fact that more and more fields are being found in deep water increases the importance of the analyses of risers, since they must be long and consequently the forces that they are submitted to are high, leading to investments in researches in this area. For exploration fields in deep water, lazy-wave configurations, which have at least one segment with floaters, are being considered as a possible alternative.

The aim of this article is to analyze the influence of the floating segment in lazy-wave configurations using a methodology of parametric analyses. For that, three identical cables, with different lengths of the floating segment, were simulated under the same environmental conditions. For each cable, the position of the floating segment was changed in order to verify the influence of the position in the response. All this process was repeated for three different weights of the floating segment.

2. Methodology

The developed methodology builds automatically the configurations to be simulated, combining all the user defined parameters described next.

Figure 1 shows a lazy-wave configuration with three segments like the ones analyzed in this paper and also the coordinate system, whose origin is at the touchdown point (TDP). The user can choose from one to five segments and the input data are the minimum and maximum values of the lengths, as well as the number to divide the interval. For instance, when the riser has three segments, and each segment can assume four different values, 64 configurations are built.

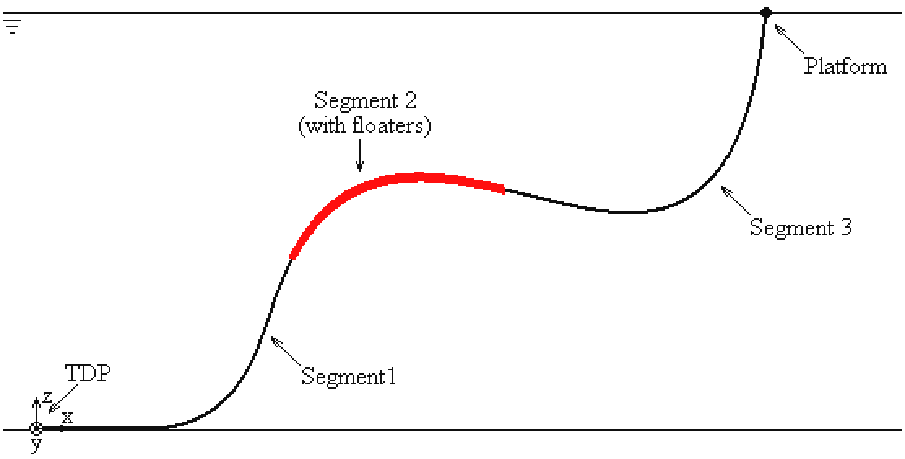

Figure 1. Lazy-wave configuration

When the segment has floaters, the parameters of the floaters must also be entered. Figure 2 shows a piece of a segment with floaters and indicates the floater parameters, where D_f is the diameter, L_f is the length and S_f is the pitch.

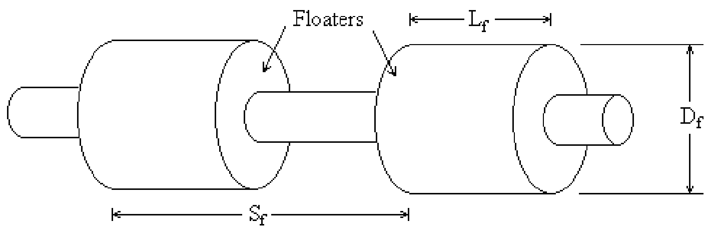

Figure 2. Parameters related to the floater

After combining all the possible configurations, five types of analysis, each one with different load cases, are done in the following order: Neutral, Static, Dynamic, Internal and Fatigue.

Figure 3 shows the sequence of the analyses. If one configuration is not geometrically feasible or it does not obey to at least one of the design criteria, it is considered not approved and it is not simulated in the following analysis. The criteria concerns the minimum and maximum values that each result can assume, to say: top tension, top angle, curvature radius in all the segments, tension in all the segments, TDP tension, TDP position, minimum and maximum height of the waves when it is in lazy-wave configuration, and they are also inputted by the user.

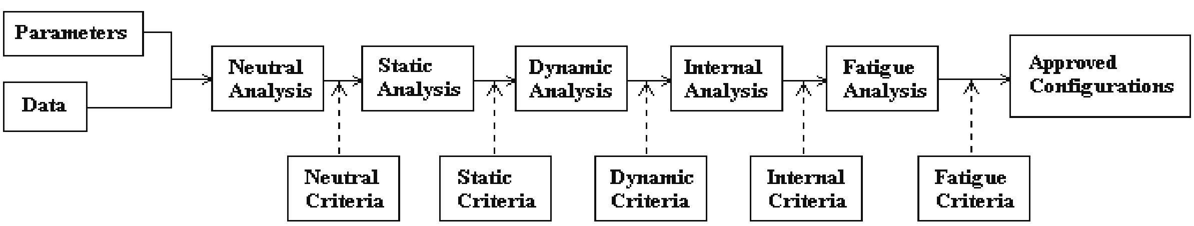

Figure 3. Analyses sequence

The objective of the neutral analysis is to find the balance configuration of a riser submitted only to the action of the gravity and hydrostatic forces, without considering the effect of current on the riser and on the floating unit position. That is the same for the static analysis, but the loads, caused by the current on the riser and the change of the top position due to the floating unit offset, are considered.

The dynamic analysis corresponds to the problem of a suspended riser submitted to loads caused by the current on the riser and on the floating unit position and loads caused by the waves on the riser and on the movement of the floating unit.

The internal analysis calculates the von Mises equivalent stress at the top and touchdown point, also known as TDP, as a result of the applied static and dynamic loads.

The objective of the fatigue analysis is to determine the riser life. For that, many different load cases weighed for the respective probabilities of occurrence are considered. Using the stresses on the riser and S-N curves, it is possible to estimate the accumulated damage and the fatigue life.

The aim of this methodology is to verify which the best configurations are as quick as possible. Therefore, some simplifications were done in the models to make all the analyses feasible in the early stages of the riser design.

3. Models

The models used in this methodology are presented in this section. They were thoroughly tested and the results compared with other tools.

3.1. Static

The static analysis consists on finding the balance configuration of the riser. Based on the model found in Santos (2003), the elastic line depends on the immersed weight, riser length, anchor and top coordinates as well as boundary conditions and current forces.

The forces acting on the cable that are considered in this model are: gravitational, hydrostatic and hydrodynamic, that corresponds to the riser weight, buoyancy and mean ocean current, respectively.

The modeling does not consider, initially, the effects of flexional rigidity, because it does not have significant influence on the global configuration. However, it is important in areas close to the TDP, top and also in the change of segments, since there is a discontinuity in the curvature at those regions in the ideal cable model, as in Aranha, Martins and Pesce (1997). For that reason, a correction using the boundary layer technique is done later. The axial rigidity is considered infinite, but the riser is free to twist and the sea bed is considered plain, horizontal and rigid.

A full explanation can be found in Silveira *et al.* (2005).

3.2. Dynamic

As the order of magnitude of the amplitudes of the dynamic movements is smaller than those of the static displacements, the dynamic response is considered a perturbation of the static configuration. The linear model in frequency-domain produces similar solutions to those of the time-domain, as in Liu and Bergdahl (1997). And as the solution is produced faster in frequency domain, it can be advantageous in early stages of riser design.

The influence of the sea waves on the riser is considered through the top motion of the riser induced by the floating unit and the direct action of the waves using Morison´s formula. The aim is to determine the displacements and forces on the cables, when submitted to time-dependent loads.

The model does not consider the effects of flexional and torcional rigidity, but the riser can deform axially. As in Martins (2000), the touchdown point is fixed and represented by a simply supported end, which simplifies the problem and changes only locally the dynamic response not modifying the global response. However, its movement is later recovered by the boundary layer technique, which considers the effect of flexional rigidity at the TDP.

The total force acting on the line is represented by the inertia of the structure, additional inertia and drag caused by the interaction with the structure. The inertia force corresponds to the product of mass and acceleration, the additional mass is represented by the product of the displaced mass and the constant c_m and the drag corresponds to two parcels one of the force caused by the direct incidence of the waves and another one for the viscous damping. Through the Morison's formula, the viscous damping can be written in a linear formulation, considering that the dissipated energy in a cycle is constant. Because of that, the dynamic problem could be solved in frequency domain.

The movement equation in the integral form was obtained using the principle of the virtual works that considers that a system is in balance if the virtual work of the applied forces is null. After that, the equation was written in the discrete form using the finite elements method.

A full explanation can be found in Tanaka *et al.* (2005).

3.3. Fatigue

The fatigue model considers different given sea states weighed for the respective probabilities of occurrence. Each state represents one of the environmental condition under which the riser is submitted during its life.

The probable fatigue points are: the top, TDP, which is different for each sea state, and also the wave position. But for this paper, only the TDP is analyzed, since it is the most critical point.

To calculate the damage per cycle an S-N curve is used. After that, the Miner's rule is used to sum the effects of each load case.

With this data and the wave period, the number of cycles can be calculated for this sea state, and then the Miner's rule can be applied.

A full explanation can be found in Balena *et al.* (2005).

4. Analysis data

The example considers real case design data that are presented in this section. Table 1 shows the environmental data and the position of the semi-submersible floating unit.

Table 1. Environmental data and platform position.

$X_{platform}$ (m)	-2339.899
$Y_{platform}$ (m)	0
$Z_{platform}$ (m)	1247.9
Water Depth (m)	1255
Gravity Acceleration (m/s_2)	9.81
Water Density (t/m^3)	1.03

For this real oil field, the load cases were built to maintain the stresses in an allowable level, in accordance with API RP 2RD for an extreme condition simulation, to ensure that only the most robust configurations are approved to be simulated in the following analysis.

For the static analysis, the load cases were compounded with extreme offsets and currents. The offsets are 5% of the water depth in eight directions varying 45º from each other. The currents are centenary currents and also vary from 45º from each other.

For the dynamic analysis, the offset that has already been tested in static analysis is now combined with extreme waves and currents. All configurations were tested in 128 different conditions, which can be divided in two groups of 64. The first group was created using a combination of decenary currents and centenary waves and in the second were grouped centenary currents and decenary waves.

The 64 cases of each group were created combining 8 currents which directions vary 45º from each other with 8 waves in the same directions. For all cases the same RAO was used.

For the fatigue analysis, a vast number of load cases were built. They are a combination of currents, two waves and offsets that vary from 0% to 3.57%, in all directions.

In Tab. 2 the riser properties can be found. They are the same for all the cases; the only difference is that the second segment has floaters.

Table 2. Riser properties

	Segment 1	Segment 2	Segment 3
Outer Diameter (m)	0.4572	0.4572	0.4572
Inner Diameter (m)	0.4064	0.4064	0.4064
Density (t/m^3)	7.85	7.85	7.85
Contents Density (t/m^3)	0.917	0.917	0.917
Normal Drag	1.0	1.0	1.0
E (MPa)	207800	207800	207800
Floaters	No	Yes	No

The total length of the cable was kept constant and the value was 2900m. Many different configurations were simulated and considering the acceptance percentage in function of total length, the value of 2900m were chosen because it was the most accepted, as shown in Fig. 4.

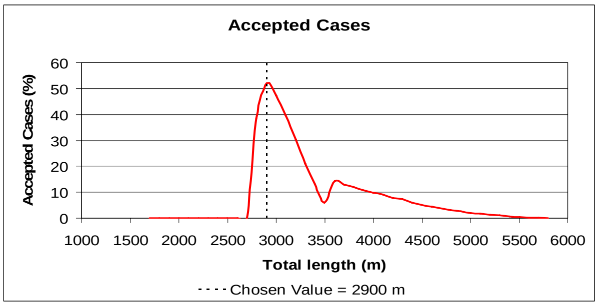

Figure 4. Acceptance percentage of different lengths of the riser

For all the configurations, the floater length (L_f) and the pitch (S_f) were not changed, and their values are 1.5m and 2.0m, respectively. Only the floater diameter was varied in order to change the segment weight. The simulations were done with 1.0m, 1.2m and 1.40m, which correspond to -0.16kN/m, -1.46kN/m and -2.99kN/m, respectively.

The lengths of the floating segments, simulated for this paper, are: 100m, 300m and 500m. The floating segment was placed all over the cable in order to verify the influence of the position on the response.

To choose floater diameter and length of the floating segment many configurations were simulated, as done to choose the total length. According to the acceptance percentage the values presented above were chosen.

5. Results

Some results will be presented in this section. Figure 5 shows the top tension, top angle, TDP tension and TDP position for neutral analysis in function of the length of the first segment (L_1). For that, three risers with different lengths of the floating segment (L_2), but with the same water weight per unit of length ww = -1.46kN/m, were simulated.

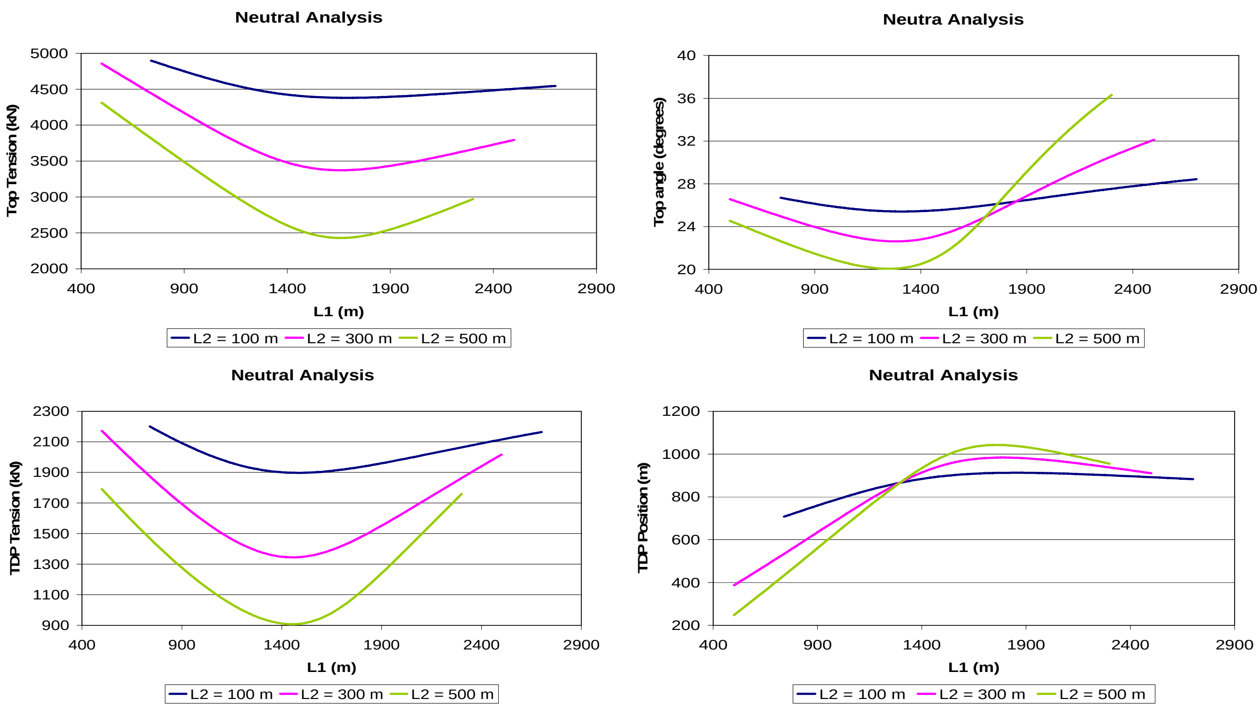

Figure 5. Response of the neutral analysis for cables with three different lengths of the floating segment

As the length of the floating segment increases, the top tension and TDP tension reduce. However, they are influenced by the position of this segment on the riser. It is noticeable that there is a point of minimum top tension, top angle, TDP tension and maximum TDP position for each cable. In the four graphics it is at the same region of L_1.

As the length of the floating segment increases, top angle reduces, but only for values of L_1 smaller than 1850m, at this region there is an inversion. The same behavior is found on TDP position, which decreases as the floating segment increases for values of L_1 smaller than 1300 m.

All graphics shows that the variation of the values grows as the floating segment length increases. For instance, the TDP position for $L_2 = 100$ m varies from 700 m to 900 m and for $L_2 = 500$ m, the variation is from 250 m to 1050 m.

Figure 6 shows the static response of the same three cables.

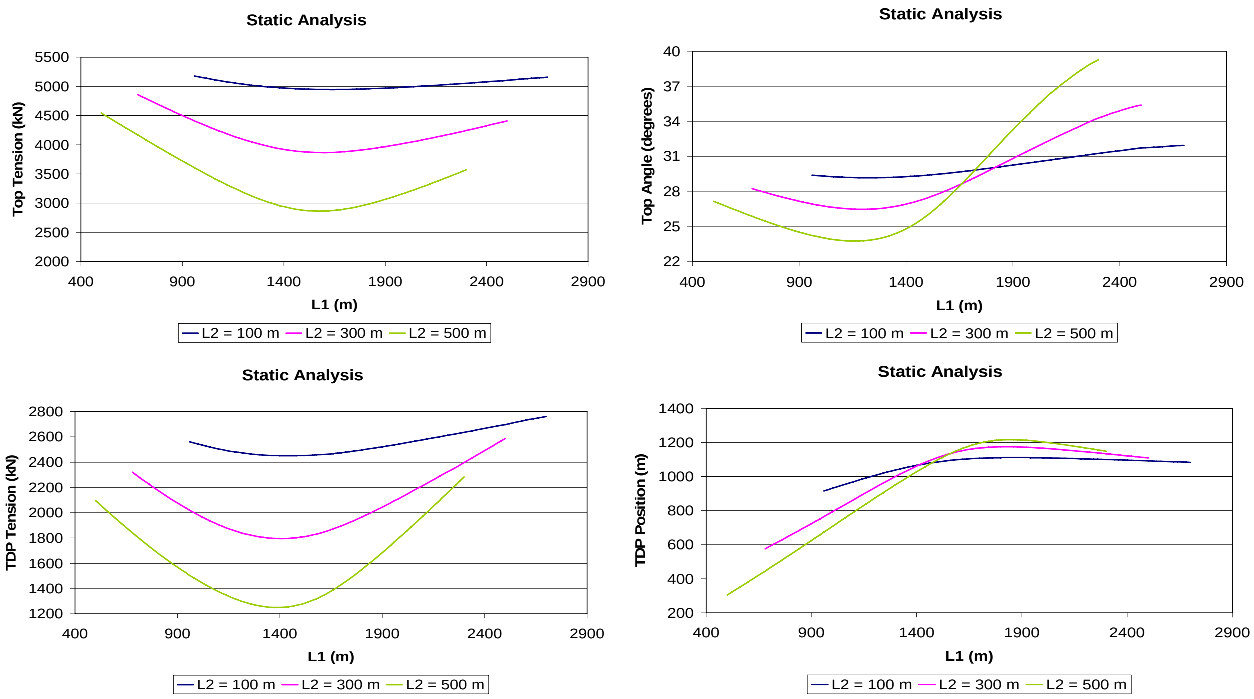

Figure 6. Maximum response of the static analysis for cables with three different lengths of the floating segment

The behavior is the same of the neutral analysis only the values have changed. Figure 7 shows the dynamic response for the same three cables.

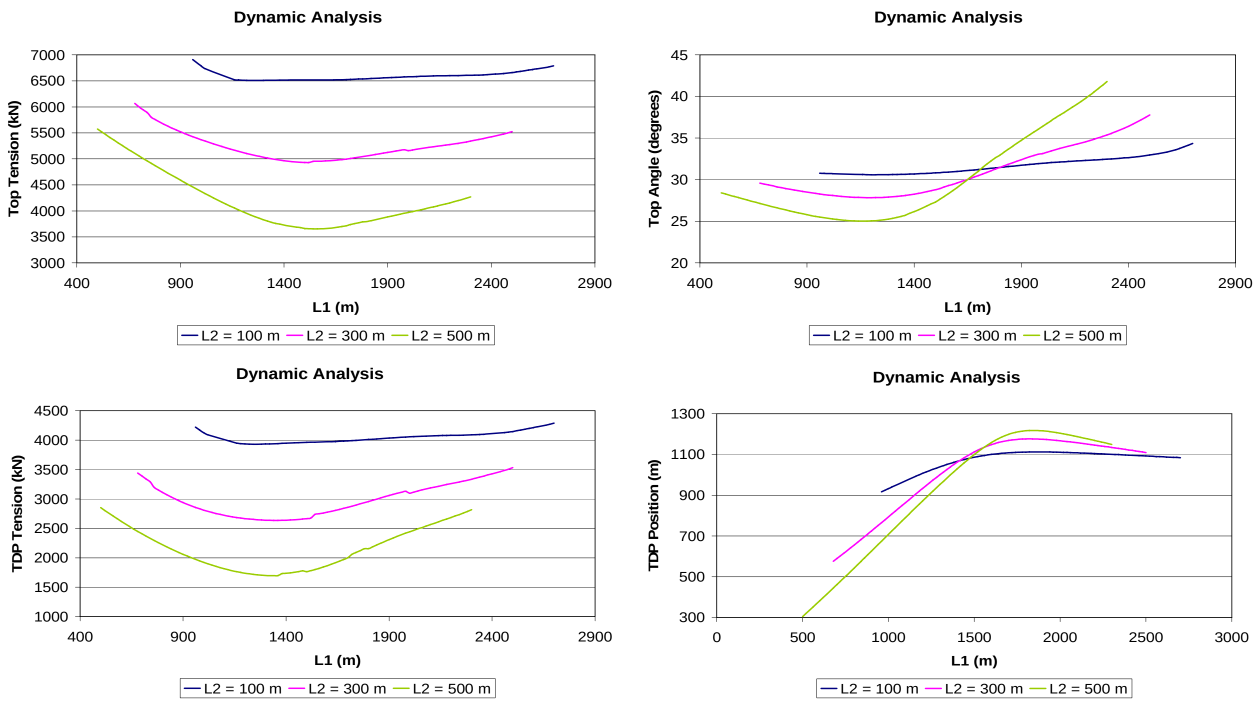

Figure 7. Maximum response of the dynamic analysis for cables with three different lengths of the floating segment

The behavior of the dynamic analysis is also alike the behavior of the neutral and static analyses.

Now, the riser with L_2 =300 m was chosen to be simulated, but with three different water weight per unit of length (ww) of the floating segment. Figure 8 shows the top tension and TDP position in function of L_1 for the neutral analysis.

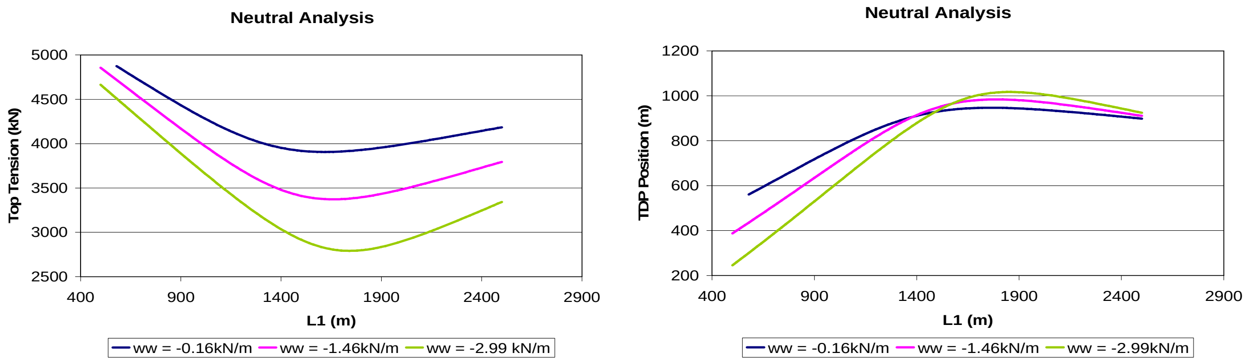

Figure 8. Response of neutral analysis for three different water weight of the floating segment

The neutral response is similar to the response seen in Fig. 5. It is possible to see a minimum point at top tension and a maximum point at the TDP position. As the water weight increases, the top tension decreases. The same happens to the TDP position, but there is also a value where it inverts.

Figure 9 shows the maximum static response for the same cable with three different water weight of the floating segment.

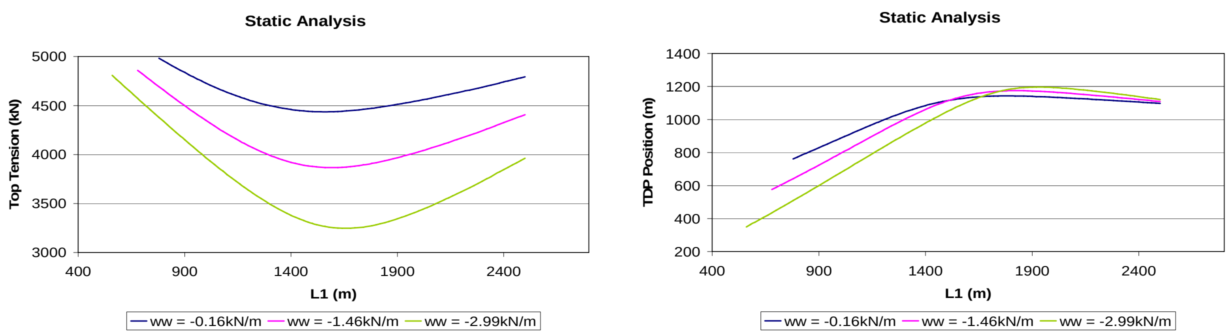

Figure 9. Maximum response of static analysis for three different water weight of the floating segment

The results for the static analysis are similar to the neutral analysis, besides the values of the top tension and TDP position.

Figure 10 shows the maximum dynamic response for the same cable with three different water weight of the floating segment.

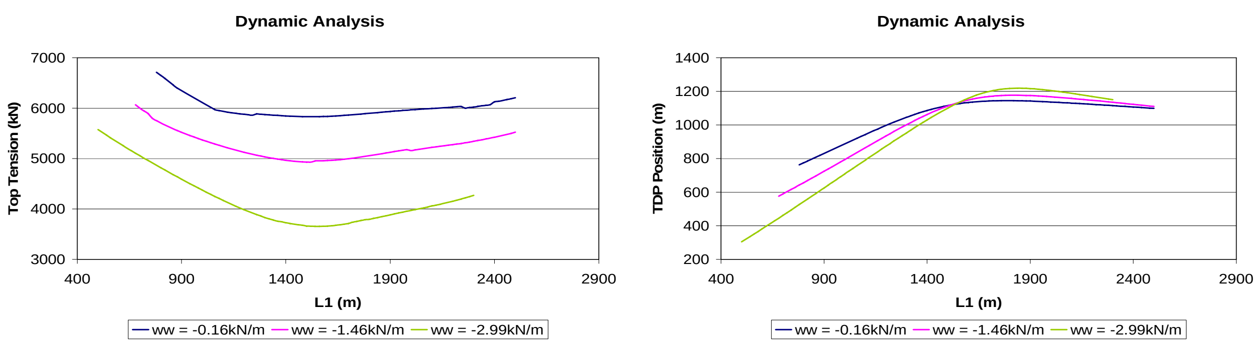

Figure 10. Maximum response of dynamic analysis for three different water weight of the floating segment

Again the dynamic curves are similar to the neutral and static analysis.

6. Conclusion

For each water weight around 300 configurations were simulated. As the configurations were chosen based on the most accepted total length, as shown in Fig. 4, almost all configurations were approved in the static, dynamic and fatigue analyses. As three different water weights were chosen, three times those configurations were simulated. The computer used for these simulations was a Pentium IV 2.4 GHz, with 1 Gb RAM, and, with that, 100 computational hours were needed. That is really fast if compared to time-domain commercial softwares.

Comparing the results, some conclusions can be drawn.

The influence of total water weight (ww x L_2) of the floating segment is similar when the ww is constant and L_2 changes and when the ww changes and L_2 is constant. That can be clearly seen comparing Fig. 5, Fig. 6 and Fig. 7 with Fig. 8, Fig. 9 and Fig. 10.

As the total weight of the floating segment decreases, the variability of the results grows. For the dynamic response, relatively small values of the total weight may cause dynamic compression on the cable, which is not desirable.

There is a relationship between TDP position and top tension for a given riser length. As TDP position increases, the suspended length of the riser decreases, and also the top tension decreases. This means that only one of those parameters can be chosen to be analyzed in the early stages of the riser design.

And finally, the results show that neutral, static and dynamic response have the same behavior. It means that the decisions can be taken based on the neutral analysis, reducing the necessity of making static and dynamic analyses for all configurations, only the pre-selected ones.

7. Acknowledgements

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