RISER-SEABED FRICTION MODELLING

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Abstract. *In some configurations, the risers are in contact with the seabed, which introduces frictional forces between the cable and the soil to the problem. Differently from the two-dimensional analyses, in three-dimensional analyses frictional forces can be found not only in the axial direction, but also in the transversal direction of the riser. The aim of this work is to present a model to include friction in three-dimensional static analysis of risers, using three-dimensional Finite Element Method. Comparisons of the results obtained for a catenary configuration with a commercial software are discussed.*

Keywords: *Offshore, Risers, Riser-seabed friction, Finite Element Method, Static analysis*

1. INTRODUCTION

The static analysis searches the balance configuration of a submerged cable under non-time-dependent loads, such as weight and buoyancy, and current loads. However, different configurations were developed in order to make deep water oil extraction feasible. In some of these configurations the lower portion of the riser is in contact with the seabed, as in Fig. 1, which makes the study of friction important for the static configuration, since the inclusion of friction may have significant changes in forces and in the configuration itself, especially in three-dimensional ones.

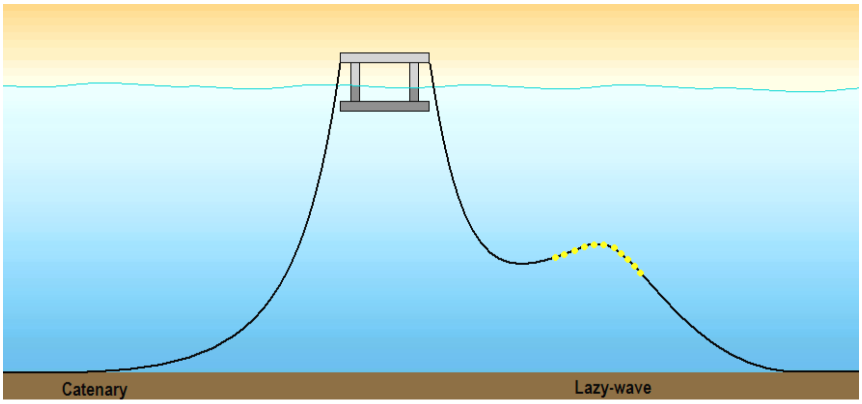


Figure 1. Catenary and Lazy-wave Configurations

The focus of this paper is to propose a model to include friction in both axial and transversal directions in the static analysis of risers to make it more realistic.

The solution is obtained through the Finite Element Method and a brief explanation of the static model, used in the in-house software, can be found in section 2. In section 3 the friction model is presented and it is followed by the data of the case study. The comparisons of results obtained with the in-house software and Orcaflex are presented in section 5. Finally, in section 6 some conclusions are drawn.

2. STATIC MODEL

In this section the static analysis of the in-house software is concisely described.

As it has already been mentioned, in this model the static analysis is performed through the Finite Element Method (FEM). For a three-dimensional analysis, the element chosen has two nodes and each node has 6 degrees of freedom, known as 3D beam element, as shown in Fig. 2.

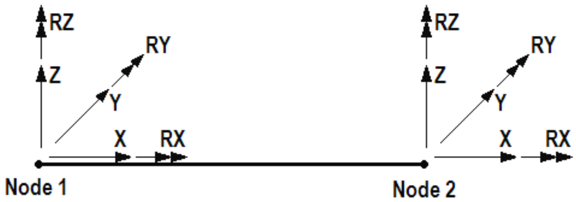


Figure 2. Element with 12 degrees of freedom

The origin of the coordinate system is at the anchor and z-axis is vertical upwards, as in Fig. 3. The seabed is considered flat and rigid. The touchdown point (TDP) is the first point where the cable touches the ground. So the friction will be considered in the piece of cable between the anchor and the TDP.

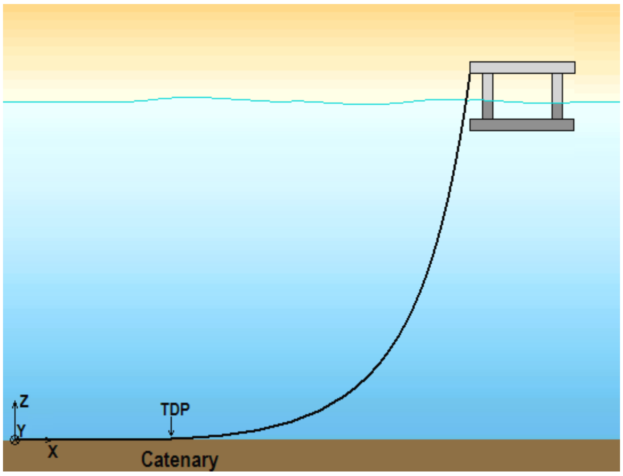


Figure 3. Catenary riser, showing the origin of the coordinate system and the touchdown point

This is a non-linear problem, which is solved through the Newton-Raphson Method. It divides the problem in linear iterations and in each iteration the stiffness matrix is rebuilt. The loads acting in the static problem are the weight, buoyancy and sea current, which is calculated using the Morison's Formula. The friction is an extra non-linear load, acting only in the part that is in contact with the seabed and its value may vary along the riser.

At last, it is important to say that, the static balance of submerged cables is determined not through the total tension of the cable, but through the effective tension. Since the cable is immersed in a fluid, the effective tension considers, besides the gravitational effects, the hydrostatic pressure.

3. FRICTION MODEL

In this section, the friction model, included in the static analysis described before, will be presented.

Since the history of the riser movements is not known, when the friction is included the coordinates of the anchor and the floating unit and the length of the cable are not enough to have a unique solution. Because of that, in this model, it will be assumed that the cable was laid on the line between the anchor and the top, which will be called here lay line. This model considers the same frictional coefficient μ for axial and transversal directions and it is divided in two cases: the first occurs when the element is on the lay line; and the second when the element is not on the lay line.

3.1 Axial friction

Considering a piece of cable lying on the seabed subjected only to axial forces (T), a resistance force (F_f) will appear from the contact with the soil, as shown in Fig. 4, where ψ is the angle that the line between the node and the anchor does with the x-axis and α is the lay angle, the angle that the lay line does with x-axis.

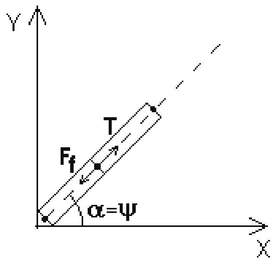


Figure 4. Top view of two elements on the seabed aligned with the lay line

The frictional force will be calculated through the Coulomb's Formula. Since its value depends on the effective tension's value and direction, the following steps are used to include this effect on the static analysis:

(1) The maximum permitted value of frictional force is calculated as: $F_{max} = -\mu.N.signal(T)$, where N is the vertical reaction force of the soil acting on the cable, T is the effective tension and F_f is the frictional force.

(2) $F_f = F_{max}$ if $|F_{max}| \le |T|$

$F_f = -T$ if $|F_{max}| > |T|$

In order to include it on the static model presented in section 2, this force has to be divided in two components: $F_{f,x} = F_f.\cos(\alpha)$ and $F_{f,y} = F_f.\sin(\alpha)$.

3.2 Transversal friction

Considering a piece of cable lying on the seabed subjected to external forces, not on the lay line direction, a resistance force (F_f) will appear from the contact with the soil, as shown in Fig. 5.

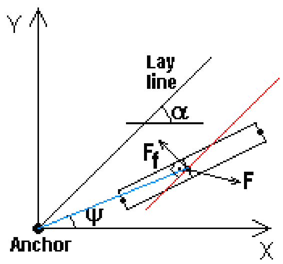


Figure 5. Top view of two elements on the seabed non-aligned with the lay line

In this case, not only axial friction will appear, but also transversal friction. Considering that the cable was laid on the lay line, the frictional force is considered, in this model, perpendicular to the lay line, aiming to bring the element as close as possible to it, as shown in Fig. 5.

Since the value of F_f is not known at the beginning, it is necessary an iterative process to calculate it, as described next:

(1) The initial value of the frictional force is calculated in both directions:

If $\psi < \alpha$: $F_{f,x} = \mu.N.\cos(\alpha + \frac{\pi}{2})$ and $F_{f,y} = \mu.N.\sin(\alpha + \frac{\pi}{2})$

If $\psi > \alpha$: $F_{f,x} = \mu.N.\cos(\alpha - \frac{\pi}{2})$ and $F_{f,y} = \mu.N.\sin(\alpha - \frac{\pi}{2})$

(2) Calculate the new position of the nodes.

(3) Make the comparison:

If $(\psi - \alpha).(\psi_2 - \alpha) \ge 0$, then the frictional forces are calculated as in step (1).

If $(\psi - \alpha).(\psi_2 - \alpha) < 0$, it means that the cable has trespassed the lay line, which is not physically possible.

In this case the node has not moved from its initial position, and the frictional force must balance the external loads. So a smaller force in the same direction but opposite sign has to be imposed to try to bring the node back to its initial position. Figure 6 helps understanding the procedure.

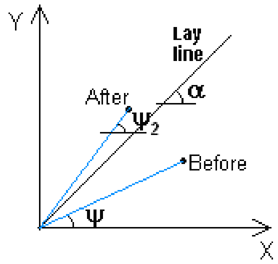


Figure 6. Top view of the node after one step with friction

The frictional force of the next step is estimated as:

$$F_{f,x}^{new} = -F_{f,x}^{old} \cdot \frac{(\psi_2 - \alpha)}{(\psi_2 - \psi)} \text{ and } F_{f,y}^{new} = -F_{f,y}^{old} \cdot \frac{(\psi_2 - \alpha)}{(\psi_2 - \psi)}$$

Step (3) is repeated while $|\psi - \alpha| > \varepsilon$, where ε is a given precision. When $|\psi - \alpha| \le \varepsilon$, the frictional force of this node will be calculated as axial friction (section 3.1).

4. CASE STUDY

The case study presented in this section consists on a catenary riser under two different loads. In the first one, the current is in the same direction of the riser, so only the axial friction is considered. And in the second case, the current makes an angle of 90 degrees with the cable's direction, making the configuration three-dimensional, so both axial and transversal friction could be considered.

The data of the riser analyzed in this paper are presented in Tab. 1.

Table 1. Riser's properties

Diameter (m)	0.1037
Weight in Air (kN/m)	0.2138
Axial Stiffness (kN)	158000
Length (m)	850.0
Drag Coefficient	1.0

The environmental data and floating unit's position are shown in Tab. 2.

Table 2. Environmental data and floating unit's position

X_{top} (m)	470.0
Y_{top} (m)	0.0
Z_{top} (m)	500.0
Water Depth (m)	500.0
Gravity Acceleration (m/s^2)	9.81
Water Density (t/m^3)	1.03

4.1 Case 1

In the first case, the current loads acts in the same direction of the cable, as shown in Fig. 7.

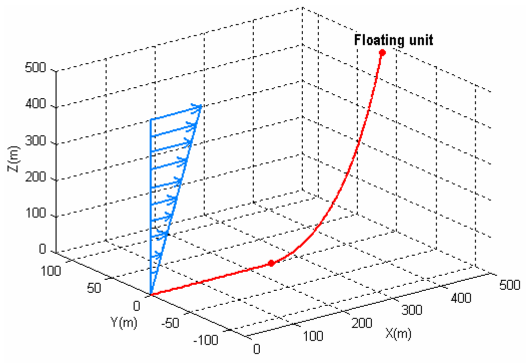


Figure 7. Current profile's direction of Case 1

The current profile can be found in Tab. 3.

Table 3. Current profile of Case 1

Z(m)	Factor	Angle (deg)
0.0	0.0	0.0
500.0	1.0	0.0

The current profile is defined with two points, as shown in Tab. 3. The values of intermediary points are found through a linear interpolation of these points. The frictional coefficient used in this case is $\mu = 0.3$.

4.2 Case 2

In order to have a three-dimensional case, the current profile makes an angle of 90 degrees with the cable, as shown in Fig. 8.

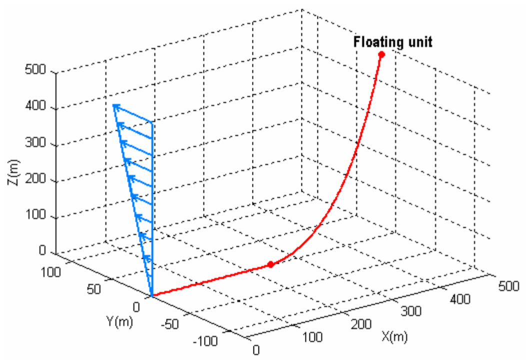


Figure 8. Current profile's direction of Case 2

The current profile can be found in Tab. 4.

Table 4. Current profile of Case 2

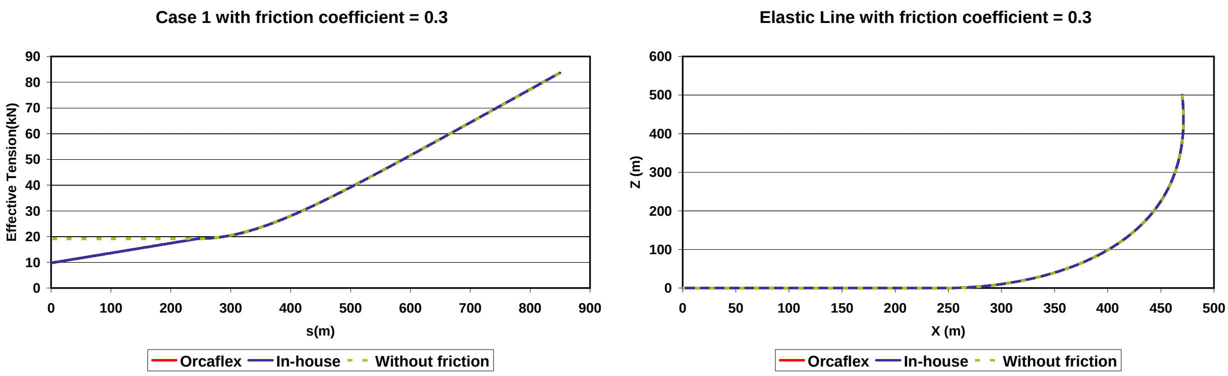
Z(m)	Factor	Angle (deg)
0.0	0.0	90.0
500.0	1.0	90.0

Again, the values of intermediary points are found through a linear interpolation of these points. The frictional coefficients used in this case are $\mu = 0.1$ and $\mu = 0.3$ in both axial and transversal directions.

5. RESULTS

In this section some results will be presented. In order to check if the presented model is a good approximation of the friction, the tension and elastic line were compared with Orcaflex.

The results of Case 1 are shown in Fig. 9.

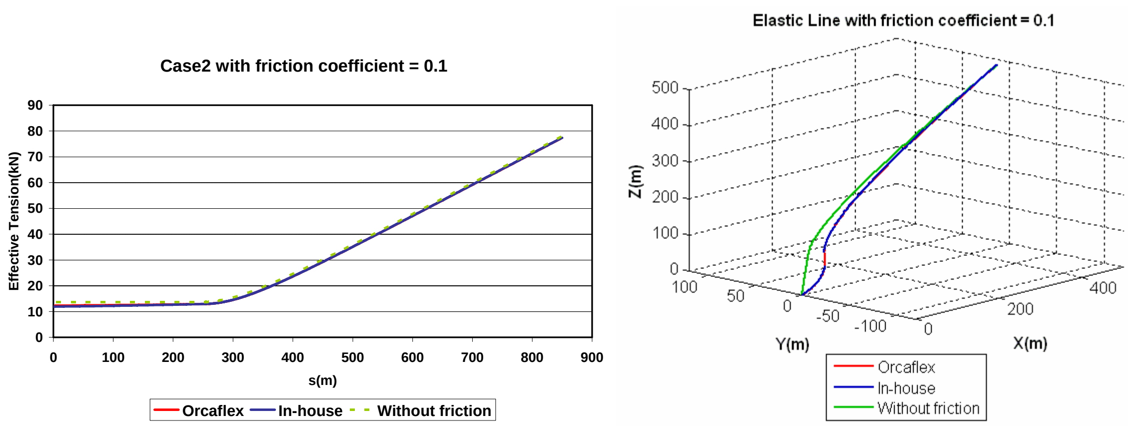


(a) (b)

Figure 9. Case 1: (a) Effective Tension's comparison of in-house software and Orcaflex. (b) Elastic line's comparison of in-house software and Orcaflex.

The graphs show that the results obtained with the in-house software and the ones obtained with Orcaflex are alike. Comparing the case without friction with the case with friction, one can see that although the elastic line is almost the same, a significant change in effective tension can be seen in the portion on the seabed.

The results of Case 2 with $\mu = 0.1$ are shown in Fig. 10.

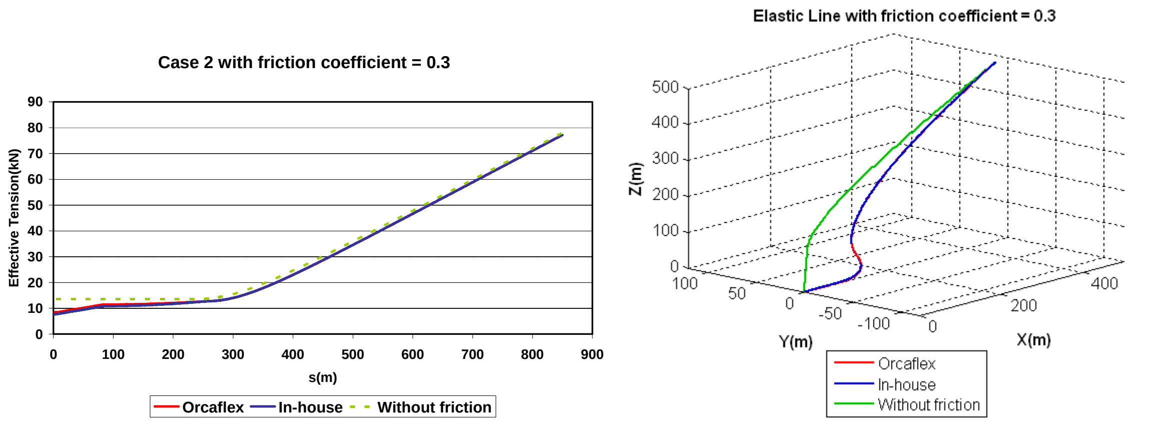


(a) (b)

Figure 10. Case 2 with $\mu = 0.1$: (a) Effective Tension's comparison of in-house software and Orcaflex. (b) Elastic line's comparison of in-house software and Orcaflex.

Again, the results presented by the in-house software and Orcaflex are similar. However, even though the frictional coefficient used in this case is small, the elastic line is not the same and the effective tension showed a little difference.

The results of Case 2 with $\mu = 0.3$ are shown in Fig. 11.



(a) (b)

Figure 11. Case 2 with $\mu = 0.3$: (a) Effective Tension's comparison of in-house software and Orcaflex. (b) Elastic line's comparison of in-house software and Orcaflex.

Analyzing these results, one can see that the model presented in this paper and Orcaflex treat the friction similarly. Changes in both graphs can be seen comparing the case with friction and without friction.

6. CONCLUSIONS

This paper presented a model to treat the friction in static analysis of submerged cables. Two cases were analyzed, in the first one only the axial friction was considered and in the second one, a three-dimensional case, both axial and transversal frictions were considered. Comparing the results obtained using the presented model with the results obtained with Orcaflex, the results obtained were good.

Another comparison is the case with friction and without friction. For all the cases, the difference in effective tension was noticeable, especially in the part that is lying on the seabed. In the first case, the elastic line almost did not change, but in the second case it changed a lot. It shows that in three-dimensional cases the friction has an important role in the configuration of the whole cable.

7. ACKNOWLEDGEMENTS

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