Torsional buckling of Dynamic Flexible Risers

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Summary

The main purpose of this work is to contribute to better understanding of the torsional structural stability and kink formation process of flexible risers in catenary configuration.

The thesis deals with installation criteria of offshore flexible lines (risers/cables) with focus on the torsional buckling behavior at the touch down point. The study includes both analytical and numerical investigations. The latter is carried out by means of the non-linear finite element program BFLEX2010.

The physical nature of the torsional buckling of catenary risers has been thoroughly analyzed and described in the present work for models with both linear and non-linear material characteristics. It has been found that such effects as including riser's tail resting on the seabed to the model and seabed friction can influence the torsional buckling capacity.

The numerical performance of the models obtained by BFLEX2010 software has been compared to the analytical solution represented by the Greenhill's equation. The limitation of the Greenhill's equation with respect to the torsional stability at the TDP has been evaluated. Significant efforts have been dedicated to investigation of the effect of non-linear moment curvature behavior (the sliding process between riser's layers) on the process of torsion buckling. It has been found that the torsional buckling capacity is directly proportional to the value of the friction moment.

The dynamic process of cyclic heave motion of the vessel has been investigated for the risers having initial utilization of torsional reaction. The parametric numerical analysis has showed that in some cases depending on a heave amplitude and amount of initial torsional utilization there can be a severe consequences leading to kink formation. Therefore, the methodology called "Dynamic criterion" has been established for evaluation of the kink formation process and verified for models with linearly elastic and non-linear material properties. Another important observation has been done from the cyclic heave motion analysis that the structure at the same time can have a compression in the TDP and remain safe against torsional failure modes. This conclusion challenges current offshore industry practice.

Conclusions

Before starting the investigation of the torsional buckling of flexible risers in the catenary shape, the simplified elastic straight beam model with constant tension subjected to torsional load has been created in BFLEX2010 and tested with respect to torsional stability. The numerical result of critical torsional reaction moment computed by software shows excellent agreement with analytical solution calculated by using Greenhill's formula.

In order to thoroughly explain the physical nature of the torsional buckling of catenary risers, the definition of the activated length has been introduced. The knowledge about the limits of activated length gives an idea where the kink can be possibly formed due to the transformation of the torsional energy into bending process.

Study cases performed for elastic PIPE31 model by means of BFLEX2010 showed that both the presence of the riser's tail resting on the seabed and the seabed friction can affect the critical torsional buckling moment and the deformational behavior of the system when the buckling occurs. Simulations carried out for this study demonstrate that at the moment when buckling occurs in case of having frictionless riser's tail on the seabed the tension in the TDZ is less than for the case of having a friction. Therefore, the critical torsion moment is smaller for the frictionless case, which from the engineering standpoint can be a good choice for prediction of the torsional buckling.

Another important outcome is that the Greenhill's analytical expression, which is valid for a straight beam with a constant tension, can not give an adequate solution of critical torsional moment in case of catenary shaped riser. This is due to the fact that in catenary configuration the tensile force is not uniformly distributed along the riser's length from the sea surface down to the bottom and, on top of that, the tension increases in the activated length during the process of axial rotation's utilization due to the transformation of the torsional energy into bending process.
A special attention has been dedicated to the study of the impact of non-linear moment curvature behavior (sliding process between riser's layers) on the process of torsional buckling. It has been determined that torsional buckling capacity of the riser is significantly affected by the non-linear material characteristics. The parametric study carried out for COMPIPE42 model (representing non-linearmaterial behavior) reveals that the critical torsional moment is directly proportional to the value of the friction moment. From another parametric study performed for non-linear COMPIPE42 model it has been determined that the influence of β parameter (governing the interaction between tensile and torsional strain components) on torsional buckling capacity is not substantial.

One of the most valuable and unique contribution of the thesis is that the dynamic criterion for evaluation of the kink formation for the catenary risers having initial torsional utilization and subjected to cyclic heave motion has been formulated and verified for models with linearly elastic (PIPE31) and non-linear (COMPIPE42) material properties. The parametric studies conducted for these models show that torsional reaction utilization and a heave motion amplitude are both of the equal importance for the kink formation process in case of elastic model, while for the model with non-linear characteristics the role of amount of torsional utilization in the system is much more crucial. It has also been emphasized that from engineering standpoint it is much more conservative to apply elastic model for lower utilizations of the torsional reactions. However, the model with non-linear characteristics needs to be implemented for the cases with larger values of torsional reaction utilizations.

With respect to the point of view related to the current offshore industry practice, an important finding has been made that the structure can remain safe with respect to the torsional failure modes having compression utilized in the TDP region triggered by cyclic heave motion.

Modeling

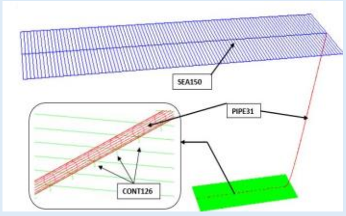

Figure 1a: BFLEX2010 Elastic model

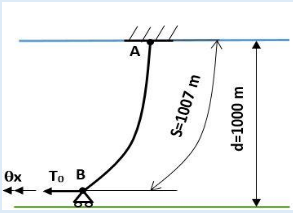

Figure 1b: model sketch of CASE STUDY A

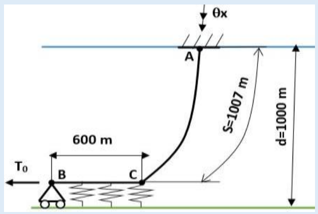

Figure 1b: model sketch of CASE STUDY B,C

Simulation results

Results for linearly elastic material characteristics (PIPE31):

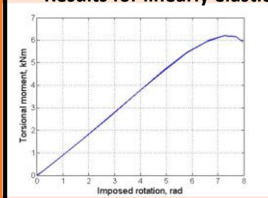

Figure 2a: Torsional behavior of the case study A (without seabed tail)

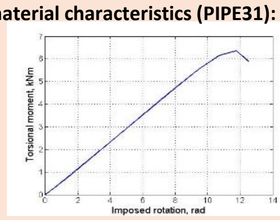

Figure 2b: Torsional behavior of the case study B (frictionless)

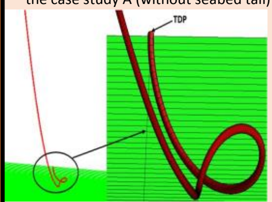

Figure 3a: Deformational behavior of the case study A

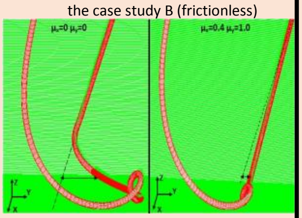

Figure 3b: Deformational behavior of the cases with different frictions

Results for non-linear material characteristics (COMPIPE42):

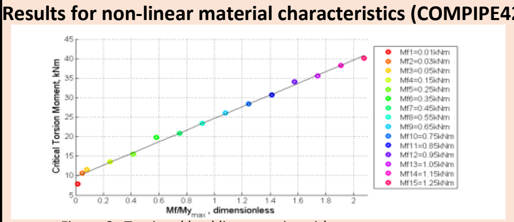

Figure 6: Torsional buckling capacity with respect to different friction moments

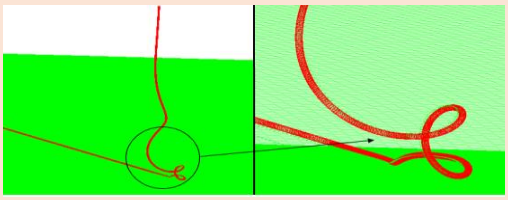

Figure 7: Deformational behavior for COMPIPE42 model with friction moment of 0.65 kNm

Verification of dynamic criterion for elastic model:

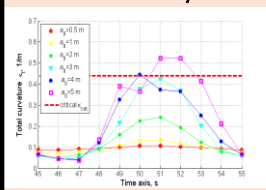

Figure 4a: 25% utilization of the critical torsion

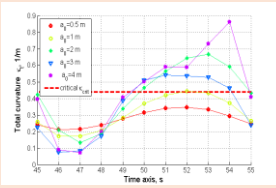

Figure 4b: 80% utilization of the critical torsion

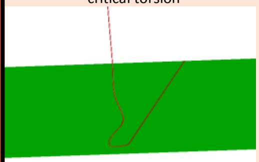

Figure 5a: 25% utilization of the crit torsion and heave amplitude of 3 m

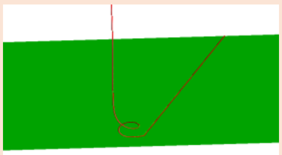

Figure 5b: 80% utilization of the crit torsion and heave amplitude of 3 m

Verification of dynamic criterion for COMPIPE42 model:

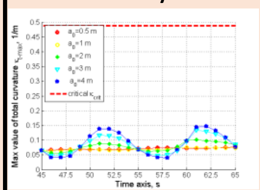

Figure 8a: 27% utilization of the critical torsion

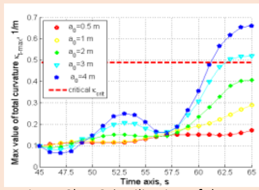

Figure 8b: 46% utilization of the critical torsion

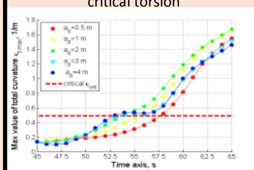

Figure 8c: 54% utilization of the critical torsion

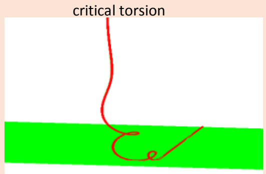

Figure 9: Example of the formed kink

Recommendations for further work

It could be reasonable to conduct a scale laboratory experiments with a purpose to reproduce elastic and non-linear riser models described in the thesis and investigate them with respect to torsional buckling capacity. Then, the experimental results might be compared with the numerical one computed by means of BFLEX2010 and the verdict about the numerical accuracy can be delivered.

The influence of the interaction between tensile and torsional strain components (β parameter) on torsional buckling capacity has been found as a result of parametric study performed for COMPIPE42 model. Broadening this study, another parametric analysis can be performed with the purpose of taking into account the impact of radial strain components on torsional buckling behavior. In order to do so, appropriate model with HSHEAR363 element type has to be assembled.

Dynamic analysis of cyclic heave motion has been performed both for elastic and non-linear models (having utilized initial torsional reactions) with intention to verify the dynamic criterion for evaluation of the kink formation. However, typically the motion of the laying vessel is much more complex than a pure heave. Therefore, a suggestion can be proposed to include sway and surge components to the heave motion of the vessel and test it with respect to the kink formation.
The dynamic analyses for elastic and non-linear models with respect to cyclic heave motion have been performed just for 3 cycles of load. Hence, it would be meaningful to perform a fatigue analysis with a high number of load cycles.

It has been found that compression in the TDP region during cyclic heave motion of the vessel can be up to the value of 9kN and the structure remains safe against torsional failure modes. However, this does not guarantee a structural safety regarding local failure modes of tensile armor (lateral buckling and birdcaging). Therefore, local FEM analysis of tensile armor layers at the TDP needs to be a part of further work.