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Torsion Instability of Dynamic Cables during Installation

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Objective and scope

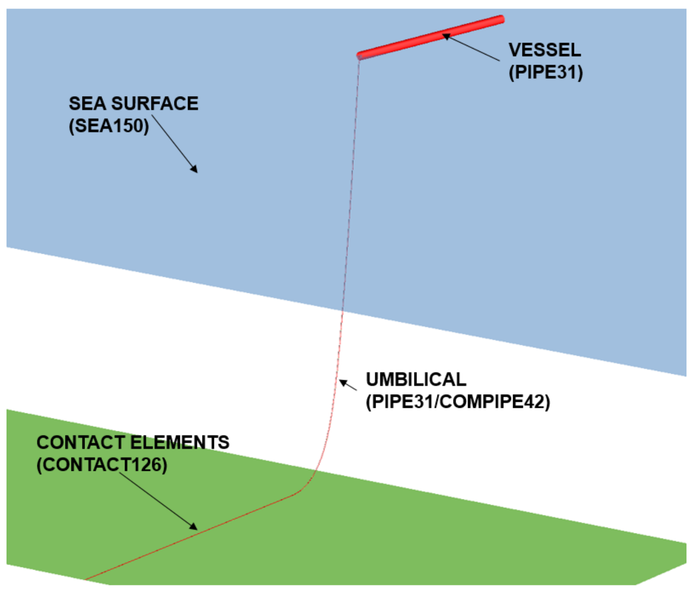
A submarine cable is a crucial connection between offshore topside facilities and equipment located on the seabed. The umbilical's function is to provide the control to operate and monitor the subsea equipment. During installation the touch down zone is critical with respect to failure of the cable. The touchdown zone may be exposed to severe curvature and axial compression due to vessel motion and environmental loading, which may result in local buckling in the cross-section causing failure. Current practice today is to avoid the occurrence of compression at the touchdown point to avoid cable failure, as well as always operate below the API criterion for minimum curvature radius. This restricts the weather window where installation is recommended. The limited weather window results in high installation costs. It is therefore of great interest to investigate whether it exists exceptions where compression at the touch down point not necessarily leads to structural failure and may be tolerated.

The purpose of this thesis is to investigate the field of torsion instability during an installation, and investigate whether it is possible to establish a design criteria where compression in the touch down zone during installation is accepted. This is done by performing numerical analyses using SIMLA

Modelling

Umbilical cross-sections

Simulation model

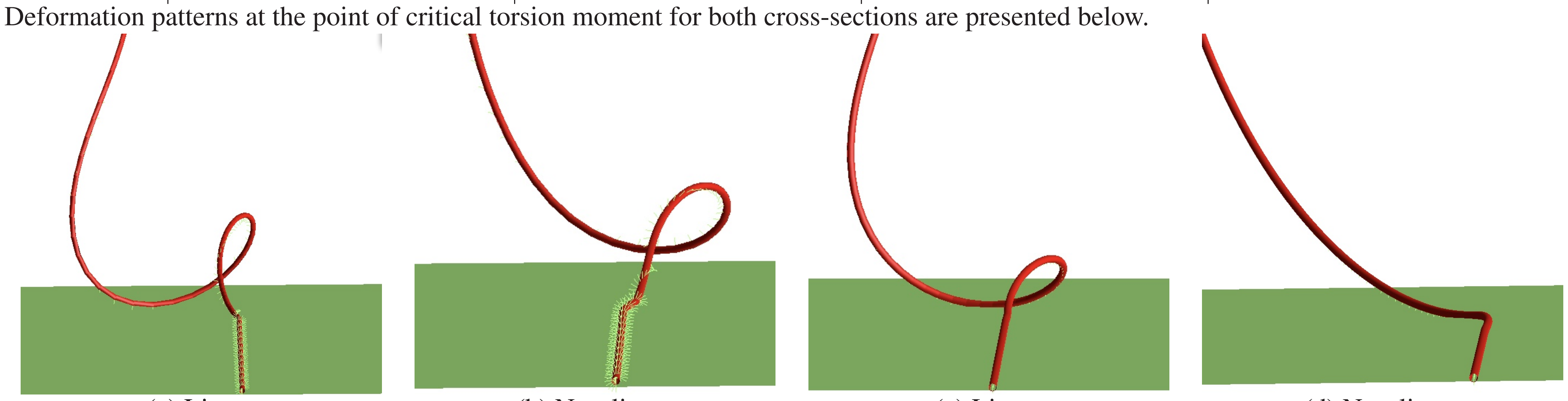


Results

The results comprehend two parts. Initially the capacity of the two cross-sections with respect to torsion failure is established. When subjected to severe axial rotation, the cable torsion moment will reach a critical value. Surpassing this value starts the process of kink formation and structural failure of the cable. The value of the resultant curvature at the point of critical curvature is defined as the curvature capacity of the cable. The table below summarizes the critical capacity values.

	Critical torsion moment [kNm]		Critical resultant curvature [1/m]	
	PIPE31	COMPIPE42	PIPE31	COMPIPE42
Umbilical 1	4.280	3.720	1.3084	0.2784
Umbilical 2	15.074	52.892	0.9009	0.0731

Deformation patterns at the point of critical torsion moment for both cross-sections are presented below.



(a) Linear (b) Non-linear — **Umbilical 1**
(c) Linear (d) Non-linear — **Umbilical 2**

Installation scenarios

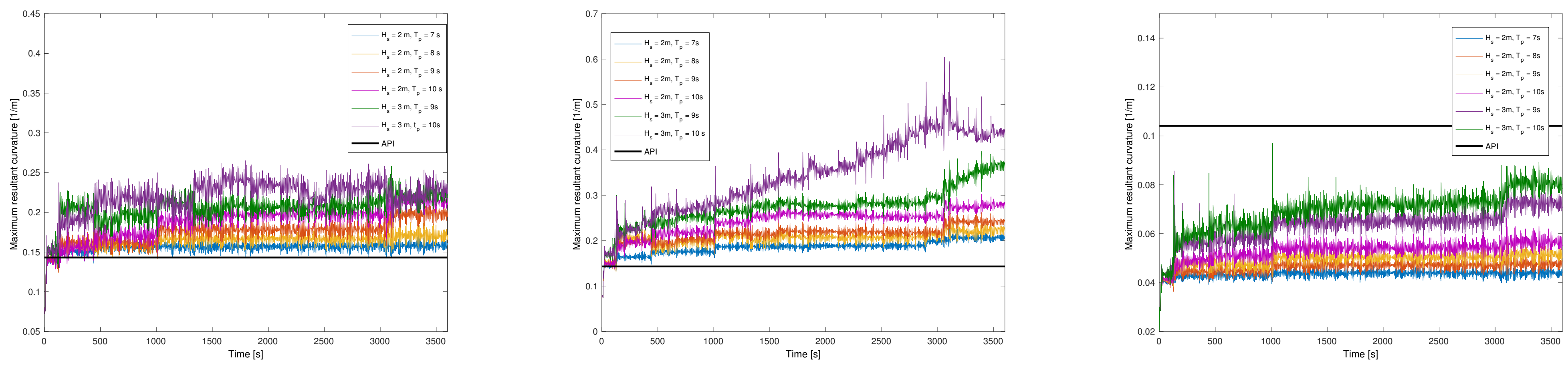
Two installation scenarios are simulated

1. End cap turn; 180 deg turn near anchor
2. Curved routing to avoid obstacles

The installation is simulated by applying the torque level associated with the installation scenario, before the wave loads and vessel motions are applied. The first installation scenario yields a too large torsion moment for umbilical 2 to handle, and is thus defined as not feasible. The other cases are run for the two cross-sections.

Resultant curvature

A sea state is determined as acceptable if a stable value of the maximum curvature is reached without exceeding the API criterion. Below is the maximum resultant curvature plotted as a function of time for the three installation scenarios simulated.



(a) End Cap Turn (b) Curved Route — **Umbilical 1**
(c) Curved Route — **Umbilical 2**

Curvature criterion

Subsea cables must be dimensioned to handle a certain minimum radius of curvature. Deformations further beyond this value is not acceptable. API has established safety factor to account for loading scenario and failure mode. This yields the following limiting curvature radius' for the two cross-sections

Umbilical 1 $\kappa_{min} = 0.1431$

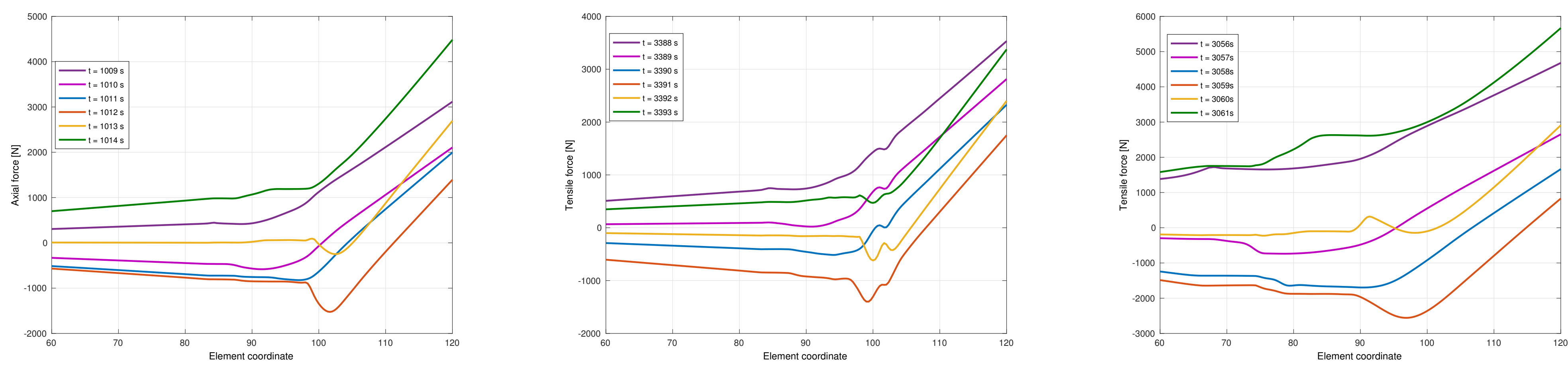
Umbilical 2 $\kappa_{min} = 0.1041$

Armour buckling loads

Failure mode	Umbilical 1	Umbilical 2
Radial failure	349 kN	235 kN
Lateral failure	3678 kN	2184 kN

Compression in TDZ

The dynamic simulations shows that nearly all sea states experience compression in the TDZ to some degree. Increasing magnitude with increasing severity of sea state. Below the variation of the axial force for various time steps is presented for $H_s = 3m, T_p = 10s$, illustrating compressive force for all three cases.



(a) End Cap Turn (b) Curved Route — **Umbilical 1**
(c) Curved Route — **Umbilical 2**

Summary and Conclusions

The numerical analyses carried out in this thesis investigate how the inherent torque and various environmental conditions affect the process of loop formation. It is found that the torsion capacity of a cable with no armouring and a very low torsional stiffness is significantly lower compared to a torsionally balanced cable as umbilical 2. It is also established that the torsion capacity of the cable is affected by implementing non-linear material characteristics. The maximum dynamic curvature criterion determined by API is validated as an adequate criterion with respect to loop formation.

Current practice does also not allow for axial compression in the touch down zone. The numerical analyses shows that some degree of **axial compression is present** in nearly all simulated load cases for both cross-sections. It is also shown that the magnitudes of the axial compression is outside the critical range for local tensile armour buckling. It is also established that **the maximum resultant curvature fulfill the API criterion** for umbilical 2 , and the sea states can hence be defined as acceptable. Umbilical 1 experience compression, but the curvature magnitudes are too high to be accepted. The analyses shows that the trend is an increasing compressive tension with increasing severity of the environmental condition. Hence it can be proposed that the criterion is too conservative to be applicable for all sea states, and it should be investigated whether some kind of relation is found between experienced compressive load and sea state parameters. This validation can be a step in the direction of increasing the weather window and thus reducing installation costs.