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Insight into the on-bottom stability of cables

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ABSTRACT: Subsea cables play a vital role in offshore wind farms. Demand in the energy sector has increased and on-bottom stability of cables is critical for integrity during wind farm construction phases and when cable cannot be buried due to seabed conditions. Assessing the on-bottom stability of cable is becoming more crucial, especially when different construction phases of the project are running in parallel and predecessor activity is delayed. The most common scenarios are the temporary wet storage conditions of cable ends before pull-in due to OSS installation completion, or temporary wet storage conditions of cable after cut and sealing prior to a cable repair. This paper presents insight into the fundamentals of on-bottom stability of subsea cables and provides results from parametric studies using numerical assessment undertaken with advanced computational methods using ORCINA Orcaflex software. A parametric study using numerical analyses was undertaken to investigate the on-bottom stability of three different cables varying in diameter (from 103 mm to 256 mm) at three different water depths under two different sets of metocean conditions in rocky seabed. Results from these parametric studies is summarized in plots that enable quick preliminary assessment of on-bottom stability for typical cables. This paper would be a useful resource to cable engineers and developers to assess the on-bottom stability of cables at the early stages of a project.

Keywords: on-bottom stability; subsea cables; numerical analysis; parametric studies; cable stability;

1 INTRODUCTION

Untrenched and surface-laid submarine cables are subjected to wave and current loads throughout their design lifetime, which can potentially destabilize them both horizontally and vertically (Figure 1-1). The cable's stability is maintained through its interaction with the surrounding seabed. Given the uncertainties in wave, current, and seabed conditions, a complex interaction arises between the wave/current, cable, and seabed, necessitating careful consideration.

Properly accounting for these interactions is crucial for ensuring the stability and integrity of the cable. This involves comprehensive analysis and modelling of the dynamic forces exerted by waves and currents, as well as the corresponding response of the cable and seabed. Advanced computational methods and simulations are often employed to predict these interactions and to design appropriate stabilisation measures. Several researchers in the past have investigated the stability of cables under waves and current loadings (N.I.Thusyanthan, Atkins, UK and S. Jegandan, 2018), (Guomin Ji, Muk Chen Ong, 2019), Bassem Youssef, (Dermot O'Brien, Atteris Pty Ltd, 2017),

The design of submarine cables against excessive displacements due to hydrodynamic loads is defined as a Serviceability Limit State (SLS) with target safety levels, as specified in guidelines such as DNV-RP-F109 and soil interaction as specified in DNV-RP-114. This ensures that the cable remains functional and within acceptable displacement limits throughout its operational life. This paper presents insight into the fundamentals of on-bottom stability of subsea cables and provides results from parametric studies investigating three different cables varying in diameter under two different sets of metocean conditions. The influence of key parameters such as lay tension of cable, metocean and seabed soil conditions was investigated, and the results provide insight into the degree of influence these parameters have on the on-bottom stability.

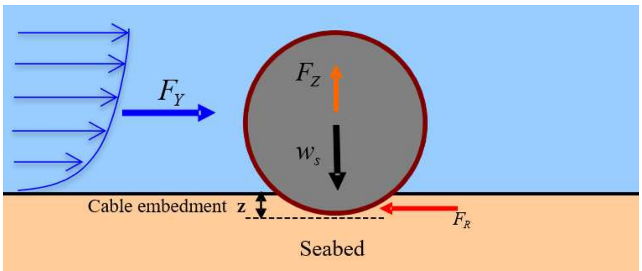


Figure 1-1 Schematic of loadings on cable on seabed

As per DNV-RP-F109, a submarine cable meets the absolute static stability requirement if it satisfies

Equations 1 and 2, ensuring stability under static loading without excessive movement or uplift.

$$\gamma_{SC} \frac{F_Y + \mu F_Z}{\mu w_s + F_R} \leq 1.0 \quad (1)$$

$$\gamma_{SC} \frac{F_Z}{w_s} \leq 1.0 \quad (2)$$

Where:

F_Y = Horizontal hydrodynamic (drag and inertia) load per unit length

F_R = passive resistance from soil per unit length

w_s = Cable submerged weight per unit length

μ = Friction coefficient between cable and seabed

F_Z = vertical hydrodynamic lift load per unit length

γ_{sc} = safety factor (DNV RP F109 provides this based on location and class low, normal and high)

2 FUNDAMENTAL OF CABLE STABILITY ASSESSMENT

The likelihood that certain tidal and wave conditions will move a cable can be predicted using specific models focussed on "on bottom stability". DNV-RP-F109 describes three on-bottom stability methods: Generalized Lateral Stability, Absolute Lateral Stability, and Dynamic Lateral Stability. The Generalized Lateral Stability method, developed for large pipelines, is straightforward and conservative, making it suitable for early designs but often leading to over-design for lighter structures like power cables. The Absolute Lateral Stability method (Eq. (1) & Eq.(2)), adapted to assess the full stability of power cables, has proven challenging due to the conservative approach and the low submerged weight of cables, which complicates achieving complete stability. In contrast, the Dynamic Lateral Stability method allows limited lateral displacement, utilizing advanced FEM simulations to model dynamic conditions more accurately. This approach is more realistic and cost-effective, as it could reduces the need for additional stabilization solutions. However, its reliance on advanced FEM simulations and precise data increases complexity and design time, requiring detailed modeling and iterative validation.

3 ON BOTTOM STABILITY – NUMERICAL PARAMETRIC STUDY

3.1 Common Cable Properties

In this study, three distinct cables, differing in geometry, electrical parameters, and mechanical properties, were analysed. Table 1 presents a summary of the primary mechanical characteristics of the cables. Cable 1 is representative of those commonly employed for interconnections between small islands and the mainland. In contrast, Cable 2 and Cable 3 are typically utilized as export cables for offshore wind farms. The electrical parameters of the three cables have been not considered for this study as negligible for on-bottom stability purposes.

Table 1. Cables dimensions and mechanical properties.

Properties	Cable 1	Cable 2	Cable 3	Units
Outer Diameter	103	175	256	mm
Weight in air	27.1	65	102	kg/m
Weight in water	19.8	37	60	kg/m
Axial stiffness	456	320	172	MN
Bending stiffness	Figure 3-1	22	22.5	kN*m²
Torsional stiffness	21	45	75	kN* m²/rad
Allowable Tension	110	145	180	kN
Minimum Bending Radius	1500	3000	3000	mm

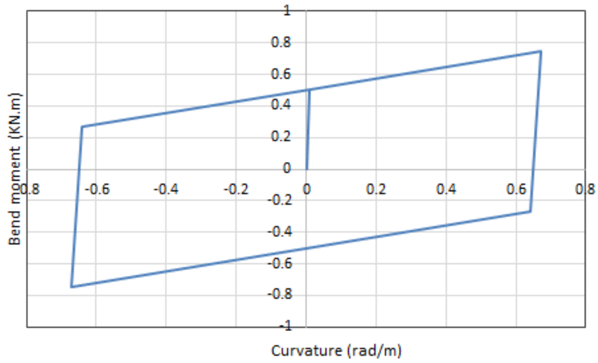


Figure 3-1 - Cable 1 bending stiffness hysteresis loop

3.2 Environmental data

The environmental data used in the simulation are shown in Table 2. For this study, two load combinations were applied (LC1 and LC2). The environmental data selection was based on randomly sampled mean values from publicly available metocean data at wind farm locations located in the North Sea. The chosen environmental dataset represents an average of values experienced in the North Sea area, rather than a direct representation of a full population mean. The values are derived from observations collected within this region, and while they are randomly sampled, they specifically reflect conditions in the North Sea rather than a broader global dataset.

The current and wave directions are considered collinear and are perpendicular to the cable route. The incident current velocity of 0.2 m/s was applied for both load conditions.

Table 2. Environmental data set

Parameters	LC1	LC2	Unit
Significant Wave Height	7.5	9.94	m
Wave Period	9.9	11.36	s
Current at 1m above cable	0.2	0.2	m/s

3.3 Numerical methodology used in parametric study

The numerical method has been used to check the dynamic lateral stability of cables which involves simulating the cable's response in the time domain, incorporating hydrodynamic loads from an irregular sea state as well as soil resistance forces. This type of dynamic simulation should cover a complete sea state; if no specific duration is provided, a three-hour sea state is suggested.

According to DNV-RP-F109, seven simulations should be run with randomly or critically chosen realizations for the random number generator to show little or no correlation between peak wave velocity and peak cable response. Once the standard deviation of the resulting displacement stabilizes, the design value should be set to the mean plus one standard deviation. In this study, the mean and SD are evaluated for each cable node's displacement time series during the simulation time. This approach captures the temporal variability of displacement at each point along the cable, providing a better understanding of its stability. This is crucial for assessing the risk of cable failure due to excessive lateral displacement of cable. For this study, the model length considered is 250m, ensuring a representative span influenced by environmental conditions. The end boundary conditions were set as pinned (pin), meaning the cable ends were fixed in position but free to rotate, preventing artificial constraints while allowing realistic dynamic behaviour. The cable is modelled using a lumped mass approach, where the line is represented as a series of mass "lumps" connected by massless springs.

Environmental and cable model was created using ORCINA ORCAFLEX software, the cable was modelled using a line object which was set with the cable properties reported in section 3. Lateral resistance for the cable is calculated as the sum of Coulomb resistance and passive soil resistance. Given the negligible passive resistance, only Coulomb resistance with a coefficient of 0.6 rock is included in the analysis. Variable drag and lift coefficients have been considered as part of the analysis, which are functions of Reynold's number and proximity from the seabed. To model the seabed conditions, the seabed in Orcaflex was represented using a standard elastic seabed with a normal stiffness of 500 kN/m² for rocky areas. This high stiffness for rocks was selected to prevent potential cable penetration into the seabed and to provide conservative values which will remain applicable whether in sand or gravel soil environments.

Time-domain dynamic analyses were conducted for all scenarios to assess the cable's performance under varying environmental and operational conditions. The simulations included different load cases based on three water depths: 20 meters, 40 meters, and 60 meters. Additionally, two environmental conditions were considered: LC1 and LC2. To account for variability, each scenario included seven different random seed variations, resulting in a total of 42 distinct simulation cases for each cable, which results in a total of 126 runs.

From each simulation, key metrics were extracted to evaluate the cable's response. The primary focus was on the maximum lateral displacement of the cable, with an allowable limit set at ten times the cable's outer diameter, following the guidelines of DNV-RP-F109. In addition, cable bottom tension of 5 kN, which represents a common value, was used in all analysis.

4 RESULTS

The design criteria for lateral stability can be generally expressed as:

$$Y/Y_{allowable} \leq 1.0 \quad (3)$$

where $Y_{allowable}$ represents the permissible lateral displacement. In cases where other limit states, such as maximum bending or fatigue, are not evaluated, the criteria can alternatively be defined to ensure that the combined lateral displacement from both temporary and operational conditions remains within 10 times the cylinder diameter (D).

Figure 4-1 through to Figure 4-6 present the maximum lateral displacements (Y) of three cables across seven wave realizations (seeds) under two different environmental load conditions (LC1 and LC2). The seven wave realizations have been randomly selected and applied to each cable and load condition, with different colors representing seven distinct run realizations.The maximum lateral displacement represents the mean plus the standard deviation of displacements during each simulation time.. Cable 1 exhibits marginal stability at a water depth of 60 m under Load Condition 1 (LC1), with displacements approaching the allowable limit. In contrast, Cable 2 and Cable 3 remain fully stable at the same depth under LC1. At a shallower depth of 40 m, Cable 1 maintains stability under LC1 conditions.

The lateral displacements of Cable 2 and Cable 3 show significant variability across the seven realizations at a water depth of 40 m under LC1, with a high standard deviation indicating scattered displacement behaviour. At a water depth of 20 m, all cables are observed to be entirely unstable under the given conditions.

Interestingly, under Load Condition 2 (LC2), the lateral displacements of Cable 2 and Cable 3 at a depth of 40 m exceed those observed at 20 m.

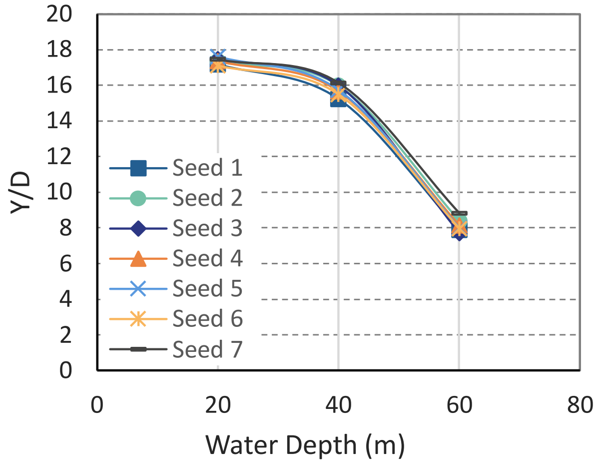


Figure 4-1 Cable 1 Max. Lateral displacement under LC1

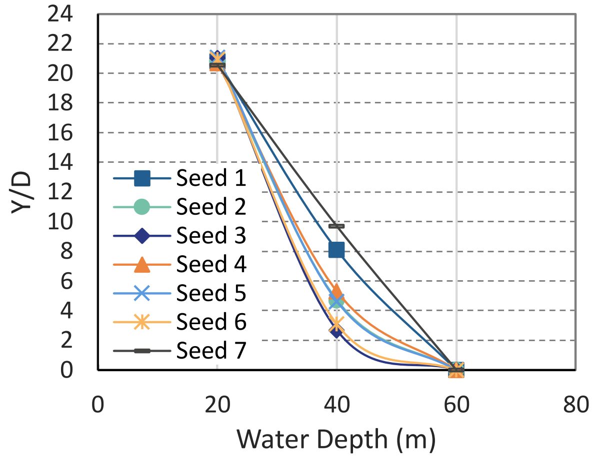


Figure 4-2 Cable 2 Max. Lateral displacement under LC1

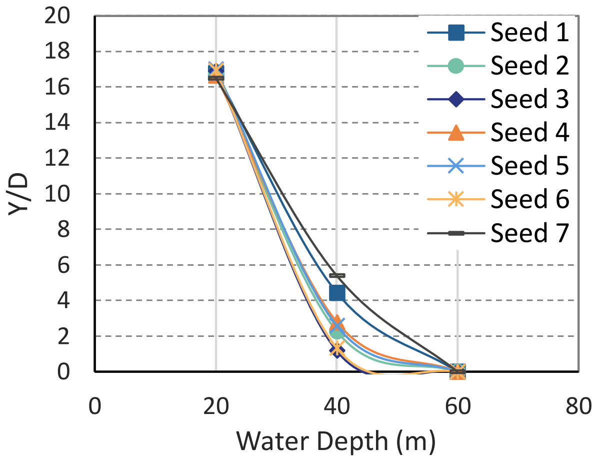


Figure 4-3 Cable 3 Max. Lateral displacement under LC1

This counterintuitive trend is linked to the dominance of wave-induced forces at shallower depths. At a depth of 20 m, the system is wave-dominant, and the oscillatory nature of wave loads causes the cables to move back in the opposite direction of the current during each half-cycle of the wave period, resulting in smaller mean lateral displacements. In contrast, at 40 m depth, the wave-particle velocity during the second half-cycle is reduced, diminishing the counteracting influence of the current. Consequently, the cables do not fully return to their initial positions, leading to larger mean lateral displacements.

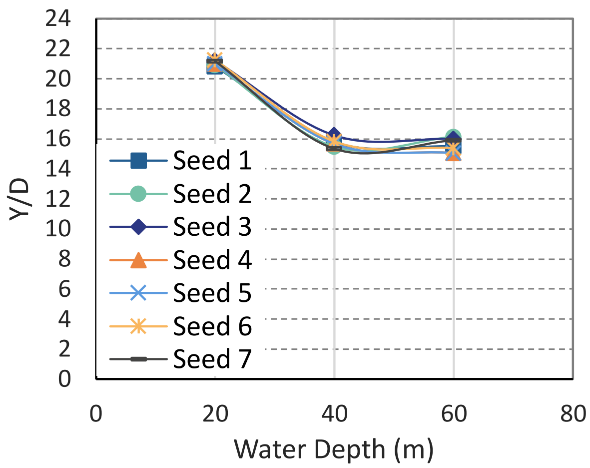


Figure 4-4 Cable 1 Max. Lateral displacement under LC2

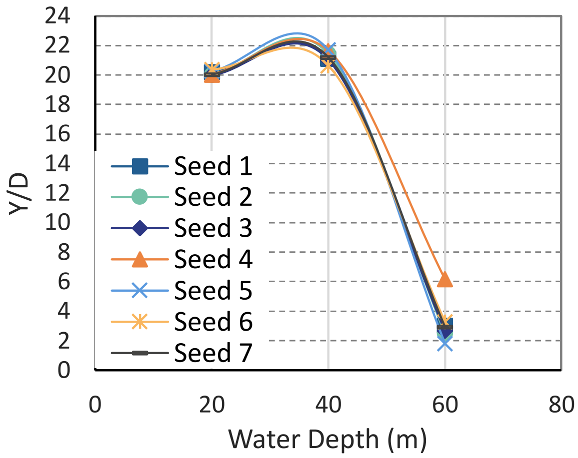


Figure 4-5 Cable 2 Max. Lateral displacement under LC2

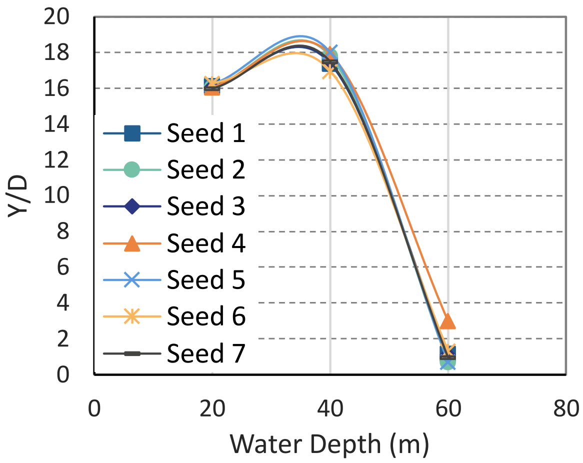
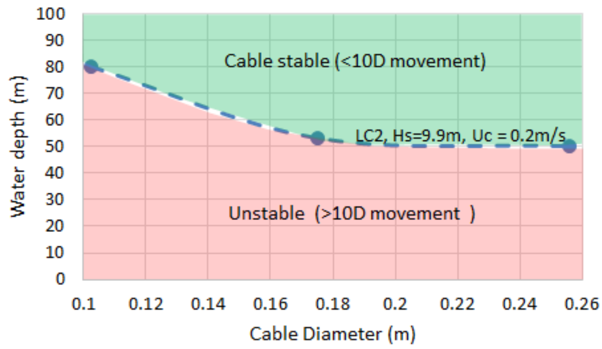


Figure 4-6 Cable 3 Max. Lateral displacement under LC2

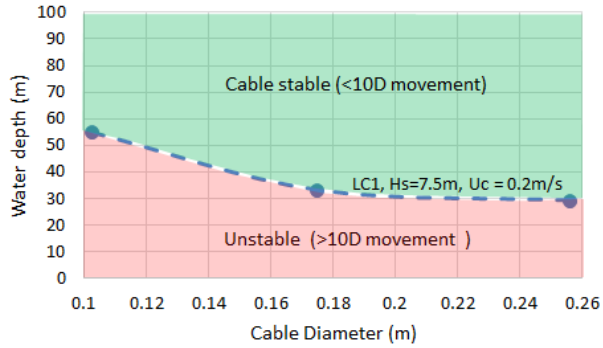
5 CONCLUSION

This study examined on-bottom stability of power cables (three different diameter) used in offshore wind farms. On-bottom stability was assessed in three different water depths under two different environmental load conditions (LC1 and LC2). All assessment were carried out with cable seabed condition assumed as rock. A total of 42 simulations for each cable were conducted using ORCAFLEX, which results in a total of 126 runs. If a cable is stable in rock, then it will be stable in sand and clay conditions, therefore seabed condition of rock is worst case scenario. Results from the study reveal that achieving absolute on-bottom stability is challenging and hence results are presented for generalised stability where the maximum lateral cable movement is less than 10D under a three-hour sea state.

As a conclusion of this study, Figure 5-1 (a) and (b) illustrate the relationship between cable diameter and stable water depth under environmental conditions LC1 and LC2. The plotted lines for LC1 and LC2 represent the critical water depths required to achieve stability, with the stability zone located above these lines (green area). All values above the plot lines correspond to a generalised stability condition where the cable lateral displacement remains less than 10 times the cable diameter. It needs to be noted that these plots provide a high-level screening results based on generic cable properties and environmental loadings used in this assessment. Project specific cable properties and environmental loads will have impact on-bottom stability. Therefore, these results should not be used for detailed design or construction decisions. Nevertheless, these results provide highlight guidance for early-stage assessments.



(a)



(b)

Figure 5-1 (a) Generalised stability under LC1; (b) Generalised stability under LC2

AUTHOR CONTRIBUTION STATEMENT

Omar Lauretta: Data curation, Formal Analysis, Investigation, Resources, Methodology, Investigation, Writing- Original draft, Writing - review & editing. **Ali Reza Vatandoust**: Formal analysis, Software, Data curation, Investigation, Resources, Writing - Original draft. **Indrasenan Thusyanthan**: Conceptualization, Resources, Supervision, Writing-Reviewing and Editing,

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