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Marine energy – On-bottom stability of cables on rocky seabeds – Guide

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Summary of pages

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Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 September 2025. It was prepared by Technical Committee PEL/114, *Marine energy – Wave, tidal and other water current converters*. A list of organizations represented on this committee can be obtained on request to its committee manager.

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Presentational conventions

The guidance in this document is presented in roman (i.e. upright) type. Any recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Additional commentary, explanation and general informative material is presented in smaller italic type.

Where words have alternative spellings, the preferred spelling of the *Shorter Oxford English Dictionary* is used (e.g. “organization” rather than “organisation”).

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Introduction

Subsea cables are used for power transmission between both onshore and offshore structures within the renewable energy and oil and gas industries, and for power grid interconnectors. Subsea cables routed between structures or shore laid directly on the seabed are subjected to hydrodynamic forces through wave and current motions. These forces, if excessive, can result in large lateral displacements and/or potential damage to the cable. Subsea cable stability design aims for the on-bottom cable to have sufficient self-weight to remain stable on the seabed and hence avoid failure. Dependent on the cable hazards and protection approach, the cable might only be on the seabed temporarily, prior to the introduction of secondary stabilization measures, such as burial. Alternatively, the cable could remain on the seabed throughout the full operational lifetime, particularly in locations where there is no requirement for protection from ship anchors, fishing trawl gear or other hazards.

The growth of offshore power generation through renewable energy sources has led to a requirement for subsea cables to be installed and subsequently stabilized in much more onerous conditions, including areas of rocky seabed. Guidelines have been previously developed for calculations of on-bottom stability; these have limited applicability to emergent conditions. Existing conventional industry guidance is primarily applicable for softer seabeds, such as sand and clay, larger diameter objects (i.e. pipelines rather than cables), with very limited guidance for performing on-bottom stability design on harder rocky seabeds.

This British Standard has been developed to consolidate industry knowledge and expertise and thus establish an improved basis for calculating the stability and integrity of subsea cables on rocky seabeds.

Industry research has led to:

- a) evidence of subsea cables being more stable in some situations than predicted, based on the application of conventional design methods; and
- b) an understanding of why this is, leading to a new basis for quantifying the stability of subsea cables on rocky seabeds. Specifically, where a rocky seabed has undulations, these undulations lead to:
 - 1) higher seabed sliding resistance; and
 - 2) lower hydrodynamic lift and drag.

The combined effect is typically higher stability, and therefore a reduced requirement to engineer additional stabilization measures.

Research has led to validated new methods to assess the seabed resistance and hydrodynamic forces, which capture the influence of the seabed undulations in a rigorous way. This British Standard presents the outputs from this research in a form suitable for use in design practice. As a result, this British Standard provides a more appropriate basis for the stability design of subsea cables on rocky seabeds than standards originally developed for other seabed types and standards developed for typically larger pipelines containing hydrocarbons.

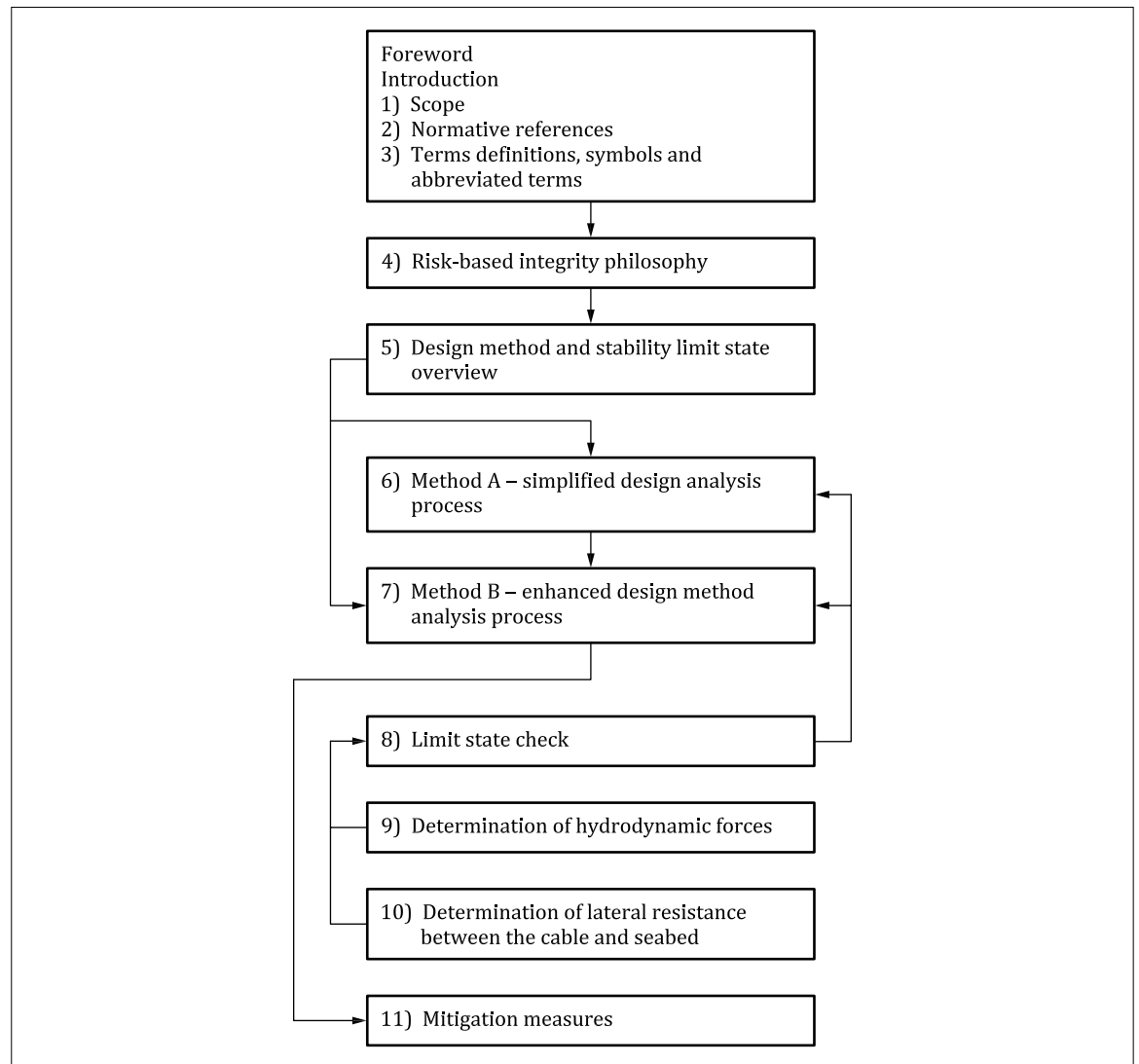
The layout of this British Standard and a typical sequence of analysis is presented in [Figure 1](#).

The design methods are summarized in [Clause 5](#) together with the relevant limit states, with the detailed analysis sequences described in [Clause 6](#) and [Clause 7](#) for Method A and Method B, respectively. Method A and Method B both apply the principles identified in this Introduction. Method A is simplified and cautious compared to the more complex Method B approach (see [5.1](#)). The calculations required to determine the acceptability of the design relative to the governing limit states are described in [Clause 8](#), supported by the calculations of hydrodynamic forces in [Clause 9](#) and lateral resistance in [Clause 10](#).

In the event that the design does not meet the limit state requirements, a range of mitigation measures is discussed in [Clause 11](#).

The typical analysis pathway using this British Standard is therefore not sequential. Instead, the clauses are linked, as shown in [Figure 1](#).

Figure 1 — *Layout and typical analysis sequence using this guide*



1 Scope

This British Standard provides guidance for assessing the on-bottom stability of subsea cables on rocky seabeds.

NOTE 1 Where seabeds consist of a layer of mobile sediment over a rocky seabed, this British Standard might be applicable in a situation where the sediment is washed away in the design extreme condition. Where a cable route consists of multiple seabed types, this British Standard can be used in conjunction with other suitable standards.

This British Standard does not provide guidance for assessing on-bottom stability on softer seabeds, such as sand and clay, and therefore is not an alternative to standards that provide guidance on these seabed types.

NOTE 2 A designer can use the design methods or guidance included in this British Standard for cylindrical products other than subsea cables, if deemed applicable, including but not limited to, umbilicals, flexible or rigid pipelines for oil, gas or other fluid service transport or telecommunications cables. Similarly, the designer can use the guidance in this British Standard for other conditions or situations where the designer believes them to be relevant, noting that relevant and appropriate failure risks and consequences might negate the applicability of [Clause 4](#).

2 Normative references

There are no normative references in this document.¹⁾

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

3.1.1 abrupt resistance feature (ARF)

location on the seabed where the following conditions are both met:

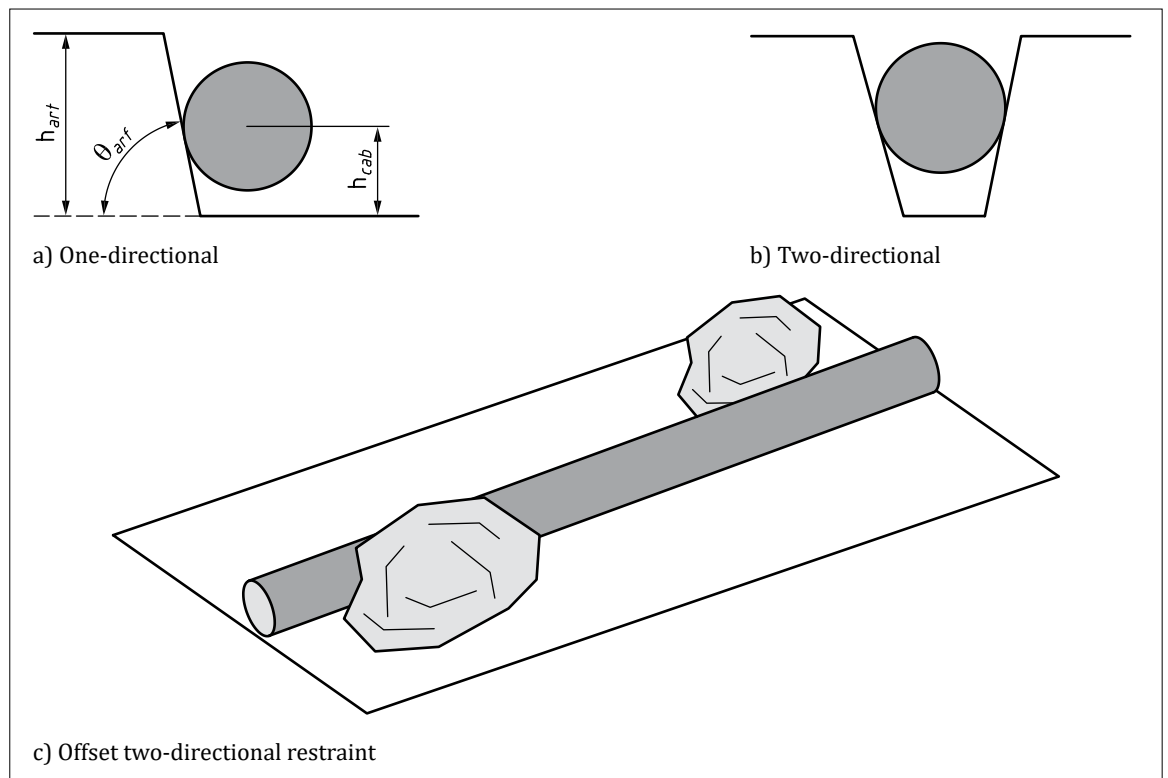
- the feature height, h_{arf} , exceeds the mid-height of the cable, h_{cab} ; and
- the feature steepness, θ_{arf} , exceeds the critical seabed slope, θ_{crit} , required for “infinite” effective friction

NOTE 1 See [10.2](#) for a full definition of effective friction. The above parameters are defined visually in [Figure 2](#).

NOTE 2 For example, for $\mu_o = 0.6$, the critical seabed slope is $\theta_{\text{crit}} = 59^\circ$ (see [10.2](#)). ARFs can be one-directional or two-directional. When a cable is at a one-directional ARF, it is restricted to move in one lateral direction. When a cable is at a two-directional ARF, it is prevented from moving in both lateral directions. In practice, it is often observed that ARFs are offset longitudinally, as shown in [Figure 2c](#)). While an ARF gives a theoretically infinite lateral resistance to the subsea cable, in practice, the resistance is finite and limited by the lesser of the lateral forces that causes the:

- cable to fail;
- strength of the rock to be exceeded; or
- rock to move.

¹⁾ Documents that are referred to solely in an informative manner are listed in the Bibliography.

Figure 2 — Schematic definition and sketch of an abrupt resistance feature (ARF)**3.1.2 axial stiffness**

ratio of axial tension to axial tensile strain in an initially unstressed cable

NOTE Typically, the appropriate value of this parameter is as advised by the manufacturer.

3.1.3 bending stiffness

ratio of moment to curvature in an initially straight cable

NOTE See 8.4 for further information, including calculation of cable bending check. Typically, the appropriate value of this parameter is as advised by the manufacturer.

3.1.4 boundary layer

flow velocity profile at the seabed surface boundary

NOTE This term encompasses both wave and current boundary layers, as well as accounting for both interactions between wave/current boundary layers and also the breakdown of the logarithmic “law of the wall”, as required (see Annex A for seabed survey guideline rationale for enhanced cable stability).

3.1.5 breaking wave height

breaker height limit for a given location, wave period, seabed slope and water depth

NOTE See 9.5 regarding near-bed wave velocities.

3.1.6 cable heading

planned direction of the cable lay route, aligned with the cable longitudinal axis

NOTE Where the cable might experience significant variance in heading between the planned route and actual as-laid heading, the design to omni-directional conditions or to a range of representative likely cable headings needs to be taken into account. This situation arises, for example, at overlength laydown loops, during wet-storage of cable ends prior to pull-in and around planned route bends.

3.1.7 cable route segment

section of cable route of length, L , analysed with a single set of input parameters, on the basis that similar values of the following properties apply:

- a) seabed geotechnical and roughness characteristics;
- b) metocean conditions;
- c) water depth (which changes the near-bed flow for given metocean conditions); and
- d) cable heading

NOTE 1 The length-averaged stability calculations are to be performed using length L , such that longitudinal averaging is taken over a distance of not less than $10 L_{cr}$ and not greater than $100 L_{cr}$, which is shown to be an acceptable averaging approach. $L < 10 L_{cr}$ risks not capturing representative large-scale seabed features. $L > 100 L_{cr}$ risks missing localized variations of stability where seabed roughness is reduced.

NOTE 2 An example cable route segmentation is by 10% increments of water depth and 10° increments of cable heading around planned route bends, in addition to zonation by properties a) and b).

3.1.8 cast-iron shell (CIS)/articulated pipe (AP)

interlocking and/or articulated exoskeletal shells for the mechanical protection and enhanced stabilization of subsea cables

3.1.9 characteristic length (L_{cr})

length of subsea cable that, when held by pinned connections, sags by one diameter under its own submerged self-weight and residual lay tension (3.1.19)

NOTE See 8.3.2 regarding calculation of cable characteristic length.

3.1.10 drag force

calculated horizontal load applied to a subsea power cable, including any attached marine growth, as a result of hydrodynamic pressure and shear caused by wave/current particle velocities

3.1.11 friction coefficient

3.1.11.1 effective friction coefficient, μ_{eff}

maximum ratio between the horizontal and vertical resultants of the contact forces between the subsea cable and the seabed, accounting for the influence of meso- and macro-scale seabed features

NOTE 1 The effective friction coefficient is used in the stability check, which is based on horizontal equilibrium (see Clause 6 and Clause 7).

NOTE 2 The lateral resistance amplification factor, R_{μ} , is defined as μ_{eff}/μ_0 (see 10.2).

NOTE 3 Interface friction coefficient μ_0 can be found as the median friction from lateral resistance tests, as per Griffiths et al. [1].

3.1.11.2 interface friction coefficient, μ_0

maximum ratio of tangential and normal forces at a contact point between cable and seabed, where the tangential and normal directions are parallel and perpendicular to the local slope of any meso- and macro-scale seabed feature, respectively

NOTE The interface friction coefficient represents the resistance due to material sliding, including the effect of micro-scale asperities of the cable and the rock.

3.1.12 gappiness

distribution of gap height, e , along the cable route segment

NOTE Gap height is zero where the cable is on the seafloor. In general, high gappiness occurs where there is high seabed roughness. As defined, gappiness is a measure of both the height and spatial extent along the cable of gaps between the cable and the seabed.

3.1.13 installation phase

temporary period considered to have a duration less than 12 months but in excess of the period for which the current weather forecast is considered reliable

NOTE See DNV-RP-F109 [2]. Typically, the forecast is accepted as reliable to a duration of three days.

3.1.14 lift forces

calculated vertical load applied to a subsea power cable, including any attached marine growth, as a result of hydrodynamic pressure and shear caused by wave/current particle velocities

NOTE As per the findings of Griffiths [1], hydrodynamic lift forces might not increase due to the presence of marine growth compared to the forces for a non-biofouled cable.

3.1.15 marine growth

accumulation of sessile epibenthic organisms, both plant and animal, on the surface of the cable leading to changes in the effective diameter, surface roughness and/or mass of the cable

NOTE Marine growth might be seasonal, might change over the lifetime of the cable and might be damaged/removed by storm activity. Site-specific estimates of marine growth need to be made. See B.2 for further guidance on improved models accounting for marine growth.

3.1.16 maximum wave height

highest wave expected in a given sea state

NOTE For further information on maximum wave height, see CIRIA C666 [3], DNV-RP-C205 [4], Tron and Buchan [5] or similar appropriate publications.

3.1.17 metocean data

wave and current data selected for design

NOTE See CIRIA C666 [4], DNV-RP-C205 [4] or similar appropriate publications. A cable failure response surface can be used to select the design metocean parameters, taking into account the implications arising from McGrath et al. [6].

3.1.18 on-bottom stability

cable placed onto the seabed without the placement of cover over the cable (such as quarried rock or trench backfill) subsequent to lay

NOTE On-bottom stability design aims to prevent an unburied cable from exceeding any relevant design limit states under the action of relevant hydrodynamic loads, as described in this British Standard.

3.1.19 residual lay tension, T_{lay}

anticipated horizontal component of lay tension remaining in the cable post-installation onto the seabed

NOTE This parameter is subject to uncertainty; sensitivity of results need to be tested to high, low and best estimates based on the planned lay tensioner settings for the cable.

3.1.20 rocky seabed

seabed with a surficial material that comprises rock

NOTE 1 See 5.4 with regard to seabed classification as rocky.

NOTE 2 This definition includes both natural exposed outcropping rock and artificial rock seabed (e.g. employed for scour protection). See also 5.3 regarding potential damage mechanisms.

3.1.21 safe working load

maximum cable tension permitted during operation and installation conditions, as defined by the manufacturer

NOTE The tensile working load limit is typically based on the strength member capacity and appropriate safety factors.

3.1.22 seabed roughness

3.1.22.1 macro-scale roughness

features significantly larger ($>10D$) than the cable plus CIS diameter

NOTE These features have horizontal and vertical lengths which result in them being captured within the multibeam echo-sounder seabed survey results. Similarly, macro-scale spans are larger spans of greater than $10D$ in length.

3.1.22.2 meso-scale roughness

features comparable in diameter to the cable ($0.1D < L < 10D$)

NOTE These features have horizontal and vertical lengths which result in them being too small to be captured within the multibeam echo-sounder seabed survey results but are clearly visible in visual survey results. These features strongly influence the enhanced cable on-bottom stability. Similarly, meso-scale spans are comparable in length to the cable diameter ($0.1D$ to $10D$).

3.1.22.3 micro-scale roughness

seabed features much smaller than the diameter of the cable ($<0.1D$)

NOTE 1 These features have horizontal and vertical lengths which result in them being too small to be sized accurately from video surveys of the seabed. These features together with the exterior surface of the cable or ballast units strongly influence the interface (Coulomb) friction factor between the cable and the seabed. Micro-scale spans are less than $0.1D$ in length.

NOTE 2 See 6.3 for methods to quantify seabed roughness.

3.1.23 submerged weight (W_s)

weight of cable per unit length submerged in sea water, including any contents, allowing for both unflooded and flooded conditions, where applicable, and marine growth

NOTE If the subsea cable is a free flooding design, the interstices flood with seawater once fully submerged, which can affect its weight. It is therefore important that the correct weight or weights (flooded, and/or not flooded) are used in the seabed stability calculations.

3.1.24 subsea cable

cylindrical conduit used for transmission of electric power, installed below the surface of the water, or other cylindrical products of similar size and density

NOTE For example, umbilicals, communication cables, cylindrical cable protection devices, cylindrical stabilization systems, flexible and rigid pipelines.

3.1.25 turbulence

fluid motion characterized by chaotic variations in pressure and flow velocity with time and over relevant length scales, determined by the source of the turbulence, and which might influence the cable response

3.1.26 umbilical

bundled length of conduit containing functional components designed to provide hydraulic, fluid injection, power, communication and/or other services

NOTE 1 The umbilical could be routed below the surface of the water.

NOTE 2 Functional components include electric cables, optical fibre cables, hoses and/or tubes.

NOTE 3 See also [BS ISO 13628-5](#) regarding the design and operation of subsea production systems – subsea umbilicals.

3.2 Symbols

For the purposes of this document, the following symbols apply.

C_H	horizontal hydrodynamic force coefficient
C_V	vertical hydrodynamic force coefficient
d	vertical distance from far-field seabed elevation to bottom of seabed under cable
D	as-manufactured outer diameter of cable system
D_H	drag diameter of subsea cable (including hard marine growth)
e	gap height between cable and seabed
F_H^*	length-averaged single extreme design wave horizontal force
F_V^*	length-averaged single extreme design wave vertical (lift) force
H	limiting horizontal resistance prior to cable movement
H_b	breaking wave height
$H_{\max}$	maximum wave height
H_s	significant wave height, approximately equal to the average of the highest 1/3 of waves
<i>NOTE See also BS EN ISO 19901-1 regarding metocean design and operating considerations.</i>	
K^*	Keulegan–Carpenter number = U^*T^*/D_H for the single extreme design wave
L	cable segment length
L_{cr}	critical cable length
$L_{\max}$	maximum allowable spacing between adjacent of abrupt resistance features
$L_{q0.5}$	cable span length at which the cable span is equally supported in tension and bending
M^*	current to wave ratio = V^*/U^* for the single extreme design wave
$R_H(x)$	local horizontal hydrodynamic force reduction factor
R_{Heff}	length-averaged horizontal hydrodynamic force reduction factor
R_{MGH}	adjustment factor on drag force to account for soft marine fouling
R_{seabed}	seabed roughness
$R_V(x)$	local vertical hydrodynamic force reduction factor
R_{Veff}	length-averaged vertical hydrodynamic force reduction factor

R_{μ}	seabed friction amplification factor
T^*	wave period associated with the single extreme design wave
$T_{\max}$	maximum allowable cable tension (safe working load)
T_{tot}	total tension in the cable under design extreme load condition
U^*	peak wave orbital velocity in the direction normal to the cable heading for the single extreme design wave
V	vertical reaction force at point of cable contact between seabed and cable
V^*	extreme design near-bed current velocity in the direction normal to the cable heading, comprising both tidal and residual components, given at height z_{ref} above the nominal seabed elevation
w	cable normal load
W_s	submerged weight
w_{tot}	effective normal cable load combining horizontal and vertical forces
Δx	analysis discretization length along cable axis
$\Delta(x)/D_{\text{H}}$	relative trench depth
μ_{eff}	is the effective friction coefficient (see Clause 10)
μ_o	interface friction coefficient
θ	tangential slope between subsea cable and seabed points of contact; or catenary pin-ended cable gradient with respect to cable horizontal axis
θ_c	current heading; propagation direction of the near-bed current, comprising both tidal and residual components
θ_w	wave heading; propagation direction of the maximum wave, which in the absence of reliable data can be taken as the direction of peak wave energy
ρ_w	seawater density
Ψ	utilization factor
$\Psi_{\max}$	maximum allowable utilization factor

3.3 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

AGA	American Gas Association
AP	articulated pipe
CIS	cast-iron shell
EIS	environmental impact statement
FEED	front-end engineering design
HOOS	horizontal out of straightness
LAT	lowest astronomical tide
LIDAR	light detection and ranging
MBES	multibeam echo-sounder
MBR	minimum bend radius

MG	marine growth
OWF	offshore wind farm
ROV	remotely operated vehicle
RP	return period
VIV	vortex-induced vibration
VOOS	vertical out of straightness
WTG	wind turbine generator

4 Risk-based integrity philosophy

4.1 General

Risk-based cable integrity management uses reliability-based design to achieve a target level of cable performance. Reliability-based design takes into account the consequences of failure, which for subsea cables consist of impact on:

- a) safety, to the extent that failure could endanger life, e.g. electrical hazards or causing the release of hydrocarbons or other hazardous materials;
- b) environmental impact, e.g. from release of harmful materials; and
- c) costs, including lost revenue from lost production, repair costs and any penalty costs due to non-delivery of production.

NOTE 1 In most typical situations for a subsea power cable being used for offshore wind array or export cables away from the shore crossing, the only relevant risks are c) costs, as defined.

A cable stability assessment contributes to a cable performance assessment and should be informed by sufficient definition of:

- 1) project risk assessments, which capture relative risk of failure of relevant cables (e.g. as defined by the offshore wind farm developer) and definition of consequences;
- 2) cable route optimization, and secondary stabilization costs and risk mitigation measures (e.g. as defined by the installation contractor); and
- 3) cable properties and performance limits (e.g. as defined by the cable manufacturer).

NOTE 2 In most typical situations, wind farms are designed and constructed by different parties, including an offshore wind farm developer, an installation contractor and a cable manufacturer. The examples in 1) to 3) are typical but are not to be construed as assigning responsibilities that are set in practice by the contracts between the different parties listed and any others involved.

Prior to cable stability assessment, a project risk assessment should be undertaken by the operator and installation contractor during route planning (taking into account the guidance in 5.5) and revised once mapping of the seabed has been undertaken (see Annex C for guidance on required survey methods). Risks identified in this risk assessment should be highlighted to the stability assessment engineer and the cable manufacturer to inform stability assessment, cable design and testing recommendations.

Where an allowable utilization factor, Ψ , is given in an overarching design code (see 8.1.2), this factor can be applied to the on-bottom stability design, where relevant and deemed appropriate by the designer.

NOTE 3 If an overarching design code provides a minimum factor of safety, the maximum allowable utilization factor, $\Psi_{\max}$, can be taken as the reciprocal of this.

In many cases, cables engineered using this British Standard are designed to conform to DNV-ST-0359 [7], API-RP-17J [8] or BS ISO 13628-5. Where these governing design standards do not specify the required allowable utilization factors, the risk-based design should be informed by a project-specific net present value (NPV) calculation to determine the optimum balance between pre-investment in enhanced cable stability versus the consequences of cable failure (see, for example, McGrath *et al.* [6]).

In the absence of a project-specific NPV assessment or an allowable utilization inherited from a governing design standard, see 4.2.

4.2 Integrity risk classification

If required, an integrity risk classification should be adopted based on the risk matrix in Table 1, which leads to the associated maximum allowable utilizations, $\Psi_{\max}$, for limit state checks in Table 2.

Table 1 — Integrity risk classification

	Risk matrix					
	Consequences					
	Financial (NPV)	€10k	€100k	€1M	€10M	€100M
Probability	Very rare (1/100 year)	Low	Low	Medium	Medium	High
	Rare (1/10 year)	Low	Medium	Medium	High	High
	Infrequent (1/year)	Medium	Medium	High	High	High
	Frequent (1/month)	Medium	High	High	High	High
	Very frequent (1/week)	High	High	High	High	High

Table 2 — Risk-based allowable utilization

Integrity risk classification	Maximum utilization factor, $\Psi_{\max}$
High	0.50
Medium	0.80
Low	0.95

NOTE 1 Typically:

- "low" applies to cables during the installation phase where repair or replacement does not delay completion of the project, or result in lost production;
- "medium" applies to cables during operation where production is from fewer than five wind turbine generators (WTGs) [or 25% of the offshore wind farm (OWF), whichever is the lesser], or installation where failure would delay completion and therefore result in lost production; and
- "high" applies to export cables and array cables with five or more WTGs, or more than 25% of the OWF production, whichever is the lesser.

NOTE 2 Risks of systemic failure from single mode causes should be considered in the overall risk analysis and where relevant the risks on one cable segment should not be assumed to be independent of the risk of failure across other cables segments. Examples of this include the occurrence of an extreme storm event which damages multiple cables in an OWF.

4.3 Cable design recommendations to reduce risks on rocky seabed

NOTE 1 Clause 11 defines mitigating actions that can be taken to reduce the integrity risks of cables routed on rocky seabeds.

The following should be taken into account in cable design to reduce risks.

- Outer sheathing can be used to increase abrasion resistance and bending stiffness of the cable, and improve handling for deeper water deployment.

NOTE 2 Polypropylene roving outer layers, with and without bitumen-impregnation (traditionally employed on softer seabeds in static applications), should not be used for rocky seabeds.

NOTE 3 Cast-iron exoskeletal half-shells, or other types of external ducting, might provide increased mechanical protection, increased resistance to cable bending beyond the minimum bend radius (MBR) and enhanced abrasion resistance; however, these need to be checked for abrasive wear and corrosion. See [Clause 11](#) with regard to mitigation methods.

- b) Material selection for cable outer sheathing should be based on relevant behaviour for the specific local environment and anticipated cable-seabed interaction. For elastic polymers, typical factors to take into account are cut resistance, abrasion wear resistance, deformation, surface fatigue and tensile tearing.
- c) As detailed in [Clause 8](#), bending stiffness has a significant influence on the behaviour of the cable on a rocky seabed surface. Where deployed over a rocky seabed, the introduction of venting holes should be reviewed relative to the rock surface profile and might need to be strategically placed. The cable route might need to avoid sharper regions of rock unless it can be demonstrated through testing that this does not pose significant risk to the cable.
- d) Where multiple layers of armour wire are used, metallic armour layers should be contra-helically laid to achieve a high level of torsional balance (as close to 100% as possible) in order to reduce risks of axial and torsional failure mechanisms, and achieve weight requirements for stability within this assessment.

NOTE 4 Single armoured cables are not recommended for rocky seabeds, except where additional mechanical and abrasion protection is provided (e.g. the addition of cast-iron exoskeletal half-shells). See [Clause 11](#) with regard to mitigation methods.

- e) Additional layers can be added to the cable (increased sheathing thickness, additional sheathing layers, additional armour layers) to increase the desirable properties of the cable (weight relative to diameter, stiffness, etc.). Where added to act as “sacrificial layers” (see [E.1](#)), the required thickness and quantity should be identified by testing. Testing requirements should be identified by the purchaser in consultation with the cable manufacturer.

4.4 Potential further risks following stability evaluations

The cable risk assessment should evaluate further risks based on the surface profile, the results of the stability evaluations (anticipated cable movements, cable properties and cable-seabed forces), and the possibility that the rock might move, abrade or fracture. This assessment should be based on a site-specific survey to identify rock type and bathymetry along cable routing corridor (see [Annex A](#) for seabed survey guideline rationale for enhanced cable stability).

These risks might arise due to phenomena that invalidate the stability analysis assumptions or introduce additional cable failure mechanisms. Phenomena include the following.

- a) Small pebble-sized rocks moving if stiff cables are subjected to significant tensions during lay.
- b) Rock surface wear occurring due to cable movement rather than the cable surface wearing, if the rock is soft relative to the cable stiffness and outer layer strength (see [7.2.6](#)). This includes both natural exposed outcropping rock and also artificial rock seabed (e.g. employed for scour protection).

NOTE 1 This might not be the case for harder rocks, such as dolomite limestone, but could be more relevant to softer rocks such as weak limestone. See [8.6](#) for examples of seabed wear.

- c) Cable outer layer and rock both abrading. This could lead to increased contact surface area, therefore abrasion rates could reduce as the rocky surface becomes smoother and individual rock-cable contact points become less sharp (see [8.6](#)). During this process, where wear to rock occurs, the wear process for the sheath is expected to change from cutting on an asperity scale to surface fatigue or tensile tearing.

- d) Cable outer layer and rock both abrading. This could lead to a loss of points of cable–rock contact, after which new free spans could form.
- e) Where rubbing occurs, rock might fracture instead of abrading, resulting in the formation of sharper sections, which could damage the cable through an alternative mechanism, such as gouging, slicing, serrating, or point bending.
- f) Sharp changes in elevation could lead to areas where cable slips occur under cable weight or during installation. Given the force, greater damage might be seen than typically associated with rubbing, particularly if the rock profile is sharp.
- g) Sharp changes in elevation, which might be more likely where areas contain large rocks, leading to point bending over a rock edge combined with large tensions under cable weights in free span. Repetitive lateral motion against the edge might result in localized wear or slicing of the cable.

In locations where significant risk is identified, mitigation actions might be similar to those detailed in [Clause 11](#). Where alternative routing or protection are not applied to the cable, further full-scale testing might be required. The need for testing of varying scenarios along the route should be identified by the purchaser in consultation with the cable manufacturer.

NOTE 2 See [Annex D](#) for further details on testing for abrasive-related damage.

4.5 Monitoring to assess in-service integrity of cable

The risk of in-service failure of the cable can be mitigated by early identification of cable damage, or potential damage, through surveys. These surveys can be visual surveys using the same techniques used to characterize the seabed roughness, as described in [Annex C](#).

An alternative option is to use fibre-optic sensing, where optical fibres are integrated into the cable product, allowing continuous remote monitoring of the cable through techniques such as distributed acoustic, strain or temperature sensing.

The extent to which the signals detected by this method can be linked to the physical response of the cable bending, tension or other modes should be carefully documented and qualified.

*NOTE 1 For further guidance, see *Subsea Cable Condition Monitoring with Distributed Optical Fiber Vibration Sensor* [9], Patterson et al. [10].*

These enhanced cable monitoring methods might identify if the cable stability significantly deviates from the original design intent and an acceptable range of operating behaviour, allowing early detection and remediation activities to be conducted. Data gathered from these systems also enable the validation and calibration of design models.

NOTE 2 See [5.6](#) for further discussion of the timing and frequency of surveys.

4.6 Design parameter uncertainty

The design methods provided in this British Standard are based on the use of a wide range of input parameters which are certain to be subject to both variability and uncertainty in the exact values applicable at any particular point in the design process. An example of this is the variability of important cable properties that are the result of normal manufacturing tolerances, including cable diameter (D), submerged weight (W_s), bending and axial stiffness. Similar variability is likely in seabed survey accuracy, metocean conditions and all other design inputs.

Appropriate nominal values should be adopted for design, incorporating parameter uncertainty/variability into reliability-based approaches. Assumptions regarding parameter independence should be substantiated.

NOTE Examples where parameters are highly likely to not be independent include cable diameter (D), submerged weight (W_s), bending and axial stiffness. To illustrate this, consider the effect of an increase in the diameter of armour wires, which is likely to increase all of these parameters. The outcome is that it would be incorrect to

calculate the risk of cable instability, taking into account the cable diameter and submerged weight being uncorrelated. A further outcome of the correlation between input parameters is that picking whether larger or smaller values of any given (correlated) parameter is the correct “conservative” bias becomes impossible – the so-called Goldilocks Dilemma, see Griffiths et. al. [11].

5 Design method and stability limit state overview

COMMENTARY ON CLAUSE 5

This clause provides design methods and acceptance criteria for lateral stability of cables. See also [Annex B](#) for worked examples of design method and stability limit state.

5.1 General

Two methods have been developed to assess cable lateral stability on rocky seabeds.

- a) Method A is a simplified approach which adopts analytical and numerical modelling solutions compatible with existing industry tools and typical design engineering processes. Cautious and simplified approaches are provided that suit concept engineering and FEED, and these can be used prior to obtaining accurate site-specific seabed data. The Method A analysis process is described in [Clause 6](#).
- b) Method B is for more challenging conditions requiring more extensive and complex modelling approaches, as well as accurate site-specific seabed data. Method B suits detailed design to give a more accurate and reliable indication of cable stability. The Method B analysis process is described in [Clause 7](#).

The lateral stability assessment methods can be applied to both installation and operational phases, taking into account the metocean conditions relevant to each lifetime phase. The analysis methods can also be applied during different project lifecycle phases from early conceptual design stages through operational to post-operational conditions.

NOTE There is no constraint within this British Standard regarding the development of alternative approaches to Method A and Method B, subject to satisfactory adaptation of the principles in [Clause 4](#) and [Clause 9](#) to [Clause 10](#).

5.2 Design limit states

The design limit state for on-bottom stability has traditionally been an allowable lateral displacement or a factor of safety when assessing the cable equilibrium under vertical and horizontal loading and resistance.

For cables on rocky seabeds, this approach is not automatically relevant. The rugosity, i.e. vertical undulations and large-scale roughness, commonly associated with rocky seabeds typically leads to extensive spanning and a concentration of the vertical and horizontal seabed reaction forces towards localized points. This leads to the potential for locally high cable curvature and loading. It is these local concentrations of curvature and resistance, rather than the magnitude of the displacement, that could cause cable limit states to be exceeded.

To assure cable integrity, all failure modes should be taken into account rather than only an allowable lateral displacement. Risks should be identified and evaluated within the risk-based assessment for:

- a) site conditions;
- b) cable planned route corridor; and
- c) cable mechanical design and capacity (see [Clause 4](#) and [Clause 8](#)).

Significant risks indicated by the seabed review and projected movement should be evaluated against the design limit states of the product.

The design limit states in this British Standard are based on observed failure modes for subsea cables on rocky seabeds, provided in *Pipeline scour and self-burial on a thin veneer of sand overlying rock due to steady currents* [12], as follows.

- 1) Excessive bending or tension in the cable resulting in mechanical failure due to exceedance of the manufacturer's allowable envelope for operational or installation conditions, as relevant (see 8.3 and 8.4).
- 2) Fatigue failure of an element of the cable (armour wire, conductor core, etc.) due to excessive cyclic bending and/or tensile strains imposed on any point of the cable (see 7.2).
- 3) Excessive abrasion due to repetitive rubbing against the seabed or any other object damaging outer protective or strength members and subsequently leading to mechanical failure of the cable or compromised internal components (see 7.2 and 8.6).
- 4) Lateral displacement due to hydrodynamic forces where this limit represents an expedient method of screening for the modes of mechanical failure in 1) to 3) (see 6.1, 7.2 and 8.1).

NOTE Limit states 1) and 4) represent a local failure in the operability of the cable at an instant in time. Therefore, the design approach follows the established offshore industry approach of using an extreme design single wave/current event to determine the governing load conditions.

5.3 Potential damage mechanisms outside this assessment

In addition to the design limits in 5.2, other potential damage mechanisms might need to be taken into account when determining route corridor selection, installation tension and planned inspection intervals, including:

- a) avoidance or mitigation action to avoid excessive local contact force;
- b) isolated point loading; serration or gouging of outer layers on excessively sharp-edged surfaces;
- c) excessive impact force or repetitive impact damage;
- d) excessive rotation about the cable longitudinal axis; and
- e) hockling due to excessive or uncontrolled movement during or post-lay.

Where significant risks are identified from upfront seabed measurements by the routing planner (see Annex C for guidance on required survey methods) or observations are made during early inspections of seabed along the cable route or during post-lay inspections, these should be documented.

5.4 Confirm seabed classification as rocky

COMMENTARY ON 5.4

More guidance on the classification of seabed as rocky is given in Pipeline scour and self-burial on a thin veneer of sand overlying rock due to steady currents [12].

Classification of surficial seabed should be based on accepted industry field survey techniques (e.g. BS EN ISO 14688-1), including acoustic, visual and/or physical sample analysis, and conform to one or more of the following criteria.

- a) Natural particles comprising rocks with median diameter greater than the cable diameter (D), typically cobble-sized or larger.
- b) Rock placed onto the seabed comprising particles with median diameter greater than the cable diameter (D), typically cobble-sized or larger to a layer thickness not less than 2D.

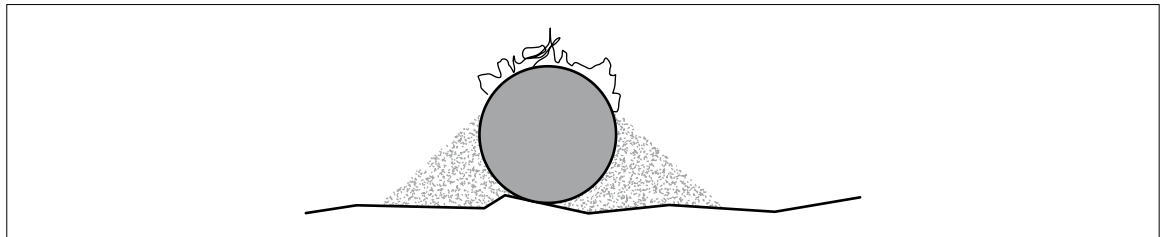
NOTE These criteria include filter and armour layers placed as a scour mitigation apron around a structure if they meet the particle size requirements in a) and b).

- c) Cemented bedrock, capstone or other monolithic material.

- d) Additionally, if the seabed has a cover of uncemented material of median particle size smaller than the cable diameter (D) overlying rock, this British Standard can be applied to address the design scenario where the overlying sediment is assumed to wash away during the design storm build-up phase, leaving the cable resting on the underlying rock. Under these conditions, the potential for alternative scenarios to also occur should be addressed separately, e.g. the sediment accumulating around the cable, as shown in [Figure 3](#). The risk of seabed mobility can be evaluated against Shield's criterion (see, for example, *Dynamics of marine sands* [13]).

Seabeds conforming to one of more of a) to c), are classified as a rocky seabed and this British Standard is applicable. If the seabed conforms to d) and it can be shown that the underlying non-mobile layer comprises rock meeting one or more of a) to c), this British Standard is applicable only for the case when the sediment is washed away during the design event.

Figure 3 — *Schematic of sedimentation trapped against a cable*



5.5 Cable routing considerations

Cable routing should take into account the following, which affect cable hydrodynamic loading, on-bottom stability and spanning.

- Cables should be oriented such that the cables align parallel to the prevailing metocean direction, or, as a minimum, are oriented with the majority of cables with less than 45° attack angle to the cable axis.
- Within the achievable cable lay tolerance, routing should preferentially select those routes that follow natural macro-scale features, such as ravines or gullies within the seabed bathymetry.
- Routing should achieve a level of redundancy in the layout such that any single point of failure minimizes the loss (e.g. for renewable energy applications, routing should minimize loss of total power produced from the project). Options such as redundancy-loops between array cable legs should be taken into account.
- For renewable energy applications, routing should prioritize preferential orientation of export cables and those array cables carrying greater levels of power (e.g. from multiple power generation devices).

In addition to stability-related considerations, cable routing should take into account avoidance of significant risk locations that pose potential damage mechanisms, such as those identified in [5.2](#) and [5.3](#).

5.6 Initial cable movement events from as-laid to stable positions

The cable positioning accuracy on the seabed during installation is constrained as being no better than the width of the lay corridor and lay tolerance of the vessel under the prevailing installation weather. This means that on laydown, the initial location of the cable is effectively random with respect to the position of meso- and macro-scale seabed features that are capable of being ARFs.

Therefore, on occurrence of the first few significant storm events post-lay, the cable might experience local displacement events that move the cable until it engages with the nearby ARFs, as shown in [Figure 4](#). A design allowing this initial cable movement within the defined cable route corridor is permitted, subject to the following.

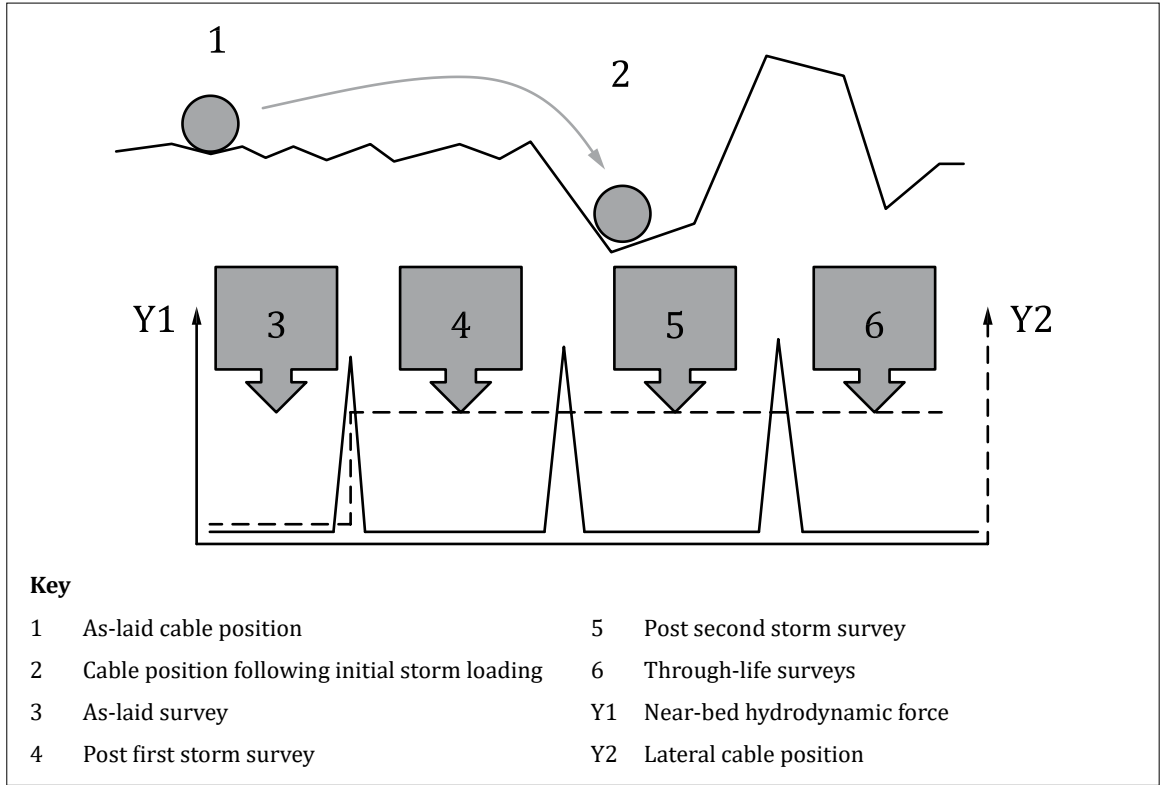
- a) The cable passing a stability design check, as defined in [Clause 5](#) to [Clause 7](#).
- b) The performance of an as-laid survey that confirms the presence of ARFs at sufficient spatial density, and the initial lateral position of the cables.
- c) The performance of a subsequent survey following the initial storm event to identify that ARFs have been encountered by the cable at adequate spacing (spacing no greater than $L_{\max}$, as defined in [8.4](#)). A storm event is defined as greater than one year RP in severity. This survey should confirm locations where lateral displacement of the cables has occurred and identify locations where supplementary restraint of the cables is required so that spacing between ARFs is less than $L_{\max}$. The survey should be undertaken as soon as possible after the storm, but not later than six months.
- d) The performance of a subsequent survey following a second storm event to confirm that no further significant cable displacement events have occurred. Any further movement should be analysed to confirm whether supplementary restraint is required.
- e) An additional survey undertaken following an event approaching or exceeding the 100-year design extreme RP event.
- f) All further cable lifetime operational integrity surveys evaluate evidence of cable movement events, including bald patches of rock (as shown in [Figure 4](#)) indicating seabed abrasion from cable movement, as evidence of cable abrasion against the rock [e.g. bald patches of cable devoid of MG or cable surface evidence of scratching or wear] and other deleterious indicators.

NOTE 1 These assessment and survey requirements are greater than those typically required for subsea cables located on non-rocky seabeds where they are trenched and buried. This reflects the higher level of operational integrity management that is warranted to manage the continual exposure of these cables to ongoing metocean loading.

The timeline for operational surveys depends on the nature of the dominant metocean conditions for the location. Where the design extreme metocean event is driven by rare but severe storms (e.g. tropical cyclones/typhoons/hurricanes) and where there is a large ratio between the one year and 100-year event severity, the surveys should be event-driven, i.e. a survey is triggered following a 10-year-level event. Where there is a small ratio between the one year and 100-year event and there are, typically, a number of severe storms of similar magnitude each year, it might be appropriate to plan for follow-up surveys in the first and second years, post-lay. Other factors might dictate additional surveys and timelines.

NOTE 2 Reference can be made to Ronalds et al. [14] for guidance on ratios of extreme design event conditions.

Figure 4 — Initial cable movement from as-laid to stable position



6 Method A – Simplified design analysis process

COMMENTARY ON CLAUSE 6

This clause defines the sequence of analysis steps, as well as the key coefficients required to account for the influence of the rocky seabed on hydrodynamic forces and lateral resistance. The detailed equations and methods for performing the limit state checks are described in [Clause 8](#). The methods for assessing hydrodynamic forces are set out in [Clause 9](#) and the methods for lateral resistance are in [Clause 10](#).

6.1 General

Method A (see [Figure 5](#)) is capable of being implemented in commonly available industry software and spreadsheet tools, taking account of the failure modes relevant to cables on rocky seabeds through the application of allowable utilization criteria.