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Introduction

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

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Foreword

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This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on **XX Month 201X**. 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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0 Introduction

Subsea cables are used for power transmission between both onshore and offshore structures within the oil and gas and renewable energy industries. Subsea cables routed between structures that are laid directly on top of the seabed are subjected to hydrodynamic forces through wave and current motions, forces which, if excessive, can result in large lateral displacements and/or potential damage. Subsea cable design uses metocean data to ensure the cable has sufficient self-weight to remain stable on the seabed and hence avoid failure either prior to installation of secondary stabilization measures, such as burial, or throughout the full operational lifetime, dependent on the protection philosophy.

Guidelines have been previously developed for calculations of stability, but there are limitations with these. An ever-increasing demand for power generation through renewable energy sources has led to a requirement for subsea cables to be installed and then subsequently stabilized in much harsher terrains. There exists extensive guidance within the industry for performing calculations on softer seabeds, such as sand and clay, but there is very limited guidance for performing calculations 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 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.

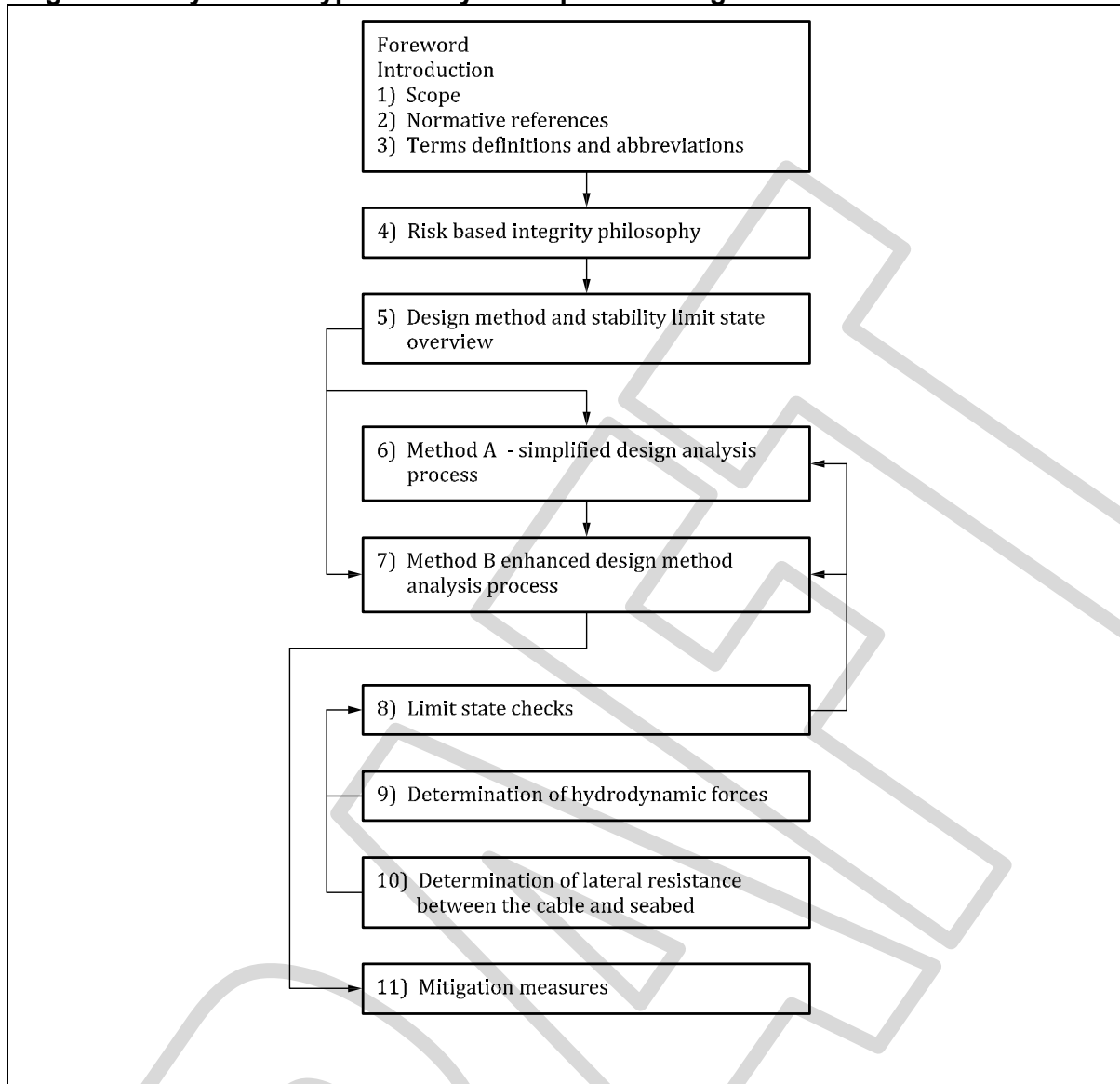
Research has led to validated new methods to assess the seabed resistance and hydrodynamic forces, which capture the influence of the seabed undulations in a rigorous way. This British Standard presents the outputs from this research in a form suitable for use in design practice. As a result, this British Standard provides a more appropriate basis for the stability design of subsea cables on rocky seabeds than standards that were 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 hydrodynamic force calculations 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 are discussed in Clause 11.

The typical analysis pathway through the British Standard is therefore not sequential through the clauses within the British Standard. Instead, the clauses are linked, as shown in Figure 1.

Figure 1 – Layout and typical analysis sequence using this Guideline



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 appropriate if it can be demonstrated that the sediment could be washed away in the design extreme condition.

Where seabeds consist of intermittent 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 The designer needs to consider the applicability of any design methods or guidance included in this British Standard to the situation they are being applied to, including but not limited to the application of this British Standard to cylindrical products other than subsea cables – typically umbilicals, flexible or rigid pipelines for oil, gas or other service fluid transport or telecommunications cables. Similarly, the designer could use the guidance in this British Standard for conditions or situations where the designer believes them to be relevant.

2 Normative references

There are no normative references in this British Standard.

3 Terms, definitions and abbreviations

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

3.1 Definitions

3.1.1 abrupt resistance feature

location on the seabed where the following conditions are met:

- a) the feature height exceeds the mid-point on the cable; and
- b) the feature steepness exceeds the critical seabed slope, θ_{crit} , for “infinite” effective friction

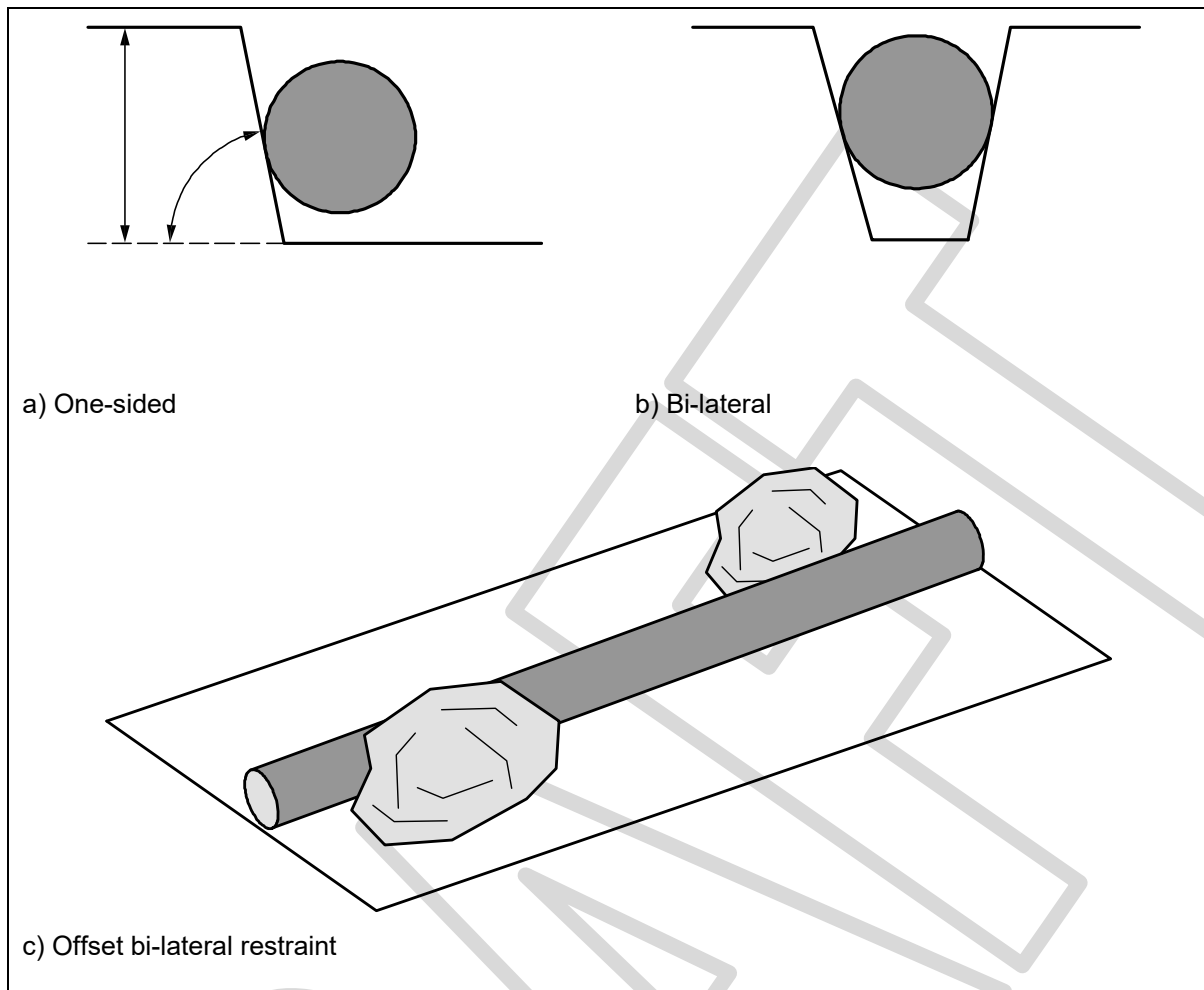
NOTE 1 See 10.2 for a full definition of effective friction.

NOTE 2 For example, for $\mu_0 = 0.6$, the critical seabed slope is $\theta_{\text{crit}} = 59^\circ$ (see 10.2). Abrupt resistance features could be one-sided or bi-lateral. While an abrupt resistance feature 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:

- a) the cable to fail;
- b) the strength of the rock to be exceeded; or
- c) the rock to move.

These conditions are defined in Figure 2.

Figure 2 – Schematic definition and sketch of an abrupt resistance feature



3.1.2 axial stiffness

stiffness of the cable along its axis, as advised by the manufacturer

3.1.3 ballast unit/cast iron shell (CIS)/articulated pipe

interlocking articulated exoskeletal cast or ductile iron shells for the mechanical protection and enhanced stabilization of subsea cables

3.1.4 bending stiffness

characteristic bending stiffness profile

NOTE See 8.4.

3.1.5 boundary layer

flow velocity profile at the seabed surface boundary

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

breaking wave height

breaker height limit for a given location/depth

3.1.6 cable heading

planned heading 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, design to omni-directional conditions or design to a range of representative likely cable headings need to be taken into account. This situation arises, e.g. at overlength laydown loops, during wet-storage of cable ends prior to pull-in and round planned route bends.

3.1.7 cable route segment

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

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

NOTE 1 The length-averaged stability calculations are performed using longitudinal averaging 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 by Robertson et al.[1].

NOTE 2 Typical cable route segmentation could be by 20% increments of water depth and/or 10° - 15° increments of cable heading around planned route bends.

3.1.8 characteristic length (L_{cr})

length of subsea cable that, when held by pinned connections, sags by one diameter under its own submerged self-weight

NOTE See 8.2.2.

3.1.9 drag force

calculated force applied to subsea power cable (including marine growth) as a result of hydrodynamic forces caused by wave/current particle velocities

3.1.10 friction coefficient

resistance to movement of the cable across the seabed surface, comprising only micro-scale used in the analysis

NOTE 1 Typically defined as between the subsea cable and seabed.

NOTE 2 This friction coefficient can also be found as the median friction from lateral resistance tests, as per Griffiths et al [2].

3.1.11 installation phase

temporary phase considered to have a duration less than 12 months but in excess of the reliable weather forecast

NOTE See DNVGL-RP-F109 [3]. Typically, the forecast is accepted as reliable out to a duration of three days.

3.1.12 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

3.1.13 maximum wave height

highest wave expected in a given sea state

3.1.14 metocean data

wave and current data selected for design based on established methodologies

NOTE See CIRIA C666 [4], DNVGL-RP-C205 [5] or similar appropriate documents. The use of cable failure response surface and the selected design metocean parameters can be taken into account, taking into account the implications arising from Gibson et al. [6].

3.1.15 on-bottom stability

stability of the cable length supported by the seabed

NOTE On-bottom refers to a cable that has been placed onto the seabed without the placement of cover over the cable (such as quarried rock or trench backfill) subsequent to lay.

3.1.16 rocky seabed

seabed with a surficial material that comprises rock

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

3.1.17 safe working load

maximum tensile working load applicable during operation and installation conditions, as defined by the manufacturer

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

3.1.18 submerged weight

weight of cable submerged in sea water, including any contents, allowing for a flooded condition (if applicable), and marine growth

NOTE 1 If the subsea cable is a free flooding design, the interstices will flood with seawater once fully submerged, which can affect its weight. It is therefore important that the correct weight (flooded, or not flooded) is used in the seabed stability calculations.

NOTE 2 See Annex B for seabed survey guideline rationale for enhanced cable stability.

3.1.19 subsea cable

transmission cable designed to carry electric power below the surface of the water, or other subsea cylindrical products

NOTE For example, including umbilicals, communication cables, flexibles, cylindrical cable protection devices, cylindrical stabilization systems, pipelines.

3.1.20 turbulence

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

3.1.21 umbilical

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

3.2 Abbreviations

For the purposes of this British Standard, the following abbreviations apply.

D	Outer diameter of cable system (see 6.2.1)
D_h	Drag diameter of subsea cable (counting hard marine growth)
F_{Drag}	Drag force
H_s	Significant wave height, approximately equal to the average of the highest 1/3 of waves. See also BS EN ISO 19901-1.
H_{max}	Maximum wave height

H_b	Breaking wave height
LAT	lowest astronomical tide (LAT)
$LIDAR$	Light detection and ranging
$MBES$	Multibeam echo sounder
MBR	Minimum bend radius, defined by manufacturer
MG	Marine growth (see 3.1.9)
MSL	Mean sea level
NPV	Net present value
OWF	Offshore wind farm
ROV	Remotely operated vehicle
SW	Submerged weight
SWL	Safe working load
T_p	Spectral peak period (see BS EN ISO 19901-1)
U_c	Nearbed current velocity, comprising both tidal and residual components, given at z_{ref} above the nominal seabed elevation
U_{cn}	Current velocity normal to cable
U_w	Peak wave orbital velocity, outside the wave boundary layer
U_{wn}	Wave velocity normal to cable
VIV	Vortex induced vibration
WTG	Wind turbine generator
μ_o	Interface friction coefficient
μ_{eff}	Friction coefficient used in the stability analysis, defined as the effective lateral resistance factor between the subsea cable and seabed accounting for the influence of meso- and macro-scale seabed features
θ_c	Current heading; propagation direction of the nearbed current, comprising both tidal and residual components
θ_w	Wave heading; propagation direction of the maximum wave, which in the absence of reliable data may be taken as the direction of peak wave energy

4 Risk-based integrity philosophy

4.1 General

Risk-based integrity is based on the premise of reliability-based design to manage cable integrity risks. For subsea cables, consequences of failure consist of:

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

NOTE 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) financial, as defined.

Cable stability analysis should be informed by sufficient definition of:

- project risk assessments (which capture relative risk of failure of relevant cables, as defined by operator) and definition of consequences;
- cable route optimization and secondary stabilization costs and risk mitigation measures (e.g. as defined by installation contractor); and
- cable limits and properties (as defined cable manufacturer).

Prior to cable stability checks, the project risk assessment should be undertaken by the operator and installation contractor during route planning (taking into account **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. A free span prediction might indicate the severity of risks.

Where a target utilization factor, ψ , is given in an over-arching 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.

In many cases, cables engineered using this British Standard will be designed to conform to DNV-ST-O359 [5], API-RP-17J [6] or BS ISO 13628-5. Where these governing design standards do not specify the required limiting utilization factors, good practice is for the integrity classification to be determined based on a project-specific net present value (NPV) calculation to determine the optimum integrity target.

4.2 Integrity classification

In the absence of a project-specific NPV assessment or limiting allowable utilization inherited from a governing design standard, the integrity class classifications should be adopted based on the risk matrix in Table 1 which lead to the associated allowable utilizations in Table 2.

Table 1 – Integrity classification

Risk matrix		Consequences				
	Financial (NPV) ⁽¹⁾	€10k	€100k	€1M	€10M	€100M
Probability	Very rare (1/100yr)	LOW	LOW	MED	MED	HIGH
	Rare (1/10yr)	LOW	MED	MED	HIGH	HIGH
	Infrequent (1/yr)	MED	MED	HIGH	HIGH	HIGH

Table 1 – Integrity classification

Risk matrix						
	Frequent (1/month)	MED	HIGH	HIGH	HIGH	HIGH
	Very frequent (1/week)	HIGH	HIGH	HIGH	HIGH	HIGH

Table 2 – Risk-based utilization

Integrity risk classification	Allowable utilization, Ψ
High	0.50
Medium	0.80
Low	0.95

Typically, it is anticipated that:

- “low” applies to cables during the installation phase where repair or replacement won’t delay completion of the project, or result in lost production;*
- “medium” applies to cables during operation where production from less than five WTGs (or 25% of the OWF, whichever is the lesser) are carried, 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.*

4.3 Cable design recommendations to reduce risks on rocky seabed

COMMENTARY ON 4.3

Clause 11 defines mitigating actions which could be taken to reduce the integrity risks of cables routed on rocky seabeds.

The following guidance should be taken into account for the cable design to further reduce risks:

- outer sheathing should be used to increase abrasion resistance and bending stiffness of the cable, and improve handling for deeper water deployment;
NOTE Polypropylene roving outer layers, with and without bitumen-impregnation, (traditionally employed on softer seabeds in static applications) are not recommended for rocky seabeds.
- 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;
- 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 this does not pose significant risk to the product;
- contra-helically laid metallic armour layers should be used 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. Single armoured cables are not recommended for rocky seabeds, regardless of installation depth; and
- additional layers can be added to the product (e.g. increased sheathing thickness, additional sheathing layers, additional armour layers) to increase desirable properties of the cable (e.g. weight relative to diameter, stiffness, etc.). Where added to act as “sacrificial layers” (see Annex D, **D.1.2**) the required thickness and quantity should be

identified by testing. Testing requirements should be identified by the purchaser to the cable manufacturer.

4.4 Potential further risks following the 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 B 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:

- a) small pebble-sized rocks moving if stiff cables are subjected to significant tensions during lay;
- b) soft rock relative to cable stiffness and outer layer strength, leading to rock surface wearing with cable movement, rather than the cable surface wearing (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 soils, such as dolomite limestone and gravel and could be more relevant to softer/weaker seabeds, such as weak limestone. See Figure 16 a) and b) and for examples of seabed wear.

- c) cable outer layer and rock, both abrading. This could lead to increased surface area over time, therefore abrasion rates could reduce as rocky surface topography becomes smoother and individual rock surfaces become less sharp (see Figure 15). 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 rock supports after which new free spans could form;
- e) where rubbing occurs, rock might fracture instead of abrading, resulting in formation of sharper sections, which could damage the cable through an alternative mechanism, such as gouging, slicing, serrating, point bending;
- f) sharp changes in elevation could lead to areas where slips occur under cable weight or during installation. Given the force, greater damage might be seen than associated with rubbing, particularly if the rock profile is sharp; and
- g) sharp changes in elevation, which might be more likely where areas contain large rocks, could lead 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 to cable manufacturer.

NOTE 2 See Annex D for further details on testing for abrasive related damage.

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.

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 to facilitate expedient estimates of key parameters for use in concept engineering and front-end engineering design (FEED), and these can be used prior to obtaining accurate site-specific seabed data. The Method A analysis process is described in Clause 6; and
- 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 is intended to be used in 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 methods can be applied to both installation and operational phases of cables, taking into account the metocean conditions relevant to each lifetime phase. The analysis methods can also be applied during different project life-cycle phases from early conceptual stages through operational to post-operational conditions.

NOTE There is no constraint within this British Standard against 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 vertical and horizontal loading and resistance.

For cables on rocky seabeds, this approach is not automatically relevant. The rugosity commonly associated with rocky seabeds typically leads to extensive spanning and a concentration of the resistance 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 which might cause cable limit states to be exceeded.

Assuring cable integrity necessitates consideration of failure modes beyond just determining an allowable lateral displacement. Risks should be identified and evaluated within the risk-based assessment for site conditions, product planned route corridor, product build and product limits (see Clause 4). 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 [7], as follows:

- a) excessive bending or tension in the cable resulting in mechanical failure which exceeds the manufacturer's allowable envelope for operational or installation conditions, as relevant (see 8.1 and 8.4);
- b) fatigue failure of an element of the cable (e.g. armour wire, conductor core, etc.) due to excessive cyclic bending and/or tensile strains imposed on any point of the cable (see 7.2);
- c) excessive abrasion due to repetitive rubbing against the seabed or 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); and
- d) lateral displacement due to hydrodynamic forces where this limit represents an expedient method of screening for all of the above modes of mechanical failure (see 6.1, 7.2, and 8.1).

Given the majority of a) to d) represent a local failure in the operability of the cable, the design approach follows the established offshore industry approach of considering an extreme design single wave/current event.

5.3 Potential damage mechanisms outside this assessment

In addition to the observed 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. This should be documented if 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 cable route or during post lay inspections.

This might include:

- 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 axis; or
- e) hocking due to excessive or uncontrolled movement during or post-lay.

5.4 Confirm seabed classification as rocky

COMMENTARY ON 5.4

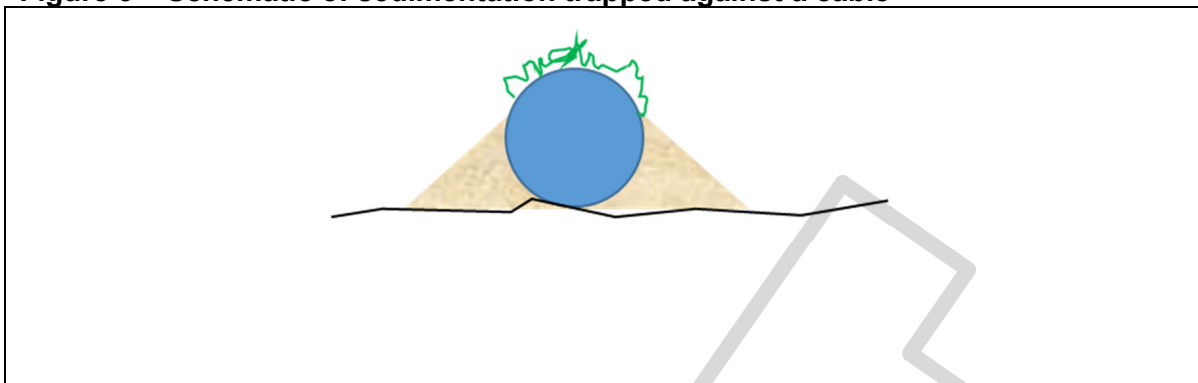
For further guidance, see Pipeline scour and self-burial on a thin veneer of sand overlying rock due to steady currents [8].

In order for this British Standard to apply, the surficial seabed should be classified based on accepted industry field survey techniques (e.g. BS EN ISO 14688-1) including acoustic, visual and/or physical sample analysis as meeting one of the following criteria:

- a) loose natural surficial seabed particles comprising rocks with median diameter greater than the cable diameter (D), typically cobble sized or larger; or
- b) quarried crushed rock placed onto the seabed comprising rocks with median diameter greater than the cable diameter (D), typically cobble sized or larger to a layer thickness not less than $2D$; or
- c) cemented bedrock, capstone or other monolithic material; or
- 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 accumulates around the cable, as shown in Figure 3. The risk of seabed mobility can be evaluated against *Shield's* criterion, see, for example, *Soulsby* [9].

If the seabed meets one of more of a)-c), it is classified as a rocky seabed and this British Standard is applicable. If the seabed meets d) and it can be shown that the underlying non-mobile layer comprises rock meeting one or more of a)-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 factors which directly affect cable hydrodynamic loading, on-bottom stability and spanning.

Where feasible:

- 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 which 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; and
- 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 factors, cable routing should take into account avoidance of significant risk locations which pose potential damage mechanisms, such as those identified in clause 5.2 and 5.3.

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

The positioning of the cable on the seabed during installation with respect to the presence of meso- and macro-scale seabed features is considered to be 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 cable's initial location with respect to seabed features capable of causing an abrupt resistance event is effectively random.

Therefore, on occurrence of the first significant storm event post-lay, the cable is likely to experience local displacement events which move the cable until it engages with the set of nearest available abrupt resistance event features, as shown in Figure 4. This initial cable movement is permitted within the defined cable route corridor, subject to:

- the cable passing this stability design check;
- the performance of an as-laid survey which confirms the presence of abrupt resistance event features at sufficient spatial density. This survey should confirm the initial lateral position of the cables;
- the performance of a subsequent survey following the initial storm event to identify that abrupt resistance events have been encountered by the cable with adequate spacing

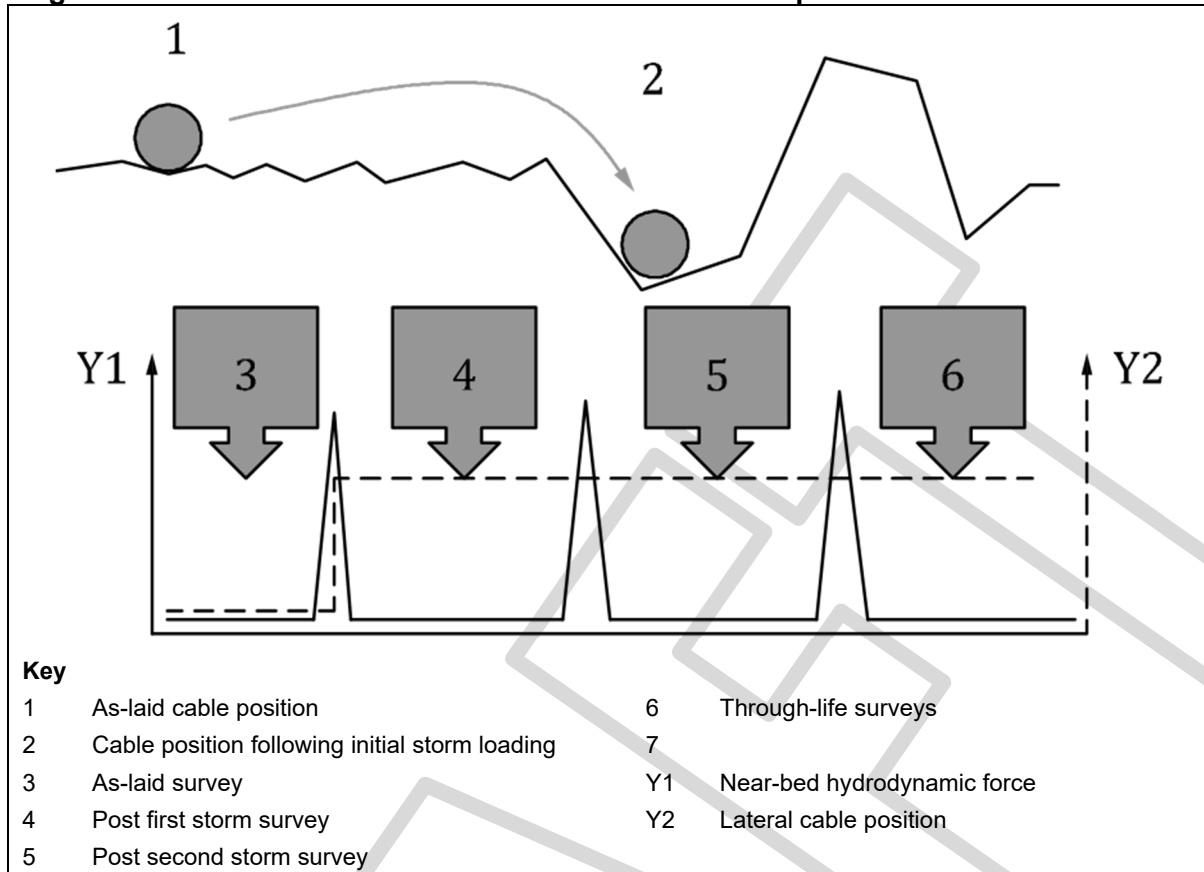
(spacing no greater than $L_{\max}$, as defined in 8.3). An initial storm event should be defined as falling between 1 year and 10 years in severity. This survey should confirm locations where lateral displacement of the cables has occurred and identify any locations where supplementary restraint of the cables are required so that spacing between point resistance events is less than $L_{\max}$. The survey should be undertaken as soon as possible after the storm, but not later than six months. An additional survey should be undertaken following an event approaching or exceeding the 100-year design extreme return period event;

- d) the performance of a subsequent survey following the second significant 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; and
- e) all further cable lifetime operational integrity surveys should evaluate any 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 marine growth or cable surface evidence of scratching or wear) and other deleterious indicators.

The timeline for these 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 where there is a large ratio between the 1-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 1-year and 100-year event and there are, typically, a number of severe storms of similar magnitude each year, it might be more appropriate to plan for follow-up surveys in the first and second years post-lay. Other factors might dictate additional surveys and timelines.

NOTE Reference can be made to Ronalds et al. [10], [11]. 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

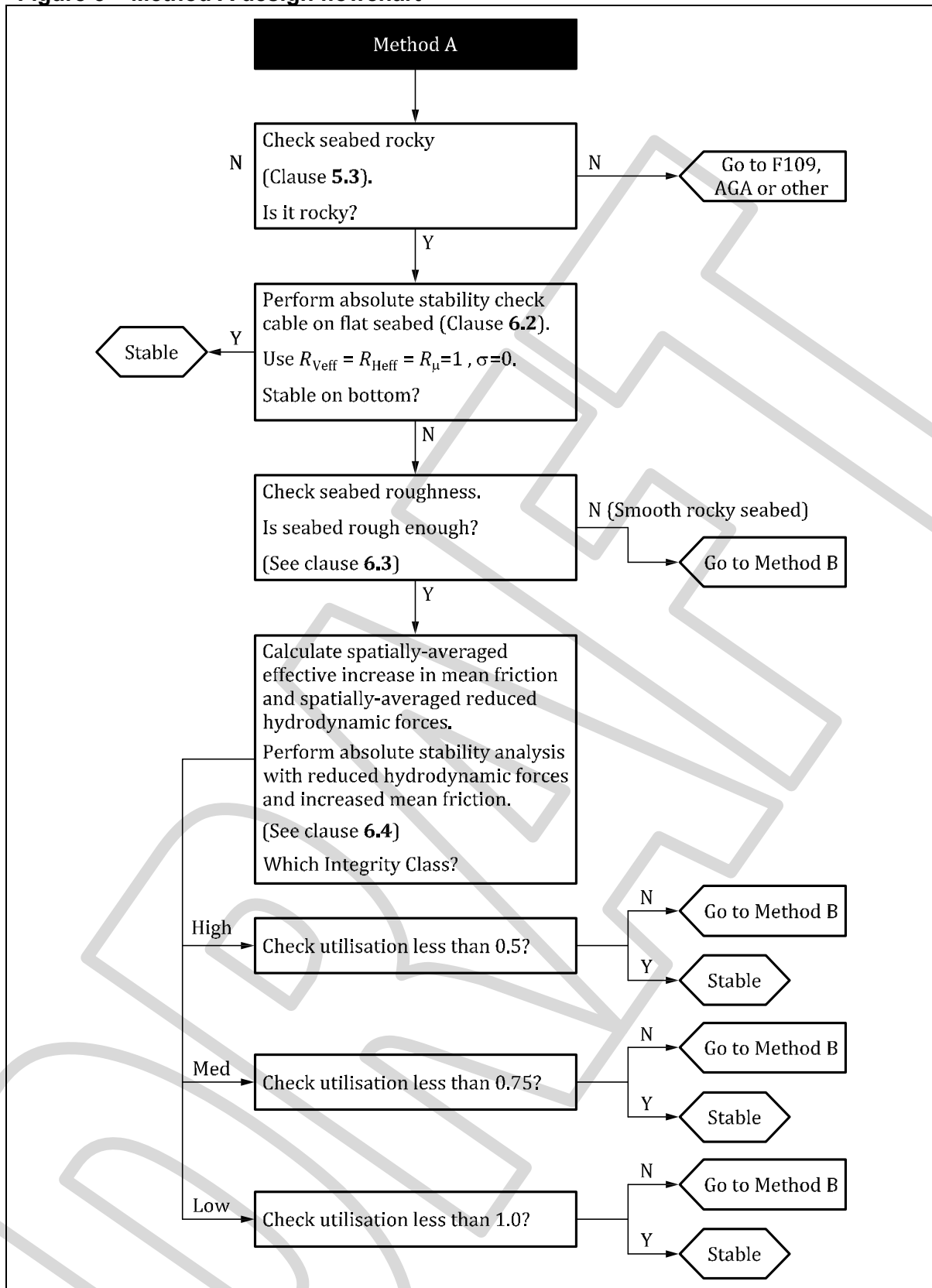
COMMENTARY ON CLAUSE 6

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 with hydrodynamic forces in Clause 9 and lateral resistance in Clause 10.

6.1 General

Method A (see Figure 5) is defined using processes capable of being implemented in commonly available existing industry software and spreadsheet tools but which take account of the failure modes relevant to cables on rocky seabeds through the application of allowable utilization criteria.

Figure 5 – Method A design flowchart



6.2 Perform an absolute stability check – plane seabed

Following the method presented in 8.1, an absolute stability check on the cable should be undertaken. For the simplified absolute stability check, $R_{\text{Heff}} = R_{\text{veff}} = R_u = 1$ should be adopted.

If the cable is found to be stable, this is a sufficient test of stability.

6.3 Check seabed roughness

6.3.1 General

The seabed roughness can be checked using alternative methods. The designer should confirm that there is sufficient presence of meso-scale roughness, with or without the presence of macro-scale roughness.

6.3.2 Analysis of multi beam echo sounder (MBES) seabed survey data

This method uses the MBES survey data to infer the presence of meso-scale roughness by filtering the seabed bathymetry to remove large-scale bedforms, leaving only the smallest macro-scale bed features.

The method requires the user to calculate the L_{cr} characteristic cable sag length in accordance with 8.2.2.

Where the seabed has been surveyed using a MBES tool to produce a detailed 3-dimensional bathymetry model of the cable route, with a measured data point cloud lateral spatial density that is not greater than 1 m, the following method should be followed:

- a) confirm whether the xyz dataset is a gridded and filtered version of the measured data. If gridded or filtered, the original data sampling density and filtering window size should be confirmed. If the data is ungridded raw data, de-spiking and careful filtering to remove physically unrealistic data anomalies should be carried out by a competent engineer who has a good understanding of the likely implications of each edit to the measured data;
- b) extract from the xyz dataset a corridor of data along the cable route alignment. This should be as wide as the allowable route lay corridor (nominally 10 m – 20 m). It should not be less than 100 m in length;
- c) the xyz corridor then needs major macro-scale features removed. This should be undertaken by subtracting the mean depth. The mean along-route gradient and across-route gradients should also be removed from the data, as shown in Figure 6;
- d) if significant large bedform features remain which are longer than L_{cr} in length, these should also be removed by using a 2-dimensional moving window filtration method with window size of not less than L_{cr} .

NOTE A Savitsky Golay [12] filter is ideal. A simple 2D moving average is not to be used.

- e) the standard deviation of the remaining xyz bathymetry should be calculated; and
- f) if the standard deviation of the data is greater than:
 - 1) the data mean lateral spacing (maximum 1 m); and
 - 2) greater than $2 \times$ the cable diameter,the seabed is accepted as sufficiently rough to indicate the presence of meso-scale roughness.