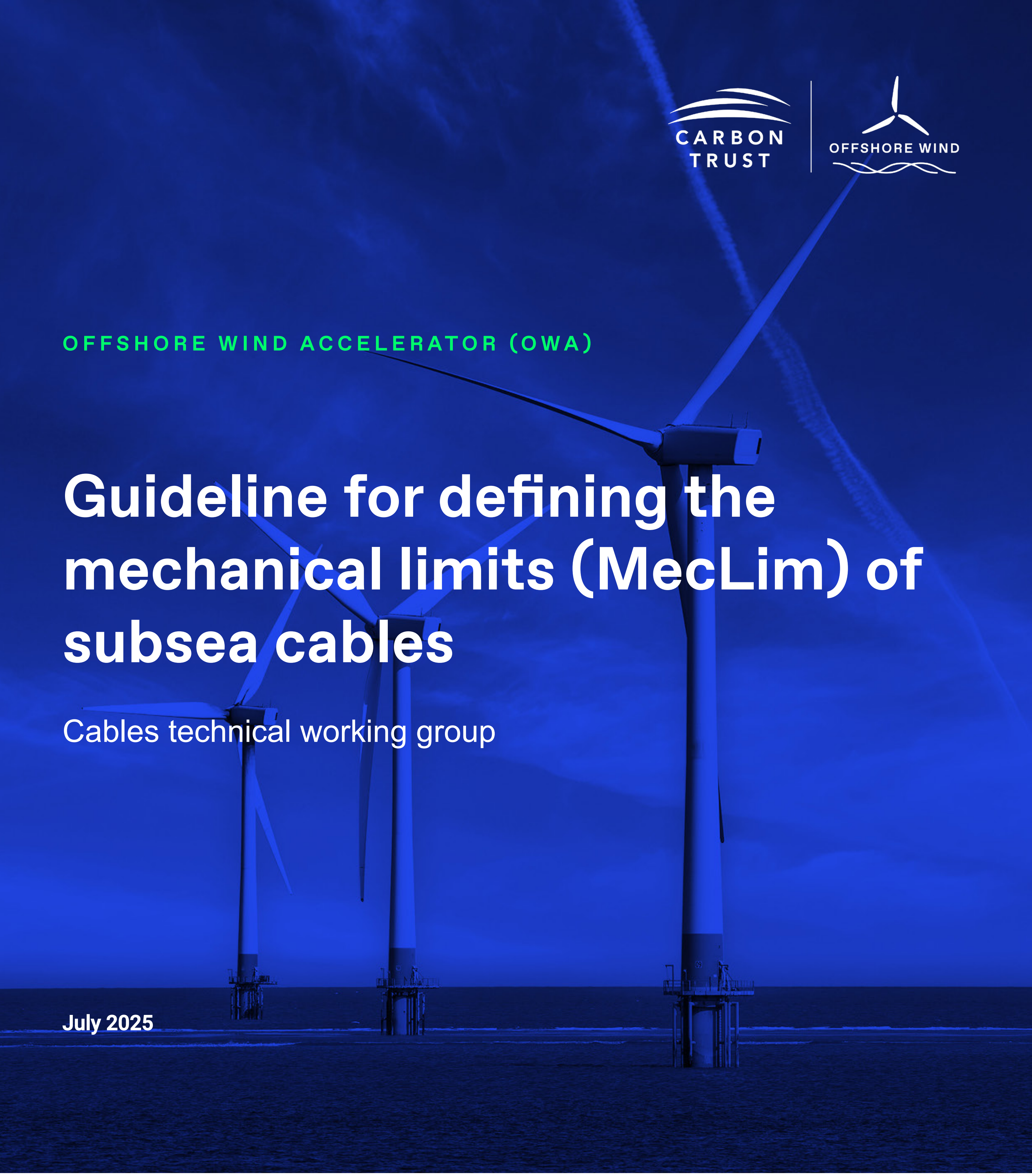

OFFSHORE WIND ACCELERATOR (OWA)

Guideline for defining the mechanical limits (MecLim) of subsea cables

Cables technical working group

July 2025

OWA parties

Participants in the Offshore Wind Accelerator (OWA) programme (Stage IV): EnBW Energie Baden-Württemberg AG, RWE Offshore Wind GmbH, Equinor ASA, Ørsted Wind Power A/S, ScottishPower Renewables (UK) Limited, Shell Global Solutions International B.V, SSE Renewables Services (UK) Limited, Vattenfall Wind Power Ltd, TotalEnergies OneTech, and the Carbon Trust.

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Contents

1. Foreword

The mechanical testing performed at present on subsea cables is designed to ensure that cables conform to the mechanical limits assigned by manufacturers; however, these mechanical limits do not necessarily reflect the performance limits of the cable, resulting in uncertainty around the margin of safety associated with the mechanical limits described for subsea cables. Use of a standard approach to the definition of the mechanical limits of subsea cables would remove this uncertainty.

The Mechanical Limitations (MecLim) project, and subsequent Mechanical Limitations 2 (MecLim II) JIP, have proposed a safety factor philosophy for the mechanical limits of subsea cables, which is contained within the guidelines outlined in this document.

The proposed safety factor philosophy is founded on a performance testing approach in combination with modelling. No new tests are prescribed, although some suggested enhancements to existing tests are described. Similarly, the guidelines can be applied using many modelling techniques.

This guidance is intended to provide a standardised methodology for the definition of key mechanical limits of subsea cables, to be used in conjunction with existing test and modelling methods to enhance the understanding and align the interpretation of mechanical limits of subsea cables within the industry. Associated benefits may include the ability to expand cable installation windows, or to further reduce cable failures with mechanical root causes.

2. Introduction

2.1. Background

The Offshore Wind Accelerator (OWA) is an industry-driven research, development and demonstration programme launched by the Carbon Trust and industry Partners. Since its inception in 2008, the OWA has worked to reduce the cost of electricity generated by offshore wind.

The OWA comprises five research areas: Cables, Electricals, Foundations, Logistics and O&M, and Energy Yield & Performance. Each research area is governed by a Technical Working Group (TWG) consisting of technical experts appointed by the OWA Partners.

The MecLim project was initiated by the OWA's Technical Working Group for Cables (TWG-C) in 2021 to investigate the definition of mechanical limits for inter-array cables for bottom-fixed offshore wind.

On completion of the first phase of the MecLim project in 2023, it was identified that adoption of a standardised approach to the definition of the mechanical limitations of cables and associated safety factor philosophies would be of benefit to the subsea cable industry.

While some recommendations exist, for example CIGRÉ TB 623 [1], it has been identified that there is variation between cable manufacturers regarding the methodologies applied in defining the mechanical limits of subsea cables. MecLim Phase I concluded that a standardised Performance Testing approach should be adopted to allow for increased understanding of the structural capacity of cables, and a limit state design approach could then be applied for numerical analysis in order to ensure consistency of interpretation of datasheet values across the industry.

The MecLim II Joint Industry Project (JIP), was conceived to facilitate a wider discussion on this topic within the industry, with the objective of achieving industry agreement on a safety factor philosophy for the mechanical limits of submarine cables in collaboration with offshore windfarm operators and cable manufacturers. This guidelines document is the principal output of the JIP. MecLim II JIP has been sponsored by Carbon Trust and chaired by Wood. MecLim II JIP comprised a total of 18 members, as represented by the logos in in Figure 1.

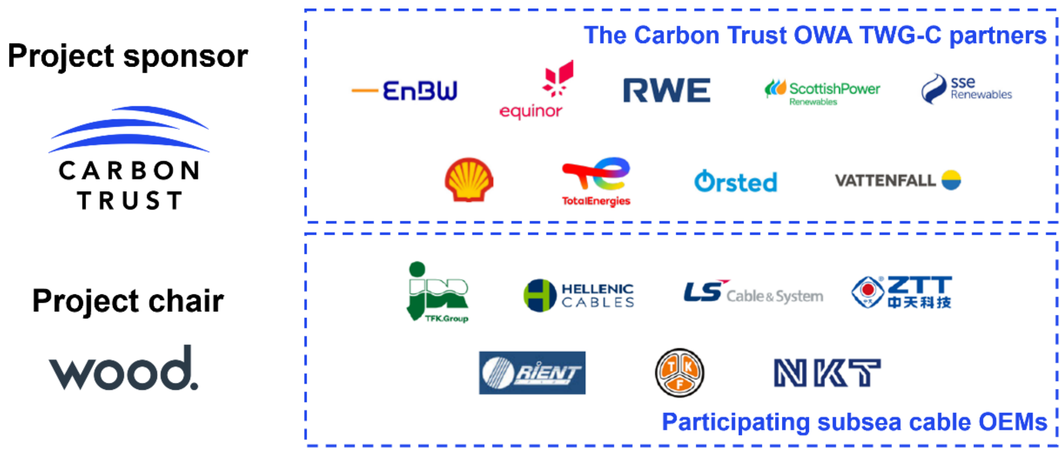

Figure 1: MecLim II JIP Members

2.2. Why are these guidelines needed?

At present, the allowable mechanical limits set for a cable are often based on rules of thumbs and confirmed through conformance testing. There is no established code, standard or guide for performance testing within the submarine cables industry.

While a conformance test adequately ensures that a cable can withstand the stated level of loading, it does not allow for determination of a known factor of safety.

A performance testing approach addresses this uncertainty through establishment of the limiting values for a mechanical parameter and allowing for application of a quantifiable margin of safety.

Adoption of a performance testing approach with a recognised safety factor philosophy, such as the one proposed in this Guideline, would increase confidence among cable purchasers through enhanced understanding of the mechanical performance limits of the cable, and would allow for more consistent interpretation of the mechanical limits listed on cable data sheets.

In cases where performance testing should facilitate a more lenient allowable limit, this may enable broader installation windows for cables, thereby reducing LCOE. On the other hand, it may be found that the resulting safety margin from a conformance test was insufficient, resulting in a more stringent limit being set following performance testing; in this case, performance testing may help to reduce the number of mechanical cable failures that occur.

2.3. Extents / limitations

The mechanical parameters to which these guidelines apply are as follows:

- Minimum bending radius
- Sidewall pressure limit
- Tension limit
- Compression limit
- Crush load limit
- Impact capacity

Although it is a characteristic rather than a limit, bending stiffness has also been considered, given its importance to the mechanical performance of submarine cables. Contrary to the other parameters where a conservative limit is typically defined, it is noted that accuracy in characterisation of bending stiffness is of high importance to ensure correct representation of cable dynamic behaviour in analytical and numerical models.

This guideline is intended to be used as an enhancement to existing standards and recommended practice, in conjunction with sound engineering judgement.

This guideline document does not prescribe any specific test or modelling methodologies. Rather, it describes a proposed safety factor philosophy and includes some suggestions for enhancement on existing test methods.

2.4. Existing guidance

At present, the most commonly used mechanical tests for inter-array cables for bottom-fixed offshore wind are those described by CIGRÉ in TB 623, "Recommendations for mechanical testing of submarine cables" [1], which includes some mandatory mechanical tests and some optional, project-specific mechanical tests. These tests typically take the form of conformance tests. In addition to TB 623, further definition of some of these mechanical tests is provided in CIGRÉ TB 862, "Recommendations for mechanical testing of submarine cables for dynamic applications" [3], which expands on TB 623 with specific reference to cables for dynamic applications including further definition of a full-scale fatigue test and additional mechanical characterisation tests.

Current guidelines for modelling of subsea cables for use in offshore wind applications focus largely on global modelling of the cable in project-specific scenarios, as in CIGRÉ TB 862 Section 5 (specific to dynamic cables), while reference to local modelling of cable cross-section is also made in CIGRÉ TB 862 in respect of fatigue analysis. There is no existing industry-standard guidelines document in place for the modelling of subsea cable cross-sections for the purpose of establishing the mechanical behaviour or limits of such a cable, nor is there published guidance on qualification of numerical models for this purpose. Each cable manufacturer has the freedom to develop and apply appropriate numerical models as they see fit. Review of these models often forms part of the due diligence undertaken by cable purchasers when purchasing cables.

2.5. Document purpose

The purpose of this document is to present the Carbon Trust Offshore Wind Accelerator's (OWA) "Guidelines for Defining the Mechanical Limits of Subsea Cables". This is a key deliverable of the OWA's MecLim II Project and includes a safety factor philosophy and associated design and test methodology.

2.6. Abbreviations

ALS	Accidental Limit State
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
CIGRE	International Council on Large Electric Systems (Conseil International des Grands Réseaux Électriques)
CPS	Cable Protection System
DNV	Det Norske Veritas
IEC	International Electrotechnical Commission
ISO	International Standards Organisation
JIP	Joint Industry Project
LCOE	Levelised Cost of Energy
MBR	Minimum Bending Radius
OD	Outer Diameter
OMAE	Offshore Mechanics and Arctic Engineering
OWA	Offshore Wind Accelerator
RP	Recommended Practice
SIED	Stress-Induced Electrochemical Degradation
SWP	Side Wall Pressure
TB	Technical Brochure
TWG	Technical Working Group
ULS	Ultimate Limit State
XLPE	Cross Linked Polyethylene

3. Proposed safety factor philosophy

3.1. General

The safety factor philosophy proposed by the MecLim II JIP is based on a combination of physical testing and modelling and takes into consideration the key stages of a cable's operational lifecycle including Installation (which in this guideline includes Load Out and Transportation, given that similar conditions apply), Normal Operation and Abnormal Operation.

3.2. Engineering and design

The first step in the process is to define the limiting criteria for a mechanical parameter (i.e. MBR, tension limit, compression limit, sidewall pressure limit, crush load limit or impact limit) through engineering and design. This can be evaluated through numerical modelling and verified by testing.

The advantage of using numerical methods during design is that these methods allow the cable designer to simulate tests on multiple variations of a cable design, under multiple variations of test parameters in a timely manner. Numerical models can also be used as a form of non-destructive performance testing; application of loads to the model until the material stress/strain limits are reached is a means of testing the cable cross-section beyond the limits of the material, without destruction of any cable samples.

Modelling techniques typically use the material properties, and the performance limits of the materials that comprise the cable cross-section as inputs, which tend to be well defined, e.g., properties of a particular grade of steel including the Yield Strength are typically tested by the material supplier for each batch of product.

Manufacturers can use the mechanical limits of the cable obtained from numerical modelling or from historical testing as inputs to physical testing. To obtain mechanical limits from numerical modelling, loading should be applied to the model until a utilisation of 1.0 is achieved in each component. Results of such modelling can be used to determine the load conditions that will be required for physical performance testing (e.g., the bending radius that will lead to damage in the armour wires). Table 1 is provided as an example of how this data could be communicated.

A limitation of this type of numerical modelling is that it typically does not reflect all aspects of cable performance; for example, it does not consider electrical integrity, and it may be found that some interaction between components may not be accurately captured by the modelling techniques used. Therefore, it is not advised to rely solely on numerical testing; physical testing is also recommended.

Table 1: Limiting criteria for definition of allowable limits

Mechanical parameter	Parameter limit	Most limiting component	From previous test?	From numerical model?
Minimum Bend Radius				
Sidewall Pressure Limit				
Tension Limit				
Compression Limit				
Crush Limit				
Impact Limit				

3.3. External effects on mechanical properties of materials

The mechanical properties of some materials used within typical cable cross-sections may vary when subjected to external factors such as thermal, chemical and electrical effects, or due to aging.

Thermal effects are typically more pronounced for non-metallic materials, at the temperatures experienced by submarine cables. Given that the operating temperature of a submarine cable is typically in the range of 60-90°C, and cables are manufactured and installed at much cooler temperatures (e.g. as low as approx. 10°C), the effect of thermal variations on mechanical properties are seen most commonly during manufacturing, transpooling and installation.

One material commonly used in cable manufacture that is subject to temperature-dependent variation of mechanical properties is bitumen. Bitumen is a viscoelastic material, which becomes less viscous at higher temperatures. It is largely produced for use in construction, with use as a coating material for submarine cables constituting a very small percentage of global bitumen usage. It is a product that can have a wide variety of material specifications, which can be adjusted to suit requirements through the use of additives. Bitumen is not a uniform product, and it is considered that the quality and material properties of bitumen can vary between suppliers, resulting in potential for uncertainty on the exact properties present. Bitumen is not subject to certification in the same way that a metallic material may be, and testing for mechanical properties may not be performed to the same degree. It is noted that the mechanical properties of bitumen are also dependent on the rate of stress application.

It has been demonstrated in numerous papers that cable bending stiffness tends to increase as temperature decreases, or loading rate increases, due to the highly non-linear viscoelastic behaviour of bitumen (e.g. [15] - [18]). Understanding the effects of temperature and loading-rate on the mechanical properties of bitumen is key, as the presence of bitumen in contact with the armour wires of a cable can significantly affect the extent to which compressive loads build up in the axes of the armour wires. The effects of this restraint are exacerbated at low temperatures when bitumen becomes stiffer, which can result in bird caging or lateral buckling of armour wires.

Bitumen is not the only material used in cable construction whose mechanical properties are temperature dependent. Cables with polyethylene outer sheaths typically do not utilise bitumen, however the mechanical behaviour of these cables is still affected by temperature. In particular, the polymer materials within the cable cross-section, including the polyethylene outer sheath, tend to become stiffer at cooler temperatures, again most commonly experienced during manufacture, transpooling and installation.

At the opposite end of the temperature range, typical operating temperatures do not appear to have as significant an effect on the mechanical properties of submarine cables as colder temperatures do. While, in general, tensile strength, yield strength and modulus of elasticity tends to decrease with increasing temperature, the effects are small within the normal operating temperature range. Thermal expansion of conductors or armour wires is not considered to be a significant issue at typical operating temperatures. Thermal cycling of metallic screens at operational temperatures can lead to fatigue cracking, which increases resistance and can lead to increased heat generation at the exterior of the cable core; this is a topic that may merit further investigation.

Cable purchasers can request the mechanical properties for cables at relevant temperatures, reflective of typical conditions, for example installation and operation.

With regard to modelling of thermal effects, the mechanical properties most appropriate to the scenario being modelled should be used, i.e. the cable / material properties applied should be reflective of the installation temperature in installation analysis. It is considered challenging to capture the non-linear, temperature-dependent nature of bitumen in numerical models, with fixed mechanical properties typically being used at present.

The main chemical effect to which submarine cables are commonly subjected is the issue of hydrogen migration within the cable, which can have an embrittling effect. Excessive embrittlement of cable components may lead to a change in mechanical properties; however, this can be mitigated by use of appropriate water blocking.

The chemical interaction of bitumen with other materials within the cable cross-section is not well understood but is considered to be negligible at the temperature range considered for submarine cables.

Electrostriction occurs in insulation materials when subjected to an electric field, resulting in elongation (strain) of the material. The impact of electrostriction on the mechanical properties of a submarine cable are not well understood, but deformation of insulation may be linked to water migration within the cable.

Mechanical fatigue of conductors is not thought to be exacerbated by electrical loading.

Electrical aging of polymeric materials may result in alteration of the mechanical properties of these materials over time.

Stress-induced electrochemical degradation (SIED) may occur in aluminium conductors for wet-design cables, particularly in deeper water applications.

Accumulation of damage in materials over time (e.g. micro-cracks, plastic deformation) is likely to result in weakening of the material, which may accelerate the mechanical fatigue process.

With this in mind, it is important to consider the impact of external effects on the mechanical properties of the cable during testing. It is recommended to develop a load case matrix, considering the loading conditions that will be applicable to the cable throughout its lifecycle and to repeat the process of modelling and testing for these load cases in the test programme. As a minimum, the ambient temperatures and loading rates that are expected during the cable lifecycle (and particularly for the installation condition, where this effect is most likely to be observed) should be considered. Temporary conditions which are challenging to represent in a numerical model such as preconditioning of cables with torsional stress due to the coiling process are not covered by the proposed performance tests.

3.4. Incorporation of performance testing

In order to determine the level of conservatism in the numerical model, it is proposed to run performance tests on cable test samples.

The general philosophy for this testing is to test the cable using the existing methodologies (e.g., those set out by CIGRÉ) to a utilisation of 1.0 (i.e., onset of mechanical damage) in the most limiting component by applying the required loading condition as determined from the numerical modelling, then to run the required electrical tests, followed by dissection of the cable cross-section and inspection for signs of damage. This process is then repeated for the least limiting component. Should the difference in the load required to initiate damage in the most limiting and least limiting components be greater than a factor of two, it is recommended to limit the second test loading condition to twice the first test loading condition. This will provide a more feasible range of testing for the test equipment and, as the cable limit will be determined by the most limiting component, it will provide sufficient assurance that it is, in fact, the most limiting component.

In the first instance, if there are no signs of damage to any components (other than the most limiting component which has been pushed to the point of visible damage), the numerical model is considered valid; otherwise, if other components show signs of damage, the numerical model should be revisited to ensure adequate conservatism.

In the case of testing for the least limiting component, the numerical model can be considered valid if there are signs of damage in all components, otherwise, the numerical model may be overly conservative and modifications to the model may be beneficial in achieving an optimal result. In the case of testing to twice the load of the most limiting component, the numerical model can be considered valid if there are signs of damage to some cable components, however, the least limiting component remains intact. Otherwise, the numerical model may be overly conservative and modifications to the model may be beneficial in achieving an optimal result.

Following the mechanical tests, it may be necessary to revisit the numerical model. The required changes to the model will be dependent on which loading regime is not accurately represented, and/or the level of conservatism within the model.

For example, if the discrepancy is in the response to MBR, this may be due to assumptions regarding geometry, stiffness (non-linearity), contact pressures within the construction or influence of temperature. Where the discrepancy is due to tension the model may not accurately represent the area over which the force is applied (lay angle) or the contribution of each component in the crosssection to support the tensile load (component axial stiffness) considering the influence of temperature or non-linear effects in the material.

Based on establishing the validity of the numerical model, the mechanical limits for each scenario can then be quantified from the model.

This process is captured visually in Figure 2.

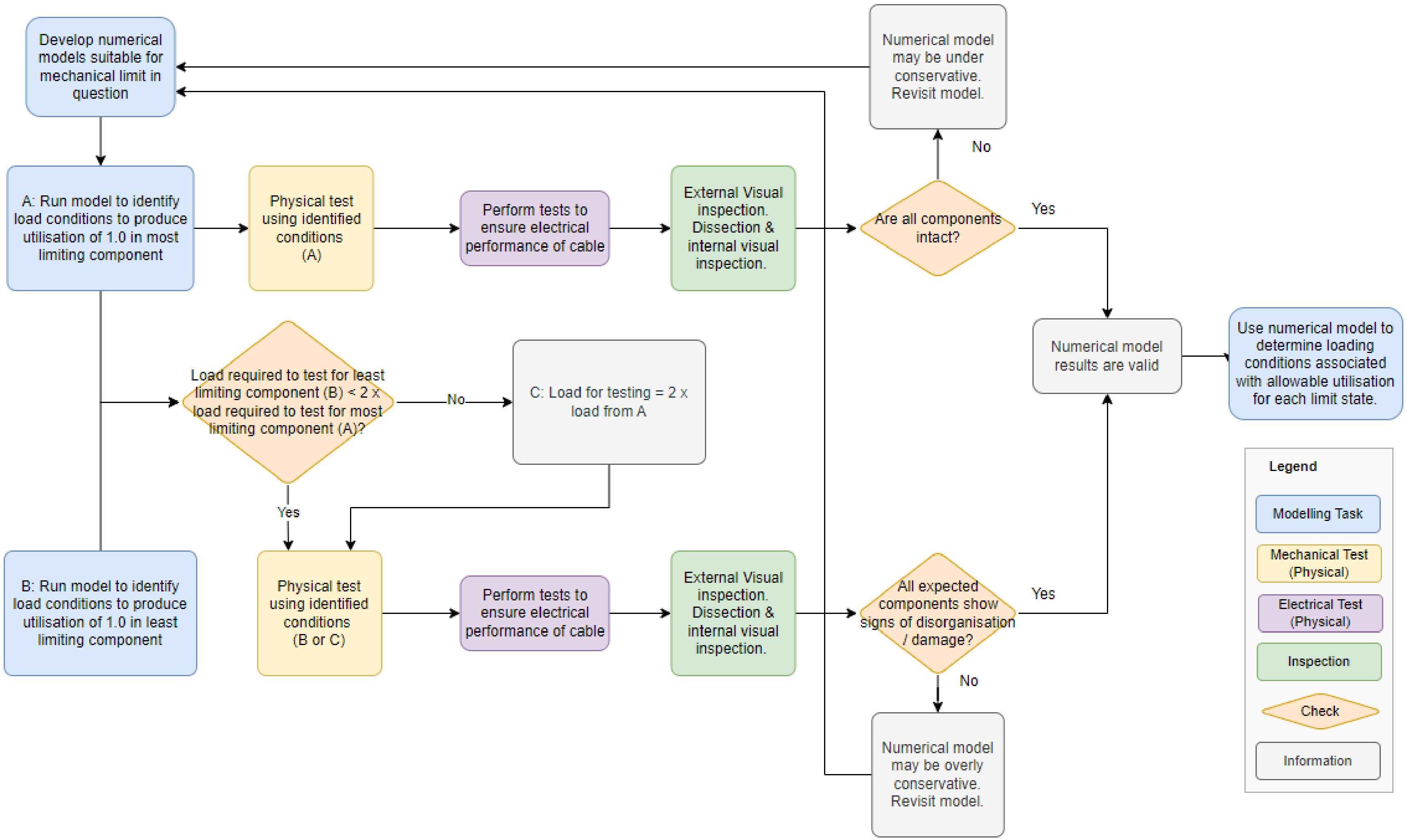

Figure 2. Flowchart of proposed safety factor philosophy

Sample modelling and test procedures for some of the key mechanical parameters are presented below from Table 2 to Table 4. It is noted that the tests mentioned in this sample procedure focus on the proposed method for determining the mechanical limits of submarine cables and are not exhaustive; the cable manufacturer must consider all relevant risks to the cable and the level of electrical testing required will vary depending on the limiting component of a given cable and the impact this component may have on electrical performance.

Note that from Table 2 to Table 4, the material property used to identify onset of damage in components (i.e. the limiting design criteria) could be the yield strength of a metallic material or strain limit for a non-metallic material. The material property used should be calculated in a realistic manner, or using realistic (if slightly conservative) values and should be applicable to the combination of material and component (e.g. a reduced strain limit is typically applicable to conductor insulation).

Table 2: Sample modelling and test procedure proposed for MBR

Proposed modelling and test procedure for MBR	
1.	**Numerical modelling step 1**
(a)	Determine bend radius that results in onset of damage (utilisation of 1.0 in the material property used to identify onset of damage) in the most limiting component.
(b)	Determine bend radius that results in onset of damage (utilisation of 1.0 in the material property used to identify onset of damage) in the least limiting component.
2.	**Mechanical tests**
(a)	Perform "bending test without tension" (CIGRÉ TB 623 [1]), using bend radius from 1(a).
(b)	Perform "bending test without tension", using bend radius from 1(b) or 2 × 1(a) whichever is lower.
3.	**Electrical testing**
(a)	Perform electrical tests (e.g. partial discharge testing per IEC 63026 [11] / IEC 60840 [12] / IEC 62067 [13], as required for electrical type test) on test samples from 2(a) and 2(b), as recommended for the "bending test without tension".
4.	**Determination of results**
(a)	Perform external visual inspection, followed by dissection and internal visual inspection (as per the "bending test without tension") on test samples from 2(a) and 2(b).
(b)	The numerical modelling can be considered valid if the following conditions are met:
i.	Sample 2(a) exhibits no signs of damage to any components.
ii.	Sample 2(b) exhibits signs of damage in all components, with the exception of the least limiting component if tested to 1(b) or exhibits signs of damage in some components but not the least limiting component if tested to 2 × 1(a).
(c)	If the conditions above are not met, the model may be overly, or under conservative and should be revisited.
(d)	If the conditions are met, the result of Sample 2(a) is the MBR for Abnormal Operation (utilisation of 1.0).
5.	**Numerical modelling step 2**
(a)	Determine the bend radius for Normal Operation by applying the appropriate utilisation factor to the material property used to identify onset of damage for the most limiting component. This is the Operational MBR under dynamic loading (for a zero-tension condition).
(b)	Determine the bend radius for Installation by applying the appropriate utilisation factor to the material property used to identify onset of damage for the most limiting component. This is the MBR for Installation (for a zero-tension condition).
(c)	Repeat the numerical modelling process but with the application of tension, in order to derive the tension vs. curvature plot. It is recommended that a minimum of two tension points be considered, with one being the maximum tension expected during installation and another being an intermediate tension point (between 0 kN and the installation tension). Generate a plot of tension vs. curvature based on the results obtained.
	Repeat steps 1-5 for the load case matrix of temperatures, considering at least the maximum and minimum temperature expected during the cable lifecycle. The MBR most applicable to the ambient temperature and loading rate should be applied during cable installation and handling.

Table 3: Sample modelling and test procedure proposed for sidewall pressure limit

Proposed modelling and test procedure for SWP
1. Numerical modelling step 1
(a) Determine bend radius of the curved surface that results in a utilisation of 1.0 in the material property used to identify onset of damage in the most limiting component under the maximum expected tension during installation. Note that the curved surface modelled should be representative of the curved surface expected to be encountered by the cable.
(b) Determine bend radius of the curved surface that results in a utilisation of 1.0 in the material property used to identify onset of damage in the least limiting component under the maximum expected tension during installation. Note that the curved surface modelled should be representative of the curved surface expected to be encountered by the cable.
The numerical modelling should consider the range of potential temperatures which a cable may be subjected to and the effect of temperature on the performance of the cable when determining the limiting criteria and the mechanical testing conditions. Should there be significant variation in temperature and a significant variation in limiting bend radius of curvature as a result of temperature, additional mechanical testing may be required at varying temperatures.
2. Mechanical tests
(a) Perform "tensile bending test" (CIGRÉ TB 623 [1]), using bend radius, curved surface shape and tension from 1(a). In order to reduce the number of test wheels which must be available to the manufacturer the following tolerance shall be considered: the test shall be performed with a radius equal to or smaller than that required and tension may be varied to achieve a stress between 100% and 120% of the yield stress of the most limiting component from 1(a) provided it does not result in yielding of the least limiting material from 1(b).
(b) Perform "tensile bending test", using bend radius, curved surface shape and tension from 1(b) or 2 × 2(a) curvature whichever is lower. Again, variation in tension may be allowed to achieve the required side wall pressure and stress.
Test temperature should be stated alongside results.
3. Electrical testing
(a) Perform electrical tests (e.g. partial discharge testing per IEC 63026 [11] / IEC 60840 [12] / IEC 62067 [13], as required for electrical type test) on test samples from 2(a) and 2(b), as recommended for the "tensile bending test".
4. Determination of results
(a) Perform external visual inspection, followed by dissection and internal visual inspection (as per the "tensile bending test") on test samples from 2(a) and 2(b).
(b) The numerical modelling can be considered valid if the following conditions are met:
i. Sample 2(a) exhibits no signs of damage to any components.
ii. Sample 2(b) exhibits signs of damage in all components, with the exception of the least limiting component or exhibits signs of damage in some components but not the least limiting component if tested to 2 × 1(a).
(c) If the conditions above are not met, the model may be overly, or under, conservative and should be revisited.
(d) If the conditions are met, the result of Sample 2(a) is the Sidewall Pressure Limit for Abnormal Operation (utilisation of 1.0).
5. Numerical modelling step 2
(a) Determine the sidewall pressure limit for Normal Operation by applying the appropriate utilisation factor to the material property used to identify onset of damage for the most limiting component and identifying the limiting bend radius. This is the Operational Sidewall Pressure Limit.
(b) Determine the sidewall pressure limit for Installation by applying the appropriate utilisation factor to the material property used to identify onset of damage for the most limiting component and identifying the limiting bend radius. This is the Sidewall Pressure Limit for Installation.
Repeat Steps 1-5 for the load case matrix of temperatures and loading rates, considering at least the maximum and minimum temperature, and maximum and minimum loading rate, expected during the cable lifecycle. The Sidewall Pressure Limit most applicable to the ambient temperature and loading rate should be applied during cable installation and handling.

Table 4: Sample modelling and test procedure proposed for crush load limit

Proposed modelling and test procedure for crush load limit	
1.	**Numerical modelling step 1**
(a)	Determine the crush load that results in a utilisation of 1.0 in the material property used to identify onset of damage in most limiting component.
(b)	Determine the crush load that results in a utilisation of 1.0 in the material property used to identify onset of damage in the least limiting component.
2.	**Mechanical tests**
(a)	Perform crush tests (e.g. per CIGRÉ TB 623 [1]), using crush load from 1(a).
(b)	Perform crush tests, using crush load from 1(b) or 2 × 1(a) whichever is lower.
3.	**Electrical testing**
(a)	Perform electrical tests (e.g. partial discharge testing per IEC 63026 [11] / IEC 60840 [12] / IEC 62067 [13], as required for electrical type test) on test samples from 2(a) and 2(b), as recommended for crush tests.
4.	**Determination of results**
(a)	Perform external visual inspection, followed by dissection and internal visual inspection (as per crush tests) on test samples from 2(a) and 2(b).
(b)	The numerical modelling can be considered valid if the following conditions are met:
i.	Sample 2(a) exhibits no signs of damage to any components.
ii.	Sample 2(b) exhibits signs of damage in all components, with the exception of the least limiting component or exhibits signs of damage in some components but not the least limiting component if tested to 2 × 1(a).
(c)	If the conditions above are not met, the model may be overly, or under, conservative and should be revisited.
(d)	If the conditions are met, the result of Sample 2(a) is the Crush Load Limit for Abnormal Operation (utilisation of 1.0).
5.	**Numerical modelling step 2**
(a)	Determine the crush load limit for Normal Operation by applying the appropriate utilisation factor to the material property used to identify onset of damage for the most limiting component and identifying the crush load. This is the Operational Crush Load Limit.
(b)	Determine the crush load limit for Installation by applying the appropriate utilisation factor to the material property used to identify onset of damage for the most limiting component and identifying the limiting crush load. This is the Crush Load Limit for Installation.
	Repeat Steps 1-5 for the load case matrix of temperatures and loading rates, considering at least the maximum and minimum temperature, and maximum and minimum loading rate, expected during the cable lifecycle. The Crush Load Limit most applicable to the ambient temperature and loading rate should be applied during cable installation and handling.

3.5. Application of safety factor

Following numerical modelling and testing, the values of each tested parameter corresponding to a utilisation of 1.0 for the limiting design criteria in the limiting component will be established. It is proposed that a utilisation factor is then applied to determine the allowable limit of the cable for various lifecycle phases. The proposed utilisation factors are provided in Table 5.

The utilisation factors for steel armour wires have been adopted from DNV-RP-F401 [7], "Electrical Power Cables in Subsea Applications". Utilisation factors for other components / materials are not provided in DNV-RP-F401, with utilisation factors for armour wires of other materials left to be decided upon by the cable manufacturer and purchaser. It has been noted by the JIP that the utilisation factors set out in DNV-RP-F401 for steel armour wires are closely aligned with utilisation factors used for subsea risers and umbilicals for pressure containment (e.g. API 17E [9], API 17J [10]). Given the differences in the nature of the product (i.e. additional risks due to presence of hydrocarbons in O&G installations) the JIP considers that these utilisations are quite conservative.

The utilisation factor defined for abnormal operation for other components has been set to 1.0 in line with current practice for the oil and gas industry (e.g. API 17J, where the material strength utilisation is allowed to reach unity for a survival event, or API 17E / ISO 13628-5 [8], where a utilisation factor of 1.00 is provided for abnormal operation) and in keeping with the guidance of DNV-RP-F401 for steel armour wires.

The utilisation factors for installation for other components is based on the allowable utilisation factors set out in API 17E / ISO 13628-5 for subsea umbilicals. A utilisation factor of 1.00 is defined for load-controlled conditions, while a utilisation of 0.75 should be considered for displacement-controlled conditions to mitigate the increased risk of lateral buckling.

The utilisation factor for normal operation for other components is selected as is typical practice for normal operation for subsea umbilicals for combined loading (API 17E).

Table 5: Proposed utilisation factors

Lifecycle phase	Utilisation factor	
	Steel armour wires	Other components
Normal operation	0.67	0.80
Installation (incl. load out and transportation)	0.78	1.00 (load-controlled) 0.75 (displacement-controlled)
Abnormal operation	1.00	1.00

Normal operation as referenced in Table 5 is defined as operation within the Ultimate Limit State (ULS) as defined in DNV-RP-0360 [4]. Abnormal operation in this context is defined as operation outside of ULS but within Accidental Limit State (ALS) as defined in DNV-RP-0360. The definitions for ULS and ALS are as follows:

- Ultimate Limit State (ULS) - a condition which, if exceeded, compromises the integrity of the item. The typical return period for ULS loading is 50 years.
- Accidental Limit State (ALS) - a ULS condition due to accidental (infrequent) loads.

3.6. Range of approval

Where minor changes to the cable cross-section are made, it may be possible to quantify the mechanical limits of the new cable design by modelling, without the need for the full suite of physical testing.

In this instance, it is important to define what constitutes a minor change. In the context of MecLim II, a minor change is one that does not materially change the response of the cable with respect to a given mechanical parameter. Typically, this would include a change that:

- Satisfies the “Range of type approval” criteria in IEC 63026 [11],
- Does not alter the order of the most- to least-limiting components for the model in question,
- Does not involve changes to the materials used,
- Does not affect the interactions or contact pressures between components.

It is critical to have a good understanding of the models used and their sensitivities when adopting this approach.

4. Numerical modelling guidelines

4.1. General

Numerical models are commonly used in the cable design process by cable manufacturers, although the extent to which numerical models are used in the definition of mechanical properties varies by property and by cable manufacturer. Where numerical models are used, the level of model complexity can vary depending on the purpose the model serves, from simple "rule of thumb" models used to estimate the minimum bend radius (e.g. 15 × Cable OD) to complex 3D finite element models of a complete cable cross-section.

The recommendations of the MecLim II JIP in relation to numerical modelling for the purpose of aiding in the determination of the mechanical properties of cables are described in this section. These recommendations are intended to provide guidance on key variables, component interactions and uncertainties to aid in the improvement of numerical models and to assist with the model review process. These recommendations are general guidance and do not demand the use of any particular modelling technique or software package.

4.2. Flexural models

As there is much similarity between models that can be used for determination of mechanical properties involving bending, such as minimum bending radius, bending stiffness and side wall pressure limit, the guidance relating to these models has been grouped in this section.

Models are commonly used in arriving at mechanical properties involving bending. One of the simplest models used is a multiple of the cable outer diameter to estimate the minimum bending radius of a cable, typically 15 × OD. While this type of model may be a convenient "rule of thumb", it does not well-inform the mechanical performance of a particular cable. More complex numerical models are also commonly used by cable manufacturers in the cable design process to assist in establishing the mechanical properties of a cable cross-section design, including MBR.

At a high level, numerical models used in the determination of a suitable MBR, or for the characterisation of bending stiffness, typically allow for application of curvature and axial tension to the cable, while models used in the determination of sidewall pressure require the additional ability to include a reaction surface. There is benefit in defining the simulation method used (e.g. moment control, cantilever load application or four-point bending) when referring to results of numerical modelling.

Numerical modelling can be used to determine a limiting MBR for a cable by various methods, including assessing stress/strain utilisations in the cable's components. It is typical for a safety factor to be applied in determining allowable utilisations when this method is used, for example, based on the proposed safety factor philosophy.

It is noted by some members of the MecLim II JIP that the stress and strain utilisations in both the armour wires and cable cores can tend to be low when curvature equivalent to the MBR as derived from 15 × OD is applied to a cable model. This suggests that either, the limiting failure mechanism is neither stress nor strain in the armour wire package nor cable core, or that the safety factors allowed are high, possibly as a result of uncertainties in the cable design process.

The presence of bitumen in a cable cross-section is one area that brings a level of uncertainty to numerical models. This uncertainty lies largely in the ability to model the non-linear, viscoelastic properties of bitumen in a way that is representative of reality, including the effects of external factors such as temperature and rate of application of shear, as well as in inconsistency of properties between batches of bitumen. There is a sense within the cable industry that bitumen manufacturers lack an understanding of the impact that a change in bitumen properties can have on a cable, given that bitumen is typically produced for use in other applications where the same degree of precision may not be relevant.

Improvements in the area of bitumen modelling may reduce the level of uncertainty in flexural modelling of cables, increasing confidence in the results of such modelling, with the potential to allow for less onerous MBRs and more accurate bending stiffness characterisation. It is important that modelling techniques applied consider the thermal operating range of cables, from cold-weather installation to room temperature handling and warmer operating temperatures, with most focus on temperatures below approx. 20°C where the thermal-response of bitumen is most variable.

In addition to this, it is important that the bitumen properties used in modelling are reflective of the bitumen that will be applied to the cable. This may be achievable by stricter quality-control on bitumen, or through developments in bitumen material characterisation testing.

In addition to uncertainties relating to bitumen, there may be other areas of uncertainty, for example interaction between components, layer separation, manufacturing variations / tolerances.

Bending stiffness is a non-linear, hysteretic property, typically reported using a Moment-Curvature plot, such as that illustrated in Figure 3. There are two distinct phases for which bending stiffness must be defined; the pre-slip phase, where the cable components have yet to overcome friction, so the cable cross-section bends “as one” and the slipped phase, where friction has been overcome and the cable components are free to slip relative to one another. As a minimum, numerical models used in establishing the bending stiffness of a cable should allow for this slip/stick behaviour to be captured.

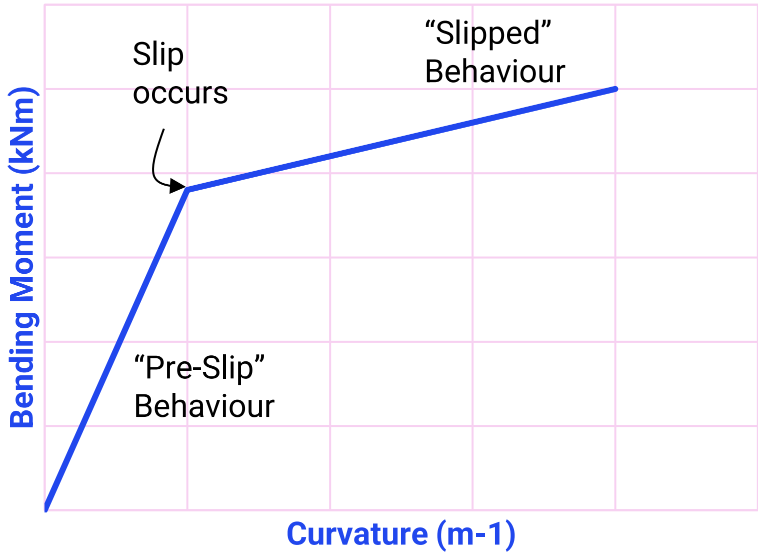

Figure 3: Generic M-κ Curve

Models used for simulation of bending (and/or tension) can benefit from inclusion of a longitudinal dimension, as well as the cable cross-section. This can allow for the radial and longitudinal response of the helically wound components within the cable under bending and/or tension to be captured.

It is common for numerical models to be calibrated to reflect test results. Such calibration can be successful in modelling the parameters for which the calibration is intended, however, care should be taken when modifying the model that the calibration is valid. It has been suggested to the JIP that calibration of numerical models to a global property that could be quantified during testing, such as bending stiffness, may be of benefit and more robust than reliance on visual inspection

4.3. Axial tension / compression models

Numerical models used for simulation of axial tension or compression can benefit from inclusion of a longitudinal dimension, for similar reasons to flexural models. In the case of compressive models, this also allows for simulation of phenomena such as armour wire lateral buckling and bird caging.

While tension is usually considered in combination with bending, a single compression limit is most commonly provided. It is noted that a test for compression with bending is provided in CIGRÉ TB 862, which may allow for provision of a combined compression and bending limit in the future. Similarly, modelling of combined compression and bending (in combination with an appropriate safety factor philosophy) could be used to help define the capacity of the cable in this respect. Improvements in this area have the potential to allow for better definition of suitable installation weather windows.

4.4. Radial compression / crush / impact models

Crush is a complex mechanism which involves interactions between all cable internal components. Numerical modelling of cable crush to a level where the model gives a good representation of reality requires highly complex models, which are expensive to develop and run. In practice, this is rarely done, given that a crush test can be performed to failure in a reasonably short time period.

Where numerical modelling is used for simulation of crush loading, these models typically include simplifications to the cross-section, for example fillers may not be modelled in detail, or tuning of cross-section stiffness to reflect results of testing may be incorporated.

It may be beneficial to incorporate temperature- and rate-dependencies of the cable response into models used for simulation of crush loading, where possible. For example, variance of the rate of application of stress during crush testing can have an impact on the response of the cable.

Project-specific impact modelling can be undertaken, for example to assess impact energies associated with a particular impact, however, numerical modelling is not routinely used for determination of impact strength of a cable. Reasons for this include the complexity of the models that would be required and the fact that it is considered more straight-forward, and likely less costly, to accommodate a conservative impact strength through the selected installation methodology, for example through modification of stone size.

No specific guidance is provided in the area of modelling of impact, at this time, although inclusion of temperature- and rate-dependencies in impact models, where possible, would be beneficial.

5. Proposed enhancements in existing cable tests

5.1. General

During the course of the MecLim II JIP, a number of enhancements to existing mechanical tests for subsea cables were proposed. These proposals are intended to add further definition to the existing tests, mainly described by CIGRÉ, in an effort to work towards a more standardised approach for definition of the selected mechanical properties. These proposed enhancements are summarised in *italics* in this section.

5.2. Minimum bend radius

Existing test(s): Tensile bending test (CIGRÉ TB 623), bending test without tension (CIGRÉ TB 623), testing for combined compression and bending (CIGRÉ TB 862)

Definition of MBR for cable lifecycle activities

The minimum bending radius of a cable is intrinsically linked to the tension applied to the cable while it undergoes curvature. The tensions and curvatures experienced by a cable vary significantly across the main phases of the cable lifecycle, for example high tensions and curvatures may be experienced during installation, while the tensions experienced during normal operation will be lower. In addition, the level of control over the tension and curvature experienced by a cable varies depending on the lifecycle phase, with a high degree of control over both of these parameters expected during manufacturing within the cable production facility, reducing once the cable leaves the factory and reducing further once the cable is being installed offshore, as illustrated in Figure 4. These variations in magnitude and degree of certainty over the loading applied indicate that definition of MBR for a variety of scenarios representative of the different activities experienced during the cable lifecycle could be beneficial.

Proposed activities for which specific MBR definition would be advantageous include:

- *Static / storage*
- *Installation (incl. repair) (with tension)*
- *Operation (exposed to dynamic environment)*
- *Installation / operation (low tension / compression)*

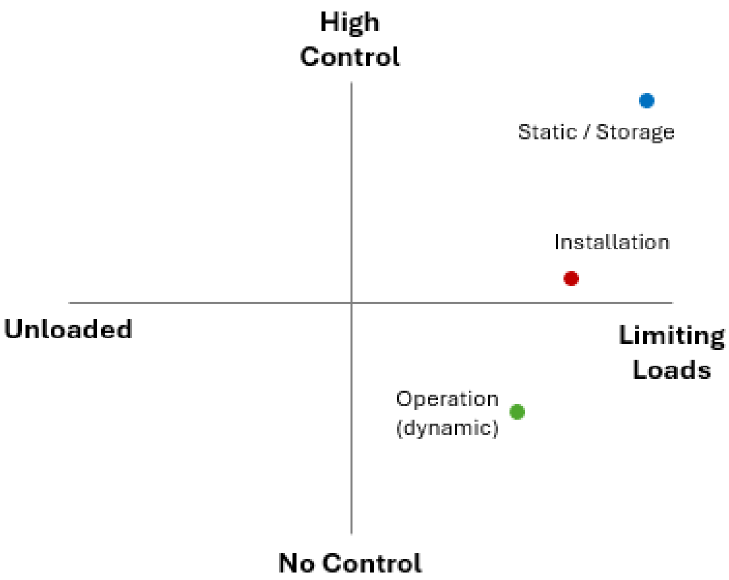

Figure 4: Relationship between load and degree of control for key cable lifecycle stages

The tensile bending test in CIGRÉ TB 623 considers the loads applied to a cable during standard installation or repair (under tension), while the bending test without tension considers the loads applied to a cable during handling or storage. The test for combined compression and bending in CIGRÉ TB 862 considers a scenario that could be experienced during installation or operation (this is also reflected in CIGRÉ TB 623 in relation to dynamic cables). No specific test considers operating conditions for static cables at present.

Proposed adaptation: The tensile bending test could be used to represent operating conditions by adapting the tension and curvature applied to be representative of the expected conditions the cable will experience in the region where it is exposed to the dynamic environment (this is typically the area where a Cable Protection System is applied). It is noted that operational conditions are not typically expected to be more onerous than installation conditions for a static cable, however, this test could be used to provide a more informed operating MBR.

Presentation of results

MBR is often provided on a cable datasheet as an individual value, or a number of individual values, representative of various activities. A capacity curve consisting of a plot of tension vs. allowable bending radius is also often provided; it is currently considered best practice to provide at least one capacity curve. A typical capacity curve is shown in Figure 5.

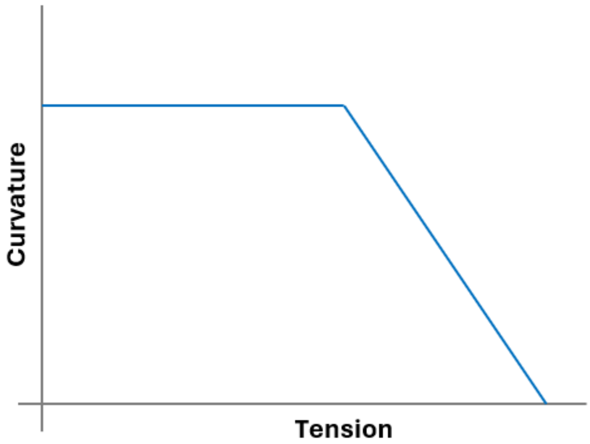

Figure 5: Capacity Curve – Tension vs. Allowable Bend Radius

The points from which a capacity curve is assembled are typically generated from the results of the tensile bending test and bending test without tension carried out as described by CIGRÉ. These test results, therefore, tend to be representative of loading associated with storage, installation and handling, rather than operation.

Proposed enhancement: To generate a capacity curve that is more relevant for operation, tensions and curvatures similar to those experienced by the cable during operation could be applied during further testing, as noted in the previous proposed adaptation.

It is noted that it is not possible to define a capacity curve for a cable by running a single tensile bending test in accordance with CIGRÉ TB 623. A basic capacity curve could be derived from two tensile bending test results and a bending without tension result. However, it is considered good practice to refine the capacity curve by including multiple tensile bending test results, performed at differing tensions and curvatures.

5.3. Accumulated low-cycle fatigue

Existing test(s): None. Adaptation of bending test without tension (CIGRÉ TB 623) proposed.

Proposed test adaptation

Low-cycle fatigue occurs when the cable is bent to a small radius which may plastically deform the components of the cable, resulting in accumulation of damage over repeated bending occurrences. At present there is not a specific test performed with the intention of establishing the limit of the cable with respect to accumulation of low-cycle fatigue; however, the bending test without tension described in CIGRÉ TB 623 states that the number of bending repetitions performed in the course of testing should be reflective of the expected conditions during cable handling.

Proposed Adaptation: An extension of this test could be considered to allow for definition of the number of bending cycles a cable can withstand at a particular bend radius, whereby the cable is bent repeatedly until failure occurs (which may require testing of multiple samples). It is noted that the result of this test is of most use to the cable owner when the number of small radius bending cycles that the cable has experienced prior to delivery is known.

Complementary numerical method

DNV-RP-C208 includes details of a numerical methodolgy for determining the number of cycles to failure for both welds/joints and base material based on the fully reversible maximum principal strain range. Given that application of strain gauges to components within a cable test piece would be impractical, determination of the maximum principal strain range could be achieved via finite element modelling and strain-based S-N curves used to identify the number of cycles to failure.

Proposed enhancement: Use of numerical methods as described in DNV-RP-C208 to complement physical specimen testing for low-cycle fatigue.

5.4. Bending stiffness

Existing test(s): Bending stiffness test (CIGRÉ TB 862)

Type of bend test

Bending stiffness characterisation tests are frequently performed for subsea cables, although there is no single standardised bend test described in the existing standards for static cables. Cable purchasers often specify their requirements in terms of the type of bend test to be performed and requirements for variation of test conditions, for example temperature, level and rate of deflection and frequency of bending. There is potential that industry-standardization of bend test requirements could lead to development of a more streamlined test plan.

The 4-point bend test described in CIGRÉ TB 862 is an example of a suitable test; other tests are also permitted, including 3-point bend tests or bend tests based on the moment method (described in CIGRÉ TB 669 [2]). The tests most commonly performed for the characterisation of cable bending stiffness are 3-point bend and 4-point bend tests. The 4-point bend test is considered to be the preferred test method for inter-array cables, as it avoids the localised curvature that can occur at the support locations when a small, low stiffness cable is bent using a 3-point bend test rig.

Proposal for improved standardisation: Adoption of 4-point bend test as industry-standard bend test.

The 4-point bend test described in CIGRÉ TB 862, with test set-up shown in Figure 6, requires a sample of the complete cable, which measures at least one pitch length of the outermost armour layer in length and must be long enough to accommodate the full range of curvatures to be tested. The supports must allow for free rotation of the cable in the plane of bending and the cable must be permitted to slide axially over the inner supports as it bends. The test should be performed until a stable hysteretic response is achieved. The results of this test are typically presented in the form of plot of bending moment versus curvature, the slope of which represents the bending stiffness. As noted in Section 4.2 above, the bending stiffness for the pre-slip and slipped condition should be identified.

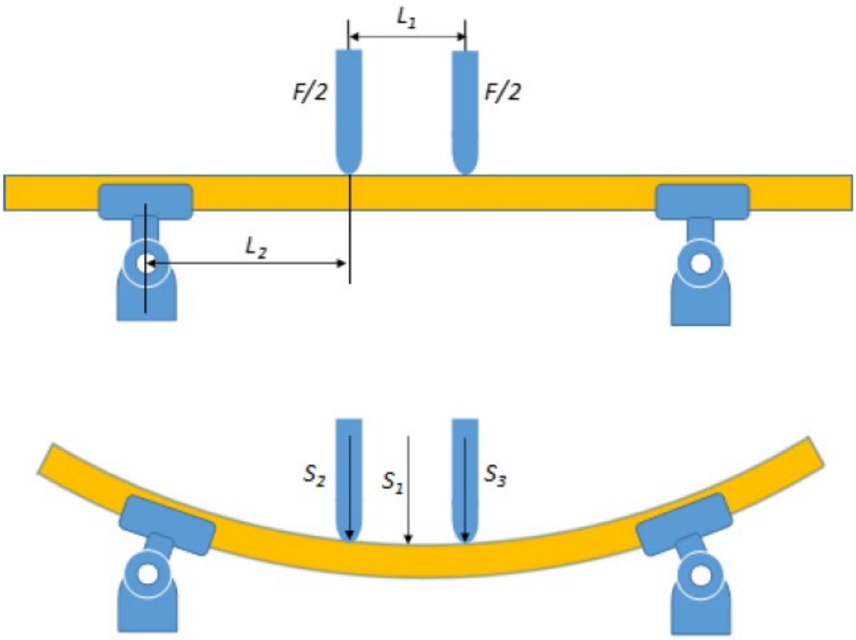

Figure 6: Four-point bend test setup, CIGRÉ TB 862 [3]

Enhanced test parameter definition

The 4-point bend test description provide in CIGRÉ TB 862 proposes variation of the cable temperature by heating or cooling the cable.

Proposed enhancement: Testing at cable temperatures reflective of the temperatures expected during the cable lifecycle would make the bend test results more relevant, e.g. cooler temperatures representative of cable installation in cold weather, warm temperatures representative of cable handling in warm weather and operational temperature test (although it is noted that a bend test at operational temperature may be beyond the capabilities of many testing facilities at present).

The test description in TB 862 also alludes to investigation of the influence of bending rate by repeating the test at differing displacement rates.

Proposed enhancement: Use of a displacement rate that reflects the rate of motion the cable will be subjected to during its lifecycle would improve the relevance of the bend test results, e.g. testing at cable lay rate and rate of oscillation of CPS / cable exposed to dynamic environment during operation.

The curvature achieved in a 4-point bend test is controlled by varying the displacement of the supports. No guidance is provided in CIGRÉ TB 862 on the range of curvatures that should be considered.

Proposed enhancement: The bend test should ideally be performed for curvatures up to and including the Minimum Bend Radius of the cable.

5.5. Sidewall pressure limit

Existing test(s): Tensile bending test (CIGRÉ TB 623), sidewall force test (CIGRÉ TB 623)

Enhanced Test Parameter Definition

Sidewall pressure limit is currently confirmed via the tensile bending test, or sidewall force in CIGRÉ TB 623. The test descriptions provided includes stipulation that the contact surfaces used should reflect the relevant equipment installed on the installation vessel and use of the maximum tension expected to be used during cable lay or recovery operations. Neither the rate of winding nor cable temperature are specified.

Proposed enhancement: Alignment of the rate of winding with the expected handling / lay rate would provide for a more relevant test result.

Proposed enhancement: Performing the tests at a temperature reflective of installation conditions expected would increase the relevance of the results obtained.

5.6. Tension limit

Existing test(s): Tensile test (CIGRÉ TB 623), tensile characterisation test (CIGRÉ TB 623)

Enhanced Test Parameter Definition

The tensile test described in CIGRÉ TB 623 is used for testing of joints, or for testing of cable to tensions planned where higher tensions will be applied than those tested in the tensile bending test, but the cable will not be subjected to bending, e.g. pull-in operations. The minimum length of cable to be tested is defined, as are the end conditions required (one cable head to be free-rotating, the other to be fixed). The tension is to be increased "gradually". The impact of temperature on results is not mentioned.

Proposed enhancement: The test results would be more representative of reality if the tests were performed at a temperature reflective of installation conditions expected and using a rate of tensioning (or range of tensioning rates) reflective of the operation during which the cable will undergo such a tension.

Test adaptation

The tensile characterisation test in CIGRÉ TB 623 can be performed during the tensile test and is used to establish the axial stiffness of the cable, and to assess the torsional balance (where applicable) and rotational characteristics of a cable.

Proposed adaptation: This test could be adapted to facilitate testing of the rotational stability of bundled cables that will be subjected to e.g. a bundled pull-in. The pull-heads used for such a test should reflect the arrangement used in the operation the bundle will undergo.

5.7. Compression limit

Existing test(s): Compression test (CIGRÉ TB 862)

Increased adoption

An overly conservative compression limit (e.g. 0 kN, as has often been used historically) can be limiting for cable installation weather windows. Definition of an acceptable compression limit can be achieved through the use of compression tests. The existing compression test in CIGRÉ TB 862 includes outline methodologies for tests for axial compression and combined compression and bending. It is noted that the compression test described in CIGRÉ TB 862 may be considered conservative in relation to cable touch-down point compression during installation as it is performed with constant compressive force, which may be more likely to lead to armour wire buckling than the short duration negative tensions typically seen in this area during cable installation.

Proposal for improved standardisation: Adoption of the compression tests in CIGRÉ TB 862 as the standard compression tests for axial compression and compression with bending for inter-array cables for bottom-fixed offshore wind.

Enhanced test parameter definition

The test parameters are well-defined, including length of test sample, loading magnitude and number of cycles reflective of operational loads, end conditions and load application method. No consideration of the effects of temperature is specified.

Proposed enhancement: The relevancy of the test results could be improved by performing the test at a temperature reflective of installation conditions expected.

Proposed enhancement: Alignment of the rate of application of compressive loading with the expected handling rate, or to be reflective of potential sudden compressive loading at the touchdown point due to vessel heave / pitch, would benefit the relevance of the test results.

5.8. Crush load limit

Existing test(s): Crush test (CIGRÉ TB 623), crush test for long term stacking (CIGRÉ TB 623), clamp squeeze test (CIGRÉ TB 862), clamp slippage test (CIGRÉ TB 862)

The existing crush tests require loading reflective of the nature of the maximum crush loads expected to be experienced by the cable. The clamp slippage test described in CIGRÉ TB 862 includes application of the maximum expected installation tension to a cable test piece held in a clamp reflective of the installation clamps to verify that the cable will not slip during installation; while this test is described for dynamic cables in CIGRÉ TB 862, it is also relevant to static cables. No specific proposals are made with respect to the crush testing described in the existing literature.

5.9. Impact strength

Existing test(s): Impact test (CIGRÉ TB 623)

The primary usage of impact strength, or impact energy limit during a cable's lifecycle is during installation, where the cable may be subjected to rock placement or protection via concrete mattressing. Impact energy limit is currently defined using the impact test described in CIGRÉ TB 623. While this test recommends use of a hammer shaped to reflect the expected impacting object, selection of appropriate impactor, strike rate and boundary conditions can be specified by the cable purchaser or left to the discretion of the party/parties involved in defining the test. This lack of standardisation naturally results in variations of the methods applied, which can lead to variances in the interpretation of results.

Enhanced test parameter definition

The impact test description in CIGRÉ TB 623 recommends use of a surface representative of actual soil conditions but does acknowledge that a rigid support will provide more conservative results and therefore be applicable for all seabed types. Use of a rigid seabed to ensure conservatism aligns with best practice reported by a number of cable manufacturers.

Proposed enhancement: Adoption of rigid support as base case boundary condition for impact tests. This would also de-couple the results from a particular project, allowing for re-use of results on other projects.

The approach taken in CIGRÉ TB 623, whereby the impactor definition is left open to interpretation, is inconsistent with impact tests carried out in other industries. For example, the impact capacity testing procedure specified for subsea flexible risers in DNV-ST-F201 [5] and defined in DNV-RP-F107 [6] provides recommended impactor weights and shapes including an edge radius of 7 mm and test mass of 1 tonne; a recommended reduction factor of 0.9 × the observed impact capacity is also provided in DNV-RP-F107 for flexible pipe and umbilicals.

Proposed enhancement: An impact test profile, similar to that described in DNV-RP-F107, should be developed for use with inter-array cables for offshore wind. Based on discussions at the MecLim II workshops and feedback from the JIP membership, it is proposed that a generalised version of the guidance in DNV-RP-F107 may be a suitable profile to use within the methodology described in CIGRÉ TB 623; the maximum edge radius and minimum impact energy proposed are presented in Table 6 .

Table 6: Impact testing – Proposed enhancement of definition.

Maximum Edge radius	Test mass	Drop height	Minimum Impact energy
10 mm	*m* kg	*h* m	200 J (see Figure 7)

The impact energy in the test can be calculated as a function of drop height and hammer mass according to:

$$E = m \cdot g \cdot \Delta h$$

where:
E – impact energy [J]
m – mass of hammer [kg]
g – gravitational constant [m/s^2]
h – drop height [m].

Figure 7. Calculation of impact energy. Extracted from CIGRÉ TB 623 Section 6.3.3

Presentation of impact capacity result

The calculation of impact energy for composite constructions such as power cables, flexible risers and umbilicals is an area where uncertainty exists. It is noted that the calculation of impact energy in CIGRÉ TB 623 is based on the potential energy of the impactor and is agnostic of the impactor shape. As described in Figure 7, the impact energy imparted by a 1-ton flat plate impactor would be the same as for a 1-ton conical impactor dropped from the same height. This is inconsistent with standardised impact tests used in material science. These tests, for example the Charpy V-Notch test prescribed for pipelines in ASME B31.8 [14], require use of a particular impactor and specific sample preparations to ensure correct interpretation of the results, which have built-in consideration for the specific impactor shape used. This approach works well with uniform materials but would not be practical for testing of a subsea power cable cross-section. DNV-RP-F107 provides an equation for calculation of impact energy for steel pipelines based on the dent geometry caused by a knife edge indenter, which again, could not be practically applied to subsea power cables; no equation is provided for flexible risers or umbilicals. The impact test methodology described in CIGRÉ TB 623 includes visual inspection and test of the Fibre Optic Unit to ensure no meaningful damage is incurred by the cable; the shape of the impactor will have an effect on this evaluation, but without an understanding of the impactor used, it is not possible to correctly interpret the "impact capacity" result.

Proposed enhancement: In the absence of a standardised impactor shape, a description of the impactor used in determination of impact capacity must be provided to allow for more informed interpretation of the limit.

Visual inspection requirements

Visual inspection of the cable interior is required as part of the impact test described in CIGRÉ TB 623. The criteria to be checked include, but are not limited to:

- Breakage, crossing or permanent bird caging of armour wires
- Harmful indentations in the cable core(s); for example, resulting in indentations or cracks in lead sheath, sharp indentations of the semi-conductive screen into the insulation.
- For paper cables: breaks in the reinforcing tapes, tears in the insulating papers or harmful creasing in insulation papers.
- For polymeric cables: cracking or damages to the insulation
- Damages to conductor which could have a detrimental effect on the cable performance.

Proposed enhancement: Addition of check for any indentations in the fibre optic casing.

Electrical testing

The impact test described in CIGRÉ TB 623 requires visual inspection and a test of the fibre optic unit to be completed following the impact test. No electrical testing is required by this test at present.

Proposed enhancement: Addition of electrical routine test to follow impact testing.

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