Subsea Power Cables in Shallow Water Renewable Energy Applications

FEBRUARY 2014

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FOREWORD

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DNV service documents consist of among others the following types of documents:

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The Standards and Recommended Practices are offered within the following areas:

A) Qualification, Quality and Safety Methodology
B) Materials Technology
C) Structures
D) Systems
E) Special Facilities
F) Pipelines and Risers
G) Asset Operation
H) Marine Operations
J) Cleaner Energy
O) Subsea Systems
U) Unconventional Oil & Gas

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CHANGES – CURRENT

General

This is a new document.

Det Norske Veritas AS, company registration number 945 748 931, has on 27th November 2013 changed its name to DNV GL AS. For further information, see www.dnvgl.com. Any reference in this document to “Det Norske Veritas AS” or “DNV” shall therefore also be a reference to “DNV GL AS”.

Acknowledgement

This recommended practice was developed by a Joint Industry Project (JIP). The work was performed by DNV and discussed in regular project meetings and workshops with individuals from the participating companies. They are hereby acknowledged for their valuable and constructive input. In case consensus has not been achievable, DNV has sought to provide acceptable compromise.

Sponsors of the JIP included the following organisations:

- Bohlen & Doyen
- DONG Energy
- Iberdrola S.A.
- JDR Cable Systems
- Offshore Marine Management
- Tekmar Energy
- Van Oord Offshore Wind Projects B.V.
- Boskalis Offshore
- Electrabel GDF SUEZ
- Inch Cape (Repsol, EDPR)
- Norddeutsche Seekabelwerke
- Siem Offshore Contractors
- Tideway Offshore Solutions
- Visser & Smit Marine Contracting

Further organisations have participated in the review process. DNV is grateful for the valuable co-operations and discussions with individuals in these organisations.
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1 General

1.1 General

1.1.1 Introduction

This recommended practice provides guidance for all phases of the life cycle of subsea power cable projects, with a focus on static service in shallow water renewable energy applications.

1.1.2 Objectives

The objectives of this recommended practice are to:

— ensure that the various phases of subsea power cable systems, i.e. concept development, design, manufacturing, testing, storage, load-out, transport, installation, commissioning, operation, maintenance and decommissioning, are conducted with due regard for health and safety, the protection of the environment and quality

— promote a risk based approach whereby risks are reduced to acceptable levels

— provide internationally applicable guidance by defining minimum requirements which constitute industry ‘best practice’

— serve as a reference document between stakeholders such as developers, designers, manufacturers, purchasers, installers, owners, operators, certifiers, investors and insurers.

Guidance note:

Locally applicable regulations should be consulted to ensure that all requirements, which can be in excess of the guidance provided in this recommended practice, are being met.

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1.1.3 Scope and application

The scope and applicability of this recommended practice are detailed in Table 1-1.

<table>
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<th>Table 1-1 Scope and application summary</th>
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<td><strong>General</strong></td>
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<td><strong>Installation</strong></td>
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1) Design details of electrical cores are not covered in this document. Reference is made to international standards, see [4.4] and [5.2].

2) Basic aspects of optical fibres used in / with power cables are covered, see [4.4] and [5.2].

3) General guidance provided applies. Detailed requirements are expected to be developed in the future.

4) Reference is made to European practice and standards generally applicable in Europe.

5) Additional considerations may e.g. be related to cable survey corridor width or cable handling equipment.
Where the subsea cable system extends onshore, the part covered by this recommended practice ends at the transition joint bay or at an onshore terminal (Figure 1-1).

**Figure 1-1**
Applicable areas of this recommended practice

This recommended practice does not cover land cables, i.e. cables starting and ending onshore and not having any subsea parts. It may be applied to crossings of rivers or fresh water lakes, except where onshore codes take precedence due to legislation.

**Guidance note:**
Land cables are normally governed by national regulations which cover a wide range of topics including public safety, traffic and roads, water ways, environmental impact, etc. Requirements in these regulations may be stricter than those given in this recommended practice for the onshore section of an export cable.

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### 1.1.4 Alternative methods and procedures

Methods and procedures alternative to those described in this recommended practice may be used, provided that they meet the overall objectives and are suitable for the application.

### 1.1.5 Structure of the recommended practice

The recommended practice is organised as follows:

- **Sec.1** contains the objectives and scope of the recommend practice. It further provides definitions and abbreviations.
- **Sec.2** contains the fundamental design philosophy and design principles.
- **Sec.3** contains guidance for conceptual design of the overall cable system, cable route studies and cable route surveys.
- **Sec.4** contains guidance for design premises, cable specifications and detailed design information for the cable route, cable protection, the cable interface at fixed offshore units, and the landfall.
- **Sec.5** contains guidance for the manufacture of components, testing, storage, load-out and transport.
- **Sec.6** contains guidance for all installation activities including preparation, cable laying, cable pull-in, landfall works, cable protection, surveys and commissioning.
- **Sec.7** contains guidance for the operation of cables including monitoring, surveys, remedial work and repair.
- **Sec.8** contains guidance for decommissioning of a cable system.
- **Sec.9** contains guidance for documentation, covering all phases of the cable project.
- **App.A** contains a generic list of hazards applicable to cable projects.
- **App.B** provides a template for cable specification discussions.

Guidance notes provide additional information, clarification or examples to a paragraph in order to increase the understanding of the requirement. Guidance notes are not binding.

### 1.2 References

#### 1.2.1 Applicability

The following documents include provisions which, through specific reference in the text, constitute provisions of this recommended practice.

References are either defined as normative or informative. Normative references in this recommended practice are essential for its application. Informative references provide additional information intended to assist the understanding or use of the document.

In case of conflict between requirements of this recommended practice and a referenced DNV code, the requirements of the code with the latest revision date shall prevail.
Guidance note:
DNV code means any DNV Offshore Service Specification, DNV Offshore Standard, DNV Recommended Practice, DNV Guideline or DNV Classification Note.
Any conflict is intended to be removed in the next revision of the document concerned.
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Where reference is made to documents other than DNV codes, the valid revision should be taken as the revision which was current at the date of issue of this recommended practice.

1.2.2 Standards - Normative

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 60183</td>
<td>Guide to the selection of high-voltage cables</td>
</tr>
<tr>
<td>IEC 60502</td>
<td>Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV)</td>
</tr>
<tr>
<td>IEC 60840</td>
<td>Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) - Test methods and requirements</td>
</tr>
<tr>
<td>IEC 62067</td>
<td>Power cables with extruded insulation and their accessories for rated voltages above 150 kV (Um = 170 kV) up to 500 kV (Um = 550 kV) - Test methods and requirements</td>
</tr>
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1.2.3 Standards - Informative

<table>
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<tr>
<td>DNV-OS-E301</td>
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<td>DNV-OS-F101</td>
<td>Submarine pipeline systems</td>
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<td>DNV-OS-H101</td>
<td>Marine operations, general</td>
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<td>DNV-OS-H203</td>
<td>Transit and positioning of mobile offshore units</td>
</tr>
<tr>
<td>EN 13383-1</td>
<td>Armourstone - Part 1: Specification</td>
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<td>IEC 60071-1</td>
<td>Insulation co-ordination - Part 1: Definitions, principles and rules</td>
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<tr>
<td>IEC 60228</td>
<td>Conductors of insulated cables</td>
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<td>IEC 60287-1-1</td>
<td>Electric cables - Calculation of the current rating - Part 1-1: Current rating equations (100% load factor) and calculation of losses - General</td>
</tr>
<tr>
<td>IEC 60287-2-1</td>
<td>Electric cables - Calculation of the current rating - Part 2-1: Thermal resistance - Calculation of thermal resistance</td>
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<tr>
<td>IEC 60287-3-2</td>
<td>Electric cables - Calculation of the current rating - Part 3-2: Sections on operating conditions - Economic optimization of power cable size</td>
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<td>IEC 60300-1</td>
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<tr>
<td>IEC 60793</td>
<td>Optical fibres</td>
</tr>
<tr>
<td>IEC 60794</td>
<td>Optical fibre cables</td>
</tr>
<tr>
<td>IEC 60853-1</td>
<td>Calculation of the cyclic and emergency current rating of cables - Part 1: Cyclic rating factor for cables up to and including 18/30 (36) kV</td>
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<tr>
<td>IEC 60853-2</td>
<td>Calculation of the cyclic and emergency current rating of cables - Part 2: Cyclic rating of cables greater than 18/30 (36) kV and emergency ratings for cables of all voltages</td>
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<tr>
<td>IEC 60949</td>
<td>Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects</td>
</tr>
<tr>
<td>IEC 61400-3</td>
<td>Wind turbines - Part 3: Design requirements for offshore wind turbines</td>
</tr>
<tr>
<td>IEC 61443</td>
<td>Short-circuit temperature limits of electric cables with rated voltages above 30 kV (Um = 36 kV)</td>
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<tr>
<td>ISO 9001</td>
<td>Quality management systems - Requirements</td>
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<tr>
<td>ISO 13623</td>
<td>Petroleum and natural gas industries - Pipeline transportation systems</td>
</tr>
<tr>
<td>ISO 13628-2</td>
<td>Petroleum and natural gas industries - Design and operation of subsea production systems - Part 2: Unbonded flexible pipe systems for subsea and marine applications</td>
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<tr>
<td>ISO 13628-5</td>
<td>Petroleum and natural gas industries - Design and operation of subsea production systems - Part 5: Subsea umbilicals</td>
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<tr>
<td>ISO 14688-1</td>
<td>Geotechnical investigation and testing - Identification and classification of soil - Part 1: Identification and description</td>
</tr>
<tr>
<td>ISO 14688-2</td>
<td>Geotechnical investigation and testing - Identification and classification of soil - Part 2: Principles for a classification</td>
</tr>
</tbody>
</table>
1.2.4 Guidelines - Informative

ISO 19901-6  Petroleum and natural gas industries - Specific requirements for offshore structures - Part 6: Marine operations
ISO 22475-1  Geotechnical investigation and testing - Sampling methods and groundwater measurements - Part 1: Technical principles for execution
ISO 31000  Risk management - Principles and guidelines
ISO 31010  Risk management - Risk assessment techniques
ISO 55000  Asset management - Overview, principles and terminology
ITU-T G.976  Test methods applicable to optical fibre submarine cable systems
NORSOK G-001  Marine soil investigations
NORSOK N-004  Design of steel structures

BSH 7004  Baugrunderkundung für Offshore-Energieparks (Ground investigation for offshore wind farms)
BSH 7005  Konstruktive Ausführung von Offshore-Windenergieanlagen (Design of offshore wind turbines)
CIGRÉ Technical Brochure 177  Accessories for HV cables with extruded insulation
CIGRÉ Technical Brochure 194  Construction, laying and installation techniques for extruded and self contained fluid filled cable systems
CIGRÉ Technical Brochure 303  Revision of qualification procedures for HV and EHV AC extruded underground cable systems
CIGRÉ Technical Brochure 379  Update of service experience of HV underground and submarine cable systems
CIGRÉ Technical Brochure 398  Third-party damage to underground and submarine cables
CIGRÉ Technical Brochure 415  Test procedures for HV transition joints for rated voltages 30 kV (Um = 36 kV) up to 500 kV (Um = 550 kV)
CIGRÉ Technical Brochure 476  Cable accessory workmanship on extruded high voltage cables
CIGRÉ Technical Brochure 483  Guidelines for the design and construction of AC offshore substations for wind power plants
CIGRÉ Technical Brochure 490  Recommendations for testing of long AC submarine cables with extruded insulation for system voltage above 30 (36) to 500 (550) kV
CIGRÉ Technical Brochure 496  Recommendations for testing DC extruded cable systems for power transmission at a rated voltage up to 500 kV
CIGRÉ Technical Brochure 560  Guideline to maintaining the integrity of XLPE cable accessories
CIGRÉ Electra 171  Recommendations for mechanical tests on sub-marine cables
CIGRÉ Electra 189  Recommendations for tests of power transmission DC cables for a rated voltage up to 800 kV
CIRIA Guideline C683  The rock manual - The use of rock in hydraulic engineering
CIRIA Guideline C685  Beach management manual
DNV-RP-C205  Environmental conditions and environmental loads
DNV-RP-C207  Statistical representation of soil data
DNV-RP-F105  Free spanning pipelines
DNV-RP-F107  Risk assessment of pipeline protection
DNV-RP-F401  Electrical power cables in subsea applications
DNV-RP-H101  Risk management in marine and subsea operations
DNV-RP-H102  Marine operations during removal of offshore installations
ICPC Recommendation 1  Recovery of out-of-service cables
ICPC Recommendation 2  Cable Routing and Reporting Criteria
ICPC Recommendation 3  Telecommunications Cable and Oil Pipeline / Power Cables Crossing Criteria
ICPC Recommendation 6  Recommended actions for effective cable protection (post installation)
ICPC Recommendation 9  Minimum technical requirements for a desktop study (also known as cable route study)
ICPC Recommendation 11 Standardization of electronic formatting of route position lists
ICPC Recommendation 13 Proximity of wind farm developments & submarine cables
IHO S-44 Standards for hydrographic surveys
IMCA D 014 International code of practice for offshore diving
IMCA D 042 (R 016) Diver and ROV based concrete mattress handling, deployment, installation, repositioning and decommissioning
IMCA M 125 Safety interface documents for a DP vessel working near an offshore platform
IMCA M 140 Specification of DP capacity plots
IMCA M 190 Developing and conducting annual DP trials programmes for DP vessels
IMO MSC/Circ.645 Guidelines for vessels with dynamic positioning systems
IMO Res. A.1047 (27) Principles of minimum safe manning
Subsea Cables UK Guideline 6 The proximity of offshore renewable energy installations & submarine cable infrastructure in UK waters
Subsea Cables UK Guideline 8 Submarine cable decommissioning

1.2.5 Other references - Informative
Offshore Site Investigation and Geotechnics Committee (OSIG) (2014). Guidance notes for the planning and execution of geophysical and geotechnical ground investigations for offshore renewable energy developments.

1.3 Definitions

1.3.1 Verbal forms

**Shall** Verbal form used to indicate requirements strictly to be followed in order to conform to the document.

**Should** Verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required.

**May** Verbal form used to indicate a course of action permissible within the limits of the document.

**Agreement, or by Agreement** Unless otherwise indicated, agreed in writing between contracting parties.

1.3.2 Definitions

**Abandonment** Activities associated with interrupting installation of a cable and releasing it from the cable installation vessel. Later, installation activities continue with recovery of the cable.

**Alter course (A/C)** Point on the cable route where the cable course changes bearing.

**Armour (cable)** One or more cable covering(s) made of typically metal tape(s) or wire(s) providing tensile strength and protecting the cable from external mechanical forces, see [4.4.1.6]. Also referred to as ‘strength member(s)’.

**Armour layer (rock placement)** Outer layer of rock berm providing protection against hydrodynamic loading (waves, currents) or aggression, made of larger material. See Figure 1-2.
**Arrour unit**  Large quarried stone or specially shaped concrete block used in protective armour layers.

**Array cable**  Subsea power cable connecting an offshore electricity generator with other offshore generators or an offshore substation within a project (e.g. an offshore wind farm).

**As-built survey**  Survey of the installed cable system which is performed to verify the completed installation work.

**Beaching**  Deliberate and controlled grounding of a vessel in a safe working area for cable installation purposes. Used in very shallow water with sufficient tidal range to re-float.

**Bedform**  Depositional feature of the seabed, formed by the movement of sediments due to tidal or wave action. Frequently distinguished into:
- ripples - small-scale bedforms with asymmetrical linguoid forms (produced by tidal currents) or straight crested symmetrical or asymmetrical forms (produced by waves)
- megaripples - intermediate-scale bedforms, formed by waves
- sand waves - large-scale bedforms, divisible into rippled and megarippled ridges, formed by (tidal) currents.

**Guidance note 1:**
Typically, ripples have heights of less than 0.1 m and wavelengths of less than 0.6 m; megaripples have heights of up to 1 m and wavelengths of up to 30 m; sand waves have heights exceeding 1 m and wavelengths from 30 m to 500 m.

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**Bellmouth**  Bell shaped opening which provides guidance for a cable, e.g. used at seabed end of J- or I-tubes. See [4.7.4.1] and [4.7.4.2].

**Bend restrictor**  Device for limiting the bend radius of a cable to a specific value by mechanical means. Included in the wider group of ‘bend limiters’. See [4.7.4.5].

**Bend stiffener**  Device which locally increases bending stiffness, reducing bending curvature and stresses of the cable. Also referred to as ‘bend strain reliever’. See [4.7.4.4].

**Benthos**  Collection of flora and fauna living on the sea floor or in the top sediments of the seabed.

**Berm**  A (a) horizontal step or plateau in an embankment or breakwater or (b) nearly horizontal area / small mound at an offshore structure supporting or keying-in an armour layer. Definition may also include the side slope(s), see Figure 1-2.

**Bight**  An S-shaped, U-shaped or Ω - shaped section of cable. Often used for a section of cable laid on the seabed during installation or hauled on board during a repair. See Figure 1-3.

**Bird caging**  Detrimental effect on cable armour due to manufacturing problems or mechanical loads outside the design parameters of the cable, opening up the armour wires.
**Bollard pull**  
Continuous static towing force applied by a vessel, e.g. continuous tow line force. A measure of a vessel’s ability to tow.

**Bundle**  
A collection of cables fastened together, e.g. two or more AC, DC or fibre optic cables.

**Burial**  
Lowering of a cable into the ground (e.g. seabed) and providing a protective cover of soil. See also Figure 1-6.

**Burial assessment study**  
Cable protection study, based on hazards to the cable (fishing, shipping, dropped objects) and site conditions (soil properties, sediment mobility), to determine burial depth and suitable tools for a section of cable which meet the risk acceptance criteria.

**Guidance note 2:**
A ‘tool capability assessment’ can determine the likely performance including achievable burial depth.

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**Burial protection index (BPI)**
Qualitative level of protection of a buried cable, relating burial depth to the strength of the seabed, considering potential external aggression, see Allan (1998).

**Cable**
A cable is an assembly consisting of one or more power cores with individual or common screen and sheath, assembly fillings and covered by a common protection (see Figure 1-4). May include packages of optical fibres.

---Figure 1-4---
Typical 3-phase AC power cable cross-section

**Cable awareness chart**
Customised chart communicating cable route and additional information (e.g. buffer zone) to specific user groups. Distinct from government produced nautical charts.

**Cable basket**
Circular storage facility for cables with side walls. See Figure 1-5 d.

**Cable drum**
Cylinder (the ‘barrel’), normally with horizontal axis, with two flanges onto which a cable is wound during manufacture, for storage, transport and onshore or offshore installation. May be powered or unpowered, made of wood or steel. Also referred to as ‘cable reel’. See Figure 1-5 a.
**Cable engine**

Collective term for machinery used to move cables. Includes, for instance, the following:

- **a)** Linear cable engine, with wheel pairs: Pairs of motor-driven wheels gripping a cable for pay-out or recovery. Holding force depends on the number of wheel pairs, the squeeze force acting on the cable and the friction between wheels and cable surface.

- **b)** Linear cable engine, with tracks: Arrangement of e.g. two or four belts / tracks gripping a cable for pay-out or recovery. Holding force depends on track length, pad shape, the squeeze force acting on the cable and the friction between pads and cable surface. Also referred to as ‘tensioner’ or ‘caterpillar’.

- **c)** Drum cable engine: A drum-shaped device for pay-out or recovery of a cable, used especially when large holding power is required. Fitted with a ‘fleeting’ mechanism to control the position of the cable on the drum. Commonly used in conjunction with a draw off / hold back cable engine.

- **d)** Draw off / hold back cable engine: Linear cable engine used in conjunction with drum cable engines.

- **e)** Transporter: Small cable engine with typically one or two wheel pairs for moving cable.

**Figure 1-5**

Cable storage options. (a) drum or reel, (b) coiling pad or cage, (c) tank, (d) basket, (e) turntable - horizontal layers, (f) turntable - vertical layers

**Cable highway**

Structure to support and transport cable on rollers or by sliding, e.g. used in factories, in cable storage areas or on vessels between storage and deployment equipment.

**Cable laying barge (CLB)**

Purpose-built or modified barge with specific equipment for cable installation and repair. Self-propelled or un-propelled, commonly with anchor positioning.

**Cable laying vessel (CLV)**

Purpose-built or modified vessel with specific equipment for cable installation and repair. Self-propelled with anchor or dynamic positioning.

**Cable protection**

Any means protecting a cable from external mechanical forces.
Cable protection system: Collective term for protective tubular elements which can be fitted onto a cable for mechanical protection to ensure that the cable can operate for its service life.

Cable reel: see ‘cable drum’

Cable route: Path of a cable, onshore and offshore, planned or installed.

Cable route study: Process of reviewing available information and identifying a safe, technically and economically viable cable route.

Guidance note 3: In this recommended practice, no distinction is made between a ‘cable route study’ and a ‘desktop study’.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Cable system: A subsea power cable system may consist of cable(s), termination(s) and joint(s).

Guidance note 4: Above definition applies specifically for testing of power cables. In a wider definition the cable system may also include components like hang-off, cable protection measures and optical fibres.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Cable tank: A static, circular storage area (on vessel, on land), where cable is coiled. See Figure 1-5 c.

Cable tension: Axial force on a cable. Inter-dependent with cable bending.

Carousel: see ‘turntable’

Catenary: A curve assumed by a cable suspended between two points (e.g. vessel and seabed).

Characteristic value: A nominal value characterising the magnitude of a stochastic variable, normally defined as a fractile of its probability distribution.

Chart datum: Water level to which water depths and tidal variations are referred to on charts. Frequently the lowest astronomical tide (LAT).

Chute: A curved channel for passing a cable from a higher to a lower level, e.g. overboard a vessel, which does not compromise the mechanical parameters of the cable.

Coastal defence: Collective term for protection of the coast against erosion (coastal protection) and flooding (sea defence).

Coiling: Simultaneous twisting and bending of a cable, one full twist per turn.

Guidance note 5: If the design of the cable allows and the manufacturer confirms that a cable can be coiled, it is often referred to as “coilable”. Otherwise, it is referred to as “non-coilable”.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Coiling pad: A flat surface, round or oval, at a cable manufacturing or storage site or in the tank of a cable installation vessel, onto which cables are coiled.

Conductor: Part of a cable core designed for transmission of electric current, typically made of copper or aluminium.

Core: An assembly consisting of a conductor and its own electrical insulation.

Corridor: Width of the area along a cable route, specified e.g. for cable route consenting, surveying purposes or post-construction exclusion zones.

Crushing load: A mechanical load that acts in the radial direction of the cable, which is limited in length along the cable.

Dependability: Collective, non-quantitative term describing availability performance which is determined by reliability performance, maintainability performance and maintenance support performance, see IEC 60300-1.
**Depth of burial**

A measure describing the lowering of a cable into the ground / seabed. Specific terms as follows apply (see Figure 1-6):

- **depth of trench** - vertical distance between bottom of trench and undisturbed (mean) seabed level
- **depth of lowering** - vertical distance between top of cable and undisturbed (mean) seabed level
- **depth (height) of cover** - vertical distance between top of cable and average level of the backfill above top of the cable.

**Guidance note 6:**

Where depth of burial has not been defined specifically for a project, it should, as a default, be understood as ‘depth of lowering’ defined above.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

**Figure 1-6**

**Depth of burial**

**Design basis**

A set of conditions which are taken into account when designing a facility or a product.

**Design criteria**

The criteria applied for verification of systems, equipment, structures, etc.

**Design life**

The service life of a component or system multiplied by an appropriate factor which is equal to or greater than 1.

**Desktop study**

see ‘cable route study’

**DP acceptance test**

Specific trials programme for dynamically positioned vessels covering key elements of a fault tolerant system including performance, protection and detection, meeting the requirements of the IMO equipment classes 1, 2 or 3 and/or those of the classification society. Typically carried out annually to demonstrate acceptance criteria are met and supplemented by shorter field arrival trials, see IMCA M 190.

**Dynamic positioning (DP)**

A method of automatically controlling a vessel’s position and heading within certain predefined tolerances by means of active thrust. IMO MSC/Circ.645 distinguishes equipment classes 1, 2 and 3.

**Guidance note 7:**

Manual position control and automatic heading control is sometimes referred to as DP0.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

**Earthing**

System or process of equalising the electrical potential of conductive parts with the potential of the Earth.

**Environmental impact assessment (EIA)**

An iterative process to assess a project at the planning stage regarding its likely significant impacts on the environment, prior to a decision to proceed.

**Environmental statement**

Final report or set of documents which contains the findings and recommendations of the EIA procedure.

**Export cable**

Subsea power cable connecting an offshore electricity generation project (e.g. an offshore wind farm) to a point to which power is delivered.

**Extreme waves**

For single waves, individual, maximum wave height measured in m. For sea states, significant wave height measured in m, with a specific return period (e.g. 1 year, 50 years or 100 years).

**Falling apron**

Layer (or additional amount) of stone, concrete blocks or other material at the slope of a rock berm, providing dynamic scour protection. See Figure 1-2.
Filter layer  Intermediate layer of protection against waves and currents, made of smaller material, preventing finer materials of the lower layer (seabed) being washed out through the voids of the upper (armour) layer. Also serving as ‘cushion layer’ for impact protection when placing armour units. See Figure 1-2.

First-end pull-in  Pull-in of the first cable end into an offshore unit or to shore.

Fixed offshore unit  Non-buoyant construction (e.g. offshore wind turbine, offshore substation) that is founded in the seabed (e.g. monopile, piled jacket structure) or on the seabed (e.g. gravity based structure), see e.g. IEC 61400-3.

Free span  Unsupported section of a cable between two intermediate support points.

Geological study  Collection and analysis of information about the geological history of the general area of development.

Geophysical survey  Indirect measurement of physical properties of the seabed, e.g. by seabed surveys, shallow seismic surveys and magnetic surveys.

Geotechnical investigation  Direct measurement of physical properties of the seabed and subsoil, e.g. by in-situ testing of soil and sampling with laboratory analysis.

Ground investigation  A methodological approach to assess the properties of the ground (soil, rock), commonly including geological studies, geophysical surveys and geotechnical investigations. Also referred to as ‘soil investigation’.

Hang-off  System used in offshore units to suspend a cable end through clamping.

High voltage (HV)  see ‘voltage’

Horizontal directional drilling (HDD)  Drilling of an approximately horizontal bore hole with a shallow arc to underpass an obstacle. Launched from a surface-based drilling rig for trenchless installation of underground pipes, conduits and cables.

Interconnector  Subsea power cable connecting two land-based electrical systems.

Intertidal  Zone off the shore between any high and low water marks. See also Figure 1-8.

I-tube  An open-ended, “I”-shaped section of a tube or pipe attached internally or externally to a fixed offshore unit for guiding and protection of a cable or cable assembly.

Jetting  Burial method employing water jets to break and/or fluidise the sedimentary layer of the seabed and sinking the cable into the soil.

Joint  Accessory making a connection between two cable ends. In general, the following types are distinguished by their application (see CIGRE Technical Brochure 490):

- factory joint between extrusion / manufacturing lengths under controlled factory conditions, leading to a minor increase of the outer diameter of the cable
- field joint made between two cables in the process of their installation, generally identical in design with a repair joint and treated as such
- repair joint between two cables that have been armoured; used for jointing of two delivery lengths and the repair of damaged subsea cables
- transition joint between two cables of different design (e.g. conductor material, conductor cross-section or insulation material).

Guidance note 8:
The transition joint between a subsea cable and a land cable is sometimes referred to as ‘landfall joint’, ‘beach joint’ or ‘sea/land transition joint’.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Joints can also be distinguished by their design:

- number of power cores - single-core, three-core
- flexibility - fully flexible, flexible with some mechanical restrictions, rigid
- deployment - inline, omega (with bight).

Guidance note 9:
Joints between two optical fibres are referred to as ‘splice’ in this recommended practice.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---
**J-tube**
An open-ended, “J”-shaped section of a tube or pipe, attached internally or externally to a fixed offshore unit, for guiding and protection of a cable or cable assembly. The J-tube extends from a platform deck to and inclusive of the bottom bend near the seabed. J-tube supports connect the J-tube to the supporting structure.

**Kink**
A curl, twist or bend in a cable caused by tightening a looped section, which may exceed allowable mechanical limits. See Figure 1-7 b.

**Figure 1-7**
Unintended shapes of cable sections. (a) Loop, (b) kink

**Landfall**
Location where the subsea cable comes on shore.

**Lay angle**
Angle between the longitudinal axis of a cable and the axis of a spiral wound component (e.g. armour wire).

**Limit state**
A state beyond which an item (e.g. cable component, cable, cable system) no longer satisfies the requirements. The following limit states are of relevance:

- serviceability limit state (SLS) - a condition which, if exceeded, renders the item unsuitable for normal operations; exceedance of a serviceability limit state category should be evaluated as an accidental limit state
- ultimate limit state (ULS) - a condition which, if exceeded, compromises the integrity of the item
- fatigue limit state (FLS) - a ULS condition accounting for accumulated cyclic load effects
- accidental limit state (ALS) - a ULS condition due to accidental (infrequent) loads.

**Load-out**
Transfer of a cable from a storage facility onto a vessel, e.g. by spooling or lifting.

**Loop**
Unintended bow of a cable, e.g. when laid on the seabed, possibly standing, with a risk of compromising the minimum bending radius. See Figure 1-7 a.

**Low voltage (LV)**
see ‘voltage’

**Manual positioning**
Any method of manually controlling a vessel’s position and heading. See also ‘dynamic positioning’.

**Marine operation**
Operation of a limited defined duration related to handling of object(s) and/or vessel(s) in the marine environment during temporary phases. In this context the marine environment is defined as construction sites, quay areas, nearshore/offshore water and sub-areas.

**Maximum tensile load**
The largest tensile load that a cable should be subjected to, at zero curvature, without causing damage to the cable.

**Mean sea level (MSL)**
Average sea level taking into account tidal effects over a period of (approximately) one year, but excluding meteorological effects. See Figure 1-8.

**Figure 1-8**
Height and depth relationships
<table>
<thead>
<tr>
<th><strong>Mean seabed level</strong></th>
<th>The average undisturbed level of the seabed before construction works. See also Figure 1-6. Not to be confused with ‘chart datum’.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical cutting</strong></td>
<td>Cutting of a trench into the seabed before, during or after laying the cable, performed by a mechanical cutter.</td>
</tr>
<tr>
<td><strong>Medium voltage (MV)</strong></td>
<td>See ‘voltage’</td>
</tr>
<tr>
<td><strong>Megaripple</strong></td>
<td>See ‘bedform’</td>
</tr>
<tr>
<td><strong>Messenger line</strong></td>
<td>Wire or rope installed in an I-tube, J-tube, J-tube-less system, trench or HDD conduit to transfer the pulling line.</td>
</tr>
<tr>
<td><strong>Minimum bending radius (MBR)</strong></td>
<td>The smallest radius that a cable may be bent to, at a specific tensile load and for a specific time.</td>
</tr>
</tbody>
</table>

**Guidance note 10:**

MBR can be assumed to mean the internal bending radius (except if specified by the manufacturer at the cable’s centre line). Conditions for which MBR applies should be stated, e.g. during storage or installation. Sometimes distinguished into ‘static’ and ‘dynamic’ minimum bending radii.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

| **Mud flat** | Area of fine silt (mud), usually intertidal or behind barriers. |
| **Nearshore** | Zone of the shore where waves are transformed through interaction with the seabed. Also referred to as ‘inshore’. See also Figure 1-8. |
| **Offshore** | Zone beyond the nearshore area. |
| **Offshore unit** | Facility (fixed to the seabed) to which a cable is connected, e.g. offshore substation or offshore wind turbine. |
| **On-bottom stability** | Ability of a subsea power cable to remain in position under lateral displacement forces due to the action of hydrodynamic loads. |
| **Out of service (cable)** | Part of a decommissioned cable system left in situ. |
| **Ploughing** | Towing a plough across the seabed to (a) bury a cable or (b) open a trench. |
| **Pre-lay grapnel run** | Dragging of a grapnel over the seabed prior to cable installation in order to clear debris (e.g. wires or ropes) which is lying on the seabed or buried in the very top layer of the soil. |
| **Pulling head, pulling eye** | Mechanical device attached to the end of a cable so that it can be loaded to / unloaded from a vessel, pulled along the seabed or pulled into an offshore unit, comprised of a housing into which the cable armouring is terminated and within which the cable core ends are contained. |
| **Pulling stocking / pulling grip** | Gripping device holding onto the outer surface (serving, sheath) of the cable, comprised of interwoven wires or rope and a built-in anchorage arrangement. Also referred to as ‘Chinese finger’. |
| **Quadrant** | Device shaped like a quarter (and up to half) of a circle for guiding a cable without compromising its minimum bending radius, e.g. used during manufacturing, on deck of a cable installation vessel or to lower a cable toward the seabed during cable installation. |
| **Ramsar site** | Protection designation according to the Convention on Wetlands of International Importance, signed in Ramsar, Iran. |
| **Reef** | Ridge of rock, sand or coral that rises to or near the surface of the sea. Natural reefs are results of abiotic processes like deposition of sand (geogenic reef) or biotic processes dominated by corals, calcareous algae, and shellfish (biogenic reef). Artificial reefs are the result of anthropogenic activities. |
| **Reliability** | The probability that a component or system will perform its required function without failure under stated conditions of operation and maintenance and during a specified time interval. |
| **Remotely operated vehicle (ROV)** | A crewless, fully submersible vehicle with three-dimensional manoeuvrability that is powered by and controlled from a vessel through an umbilical. The ROV typically features a range of sensors and manipulative devices to perform a variety of tasks. |
**Return period**
Statistical average of time period between occurrences of an event. Inverse of probability that the event will occur in the period of one year.

**Guidance note 11:**
A 100-year return period implies a probability of exceedance of $10^{-2}$ within a year.

---end---of---Guidance---note---

**Risk**
The qualitative or quantitative probability of an accidental or unplanned event occurring, considered in conjunction with its potential consequences. In quantitative terms, risk is the probability of a failure mode occurring multiplied by its quantified consequence.

**Route clearance**
Removal of identified objects on or near a cable route, such as out-of-service cables, unexploded ordnance or boulders which may affect cable installation.

**Route position list (RPL)**
List with coordinates, water depths, etc., typically in accordance with ICPC Recommendation 11.

**Routine test**
Test(s) made after manufacture on every produced component (length of cable, accessory) to demonstrate that the requirements are met.

**Salt marsh**
Intertidal area with characteristic vegetation adapted to saline soils and being periodically submerged.

**Sample test**
Test(s) made after manufacture, at a specified frequency, on samples of completed components (length of cable, accessory) to verify that the specifications are met.

**Sand wave**
see ‘bedform’

**Scour**
Erosion of the seabed caused by shear forces due to currents and waves, resulting in relocation of sediments. Due to up-speed effects, deep holes can form around fixed structures.

**Scour protection**
Protection against erosion of the seabed at fixed offshore structures or installed cables.

**Seafastening**
Structural elements, chains, wires, etc. providing horizontal and vertical support of objects on-board a vessel during transport.

**Sealing**
Filling the space between two or more mating surfaces to prevent ingress / leakage or to contain pressure.

**Guidance note 12:**
Sealing may apply, for instance, to cable end caps (preventing humidity ingress) or subsea power cable entry into an offshore unit (limiting or preventing water exchange).

Due to “less than perfect” mating surfaces, the effectiveness of a seal depends on factors like adhesion or compression. Specifications like “watertight” or “airtight” should be qualified, e.g. by a maximum fluid / gas exchange rate over a specified period of time.

---end---of---Guidance---note---

**Second-end pull-in**
Pull-in of the second cable end into an offshore unit or to shore.

**Sediment**
Particulate material broken down by weathering and erosion processes and subsequently transported. Classified by grain size or composition.

**Sediment transport**
Movement of sedimentary material by wind, current, wave, ice or gravity action.

**Service life**
The planned time period from initial installation or use until permanent decommissioning of a component or system during which the component or system shall be capable of meeting the functional requirements.

**Serving**
Outer covering of cable, over the armour layer. Typically made either as a continuous tubular polyethylene sheath or of helical polypropylene roving.

**Sidewall pressure (SWP)**
Not a ‘pressure’, but a force exerted per unit length of cable when pulled around a bend (e.g. of storage device or in a tube). SWP = pulling force / bend radius, measured in kN/m. Sidewall pressure increases with increased pulling load and smaller bend radius. Also referred to as ‘sidewall bearing pressure’.

**Significant wave height**
Four times the standard deviation of the sea surface elevation. Traditionally defined as the average trough-to-crest wave height of the highest third of the waves.

**Soil investigation**
see ‘ground investigation’

**Sprinkle layer**
Thin layer of fine grained rock aggregate applied over an armour layer to comply with fishing gear interaction requirements.
| **Storm surge** | Change in sea level caused by meteorological forcing (wind, atmospheric pressure) on the sea surface, positive (rise) or negative (fall). |
| **Tensile strength** | Ability of a cable to withstand tensile loads. |
| **Termination** | Connection between cable and equipment or panels, including for instance: |
| | — mechanical termination - fixing of cable armouring, e.g. by hang-off |
| | — electrical cable termination - device fitted to the end of a cable core ensuring electrical connection and maintaining the insulation |
| | — optical fibre termination - connection of optical fibres to connectors and patch panels. |
| **Thermal conductivity $k$** | A material’s ability to conduct heat, expressed in $\text{W m}^{-1} \text{K}^{-1}$. |
| **Thermal convection** | Heat transfer by transport of energy through fluid motion. |
| **Thermal diffusivity $\alpha$** | A measure of thermal inertia, equal to $k / (\rho c_p)$, expressed in $\text{m}^2 \text{s}^{-1}$. |
| **Thermal resistivity $\rho_T$** | A material’s ability to resist heat flow, expressed in $\text{K m W}^{-1}$. |
| **Torsional balance** | Cable characteristic achieved by its design, frequently by two armour layers applied in opposite directions, such that axial loads do not induce significant twist or torsional loads in the cable, see [4.4.1.6]. |
| **Touch-down point** | Point where, during installation, the cable first touches the seabed. |
| **Trefoil** | Arrangement of three single cores of 3-phase AC systems in a triangular formation. |
| **Trenching** | Opening of a trench for simultaneous or subsequent burial of a cable. |
| **Turntable** | A circular, large diameter horizontal rotating platform with an active drive system on which cable is stored and from which it is deployed. See Figure 1-5 e and Figure 1-5 f. |

**Guidance note 13:**
The term ‘turntable’ is often interchangeably used with ‘carousel’. Sometimes a distinction is made in that a turntable with side walls is referred to as ‘carousel’, while a turntable without side walls is simply referred to as ‘turntable’.  

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

| **Type test** | Test(s) made on components (cable, accessory) to verify their properties prior to supplying them on a general commercial basis. |
| **Unexploded ordnance (UXO)** | Explosive ordnance that has or has not been primed, fused or otherwise prepared for use and which has been fired, dropped, launched, projected or placed in such a manner as to constitute a hazard to personnel or material and remains unexploded either through malfunction, design or for any other reason. |
| **Vessel** | Barge, ship, tug, mobile offshore unit, crane vessel or other ship-shaped unit involved in a marine operation. |
| **Voltage** | Electromotive force or potential difference expressed in volts: |
| | — low voltage (LV), < 1 kV |
| | — medium voltage (MV), here e.g. 33 kV AC |
| | — high voltage (HV), in general $\geq$ 1 kV, here e.g. 132, 150 or 220 kV AC. |

**Guidance note 14:**
In general, any voltage $\geq$ 1 kV can be referred to as ‘high voltage’. The term ‘medium voltage’ is frequently used in wind energy applications when referring to the voltage level in the array cabling between wind turbines. Where the distinction between MV and HV is not relevant, ‘high voltage’ (as opposed to ‘HV’) is used in this recommended practice.  

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

| **Vortex induced vibration (VIV)** | Motions induced on structural elements or horizontal / vertical cable sections interacting with currents, generated by, or the motion generating, periodical irregularities in the flow. |
1.4 Abbreviations and symbols

### 1.4.1 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A&amp;R</td>
<td>Abandonment and Recovery</td>
</tr>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>A/C</td>
<td>Alter Course</td>
</tr>
<tr>
<td>AIS</td>
<td>Automatic Identification System</td>
</tr>
<tr>
<td>ALARP</td>
<td>As Low As Reasonably Practicable</td>
</tr>
<tr>
<td>ALS</td>
<td>Accidental Limit State</td>
</tr>
<tr>
<td>BPI</td>
<td>Burial Protection Index</td>
</tr>
<tr>
<td>BSH</td>
<td>Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency, Germany)</td>
</tr>
<tr>
<td>CAR</td>
<td>Construction All Risk (insurance policy)</td>
</tr>
<tr>
<td>CD</td>
<td>Chart Datum</td>
</tr>
<tr>
<td>CIGRÉ</td>
<td>Conseil International des Grands Réseaux Électriques (International Council on Large Electric Systems)</td>
</tr>
<tr>
<td>CIRIA</td>
<td>Construction Industry Research and Information Association</td>
</tr>
<tr>
<td>CLB</td>
<td>Cable Laying Barge</td>
</tr>
<tr>
<td>CLV</td>
<td>Cable Laying Vessel</td>
</tr>
<tr>
<td>CPS</td>
<td>Cable Protection System</td>
</tr>
<tr>
<td>CPT</td>
<td>Cone Penetration Test</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DNV</td>
<td>Det Norske Veritas</td>
</tr>
<tr>
<td>DP</td>
<td>Dynamic Positioning, Dynamically Positioned</td>
</tr>
<tr>
<td>DSS</td>
<td>Distributed Strain Sensing</td>
</tr>
<tr>
<td>DTS</td>
<td>Distributed Temperature Sensing</td>
</tr>
<tr>
<td>EEZ</td>
<td>Exclusive Economic Zone</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>EPR</td>
<td>Ethylene Propylene Rubber</td>
</tr>
<tr>
<td>FLS</td>
<td>Fatigue Limit State</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode and Effect Analysis</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>HAT</td>
<td>Highest Astronomical Tide</td>
</tr>
<tr>
<td>HAZID</td>
<td>Hazard Identification</td>
</tr>
<tr>
<td>HAZOP</td>
<td>Hazard and Operability</td>
</tr>
<tr>
<td>HDD</td>
<td>Horizontal Directional Drilling</td>
</tr>
<tr>
<td>HSE</td>
<td>Health, Safety, Environment</td>
</tr>
<tr>
<td>HV</td>
<td>High Voltage</td>
</tr>
</tbody>
</table>
1.4.2 Symbols

\( A \)  
Area (\( \text{m}^2 \))

\( c_p \)  
Specific heat capacity (\( \text{J} \) \( \text{kg}^{-1} \) \( \text{K}^{-1} \))

\( d_i \)  
Inner diameter (m)

\( d_o \)  
Outer diameter (m)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Force (N)</td>
</tr>
<tr>
<td>f</td>
<td>Frequency (Hz)</td>
</tr>
<tr>
<td>h</td>
<td>Height, depth (m)</td>
</tr>
<tr>
<td>I</td>
<td>Electrical current (A)</td>
</tr>
<tr>
<td>k</td>
<td>Thermal conductivity (W m(^{-1}) K(^{-1}))</td>
</tr>
<tr>
<td>l</td>
<td>Distance (m)</td>
</tr>
<tr>
<td>M</td>
<td>Moment (Nm)</td>
</tr>
<tr>
<td>P</td>
<td>Power (W)</td>
</tr>
<tr>
<td>R</td>
<td>Electrical resistance (Ω)</td>
</tr>
<tr>
<td>Q</td>
<td>Heat (J)</td>
</tr>
<tr>
<td>r</td>
<td>Radius (m)</td>
</tr>
<tr>
<td>T</td>
<td>Temperature (K)</td>
</tr>
<tr>
<td>T(_C)</td>
<td>Contingency time (h)</td>
</tr>
<tr>
<td>T(_{POP})</td>
<td>Planned operation period (h)</td>
</tr>
<tr>
<td>T(_R)</td>
<td>Operation reference period (h)</td>
</tr>
<tr>
<td>T(_{Safe})</td>
<td>Time to safely cease operation (h)</td>
</tr>
<tr>
<td>T(_{WF})</td>
<td>Weather forecast interval (h)</td>
</tr>
<tr>
<td>t</td>
<td>Thickness (m)</td>
</tr>
<tr>
<td>t</td>
<td>Time (s)</td>
</tr>
<tr>
<td>U</td>
<td>Rated voltage between two phases (V)</td>
</tr>
<tr>
<td>U(_0)</td>
<td>Rated voltage between phase and neutral (V)</td>
</tr>
<tr>
<td>U(_m)</td>
<td>Maximum voltage between two phases (V)</td>
</tr>
<tr>
<td>U(_p)</td>
<td>Impulse withstand voltage (V)</td>
</tr>
<tr>
<td>V</td>
<td>Volume (m(^3))</td>
</tr>
<tr>
<td>α</td>
<td>Thermal diffusivity (m(^2) s(^{-1}))</td>
</tr>
<tr>
<td>δ</td>
<td>Loss angle (°)</td>
</tr>
<tr>
<td>θ</td>
<td>Lay angle for armour application (°)</td>
</tr>
<tr>
<td>(θ)</td>
<td>Temperature (°C), where (θ = T - T_0) with (T_0 = 273.15) K</td>
</tr>
<tr>
<td>ρ</td>
<td>Density (kg m(^{-3}))</td>
</tr>
<tr>
<td>ρ(_T)</td>
<td>Thermal resistivity (K m W(^{-1}))</td>
</tr>
</tbody>
</table>
2 Design philosophy

2.1 General

2.1.1 Objective
This section presents the overall design philosophy that should be applied by stakeholders in all phases of subsea power cable system projects from concept development through decommissioning.

2.1.2 Application
This section applies to all subsea power cable systems which are planned to be designed, built and operated in accordance with this recommended practice.

The integrity of a subsea power cable system shall be ensured through all phases, from initial concept development through to final decommissioning. Three integrity stages are defined:

— establish integrity in the concept development, design, manufacturing and installation phases
— maintain integrity in the operation and maintenance phase
— retain sufficient integrity for safe decommissioning.

2.1.3 Stakeholders and interfaces
The lifecycle of a subsea power cable system may be split into specific phases, ranging from concept development through design, manufacturing (including testing, storage, load-out, transport), installation (including commissioning), operation and maintenance to decommissioning at the end of life, see Figure 2-1. Further sub-phases (or processes) can be distinguished. Sometimes a single or double circuit is being developed (e.g. offshore wind farm export cable system), sometimes a large number of circuits (e.g. array cables within an offshore wind farm). The timing of the phases and milestones depends on the specific project.

A project is a temporary endeavour undertaken to create a specific product, service or result. At the highest level, development projects and decommissioning projects could be distinguished. Many of the sub-phases can also be viewed as projects, as they have a defined scope and are executed by a project team.

Any activity related to establishing, operating / maintaining and decommissioning a cable system shall take the stakeholders affected into account. The management of stakeholders and the interfaces between them commonly involves:

— identification of stakeholders
— determination of stakeholder interests, needs and influence on project
— description of interfaces between stakeholders
— facilitation of information flow between stakeholders in a timely manner.

---

Figure 2-1
Project phases and stakeholder involvement
A project execution plan should be developed, including the following topics:

— general information, including project organisation, scope of work, interfaces and project development phases
— interfaces and contacts, e.g. with authorities, manufacturers and third parties such as engineering, verification and installation contractors
— contingency
— legal aspects, e.g. insurance, contracts, area planning, requirements to vessels
— timeline of the project, lead time of critical items.

A proactive approach is required and roles and responsibilities should be clearly defined for all parties involved. Where resources (human resources, equipment, spare parts) are constrained, sharing of resources should be considered to achieve optimum solutions.

For a new cable project under development, uncertainties should be reduced early in the design and changes should be managed in an effective way. Early involvement of parties with an in-depth understanding of the activities required can lead to better decisions with an appropriate risk profile.

**Guidance note:**
Identification of risks and their mitigation will be less costly at an early design stage compared to a later stage (Figure 2-2). A reduction of interfaces can help reducing project risks.

**Figure 2-2**
Effects of early identification and mitigation of risk

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### 2.2 Safety philosophy

#### 2.2.1 General

The concept development, design, manufacturing, testing, storage, load-out, transport, installation commissioning, operation, maintenance and decommissioning phases of the cable system shall be conducted in compliance with applicable international and national legislation and company policies. The selection of materials and processes shall be conducted with due regard for health, safety, environmental and quality aspects.

The integrity of the subsea power cable system is ensured through a safety philosophy integrating different parts as illustrated in Figure 2-3.

**Figure 2-3**
Safety philosophy structure

#### 2.2.2 Safety objective

An overall safety objective shall be established, planned and implemented, covering all phases from conceptual development until decommissioning.
Guidance note:
Most companies have policies regarding human, sustainability and financial aspects. These high-level documents may be followed by more detailed objectives and requirements in specific areas. These policies should be used as a basis for defining the safety objective for a specific subsea power cable system. Typical statements in a safety objective may include, for example:
— There shall be no serious accidents or loss of life during on-site work.
— The impact on the environment shall be reduced to as low as reasonably practicable (ALARP).
— Installation, maintenance and decommissioning should be performed without a need for divers, where possible.
— The subsea power cable system should not pose unacceptable threats to other users of the seabed, e.g. fishing activities or oil and gas activities.

2.2.3 Systematic review of risks
A systematic review shall be carried out for all phases to identify and evaluate hazards, the consequences of single failures and series of failures in the subsea power cable system, such that necessary mitigation measures can be taken. The extent of the review or analysis shall reflect the criticality of the cable system, the criticality of a planned operation, and previous experience with similar systems or operations. The uncertainty in the applied risk review model itself should also be qualified (Figure 2-4).

Figure 2-4
Risk assessment process

Guidance note:
The scope of the systematic review should comprise the entire cable system and its interfaces, and not just the subsea power cable. A systematic review can provide an estimation of the overall risk to human health and safety, to the environment and to assets and comprise:
— hazard identification (HAZID), see App.A
— assessment of probabilities and consequences of failure events
— review of accident development and escalation.

Legislation in some countries requires risk analysis to be performed, at least at an overall level to identify critical scenarios that might jeopardise the safety and reliability of a cable system. Besides HAZID, methodologies for identification of potential hazards are failure mode and effect analysis (FMEA) and hazard and operability study (HAZOP). For risk management principles, see ISO 31000; for methodologies, see ISO 31010 and DNV-RP-H101.

Special attention shall be given to sections close to offshore units or shore approaches where there is frequent human activity and thus a greater probability and consequence of damage to the cable. This also includes areas where cables are installed parallel to existing infrastructure and crossings.
The cable system shall be designed, constructed and operated in such a manner that:
— the defined health and safety as well as environmental objectives are fulfilled and the resistance against hazards during planned operational conditions is sufficient
— the probability and consequence of accidental events or unplanned operational conditions (i.e. the risks) are demonstrated to be sufficiently covered by safety margins
— the specified transmission capacity is assured
— system layout meets the requirements imposed by the systematic review.

2.2.4 Dependability and risk based design

Safety, environmental performance and functionality of the overall cable system can be ensured by application of dependability and risk based design methodologies, see [2.3]. The overall cable system should be assessed based on failure consequences and their probability to demonstrate that project objectives will be met.

**Guidance note:**
For guidance on third party damage to underground and subsea cables, see CIGRÉ Technical Brochure 398.

2.2.5 Quality assurance

2.2.5.1 General

The safety philosophy requires that gross (human) errors shall be controlled by requirements for organisation of work, competence of persons performing the work, verification of work, and quality assurance during all relevant phases.

Documented quality systems shall be applied by developers / operators and other parties involved to ensure that products, processes and services are in compliance with the requirements.

The developer / operator of a cable system and other parties involved (e.g. designers, manufacturers and installers) should establish quality objectives. The developer / operator should obtain assurance that intended quality is being, or will be, achieved.

Non-conformities can reflect systematic deviations from procedures and/or inadequate workmanship and should initiate:

— investigation into the immediate (and possibly root) causes of the non-conformities
— corrective action to establish possible acceptability of products
— preventive action to prevent re-occurrence of similar non-conformities
— re-assessment of the quality system.

Quality assurance during the manufacturing and installation phases shall be performed by the developer / operator or an appointed party. The extent of quality assurance shall be sufficient to establish that specified requirements are fulfilled and that the intended quality level is maintained.

2.2.5.2 Marine warranty survey

A Marine Warranty Surveyor (MWS) performs quality surveillance for marine operations. Where MWS services are planned to be used, a scope of work leading to approval by the MWS shall be created. The scope of work may include, subject to project-specific agreements, review and approval for cable and/or cable components:

— risk assessments, operating and installation procedures, contingency procedures
— transport, installation and lift analyses; weather restricted operations
— vessels and equipment used in the installation process
— land transport
— load-out to transport vessel, inter-vessel transfer
— transport to installation site
— installation, burial or other cable protection.

The scope of work may also, subject to project-specific agreements, include attendance of cable testing at the factory, termination works and testing before / after termination.

The MWS work will be carried out by means of review of documentation and analyses, independent calculations as well as surveys. The MWS shall establish uniform acceptance criteria covering all operations under the scope of work and communicate these to the parties concerned.

2.3 Design format

2.3.1 Approach

Items of a cable system, including their installation and operation, can be designed using various methods, including deterministic, probabilistic and testing-based approaches as well as combinations of these.

**Guidance note:**
Power cables are commonly designed based on material properties which were established through testing and proven in qualification processes. HV cables systems should be qualified as a whole to ensure overall system reliability.
Design and assessment require relevant information for the planned cable system to be available including functional requirements ([4.2.3]) and design basis ([4.2.4]) information such as:

- cable and interface characteristics (electrical, thermal, mechanical)
- temporary and operational demands
- monitoring, inspection and maintenance philosophy.

The proposed solution should be assessed as to whether it meets the design criteria. Industry recognised calculations tools, or proprietary tools documented to provide valid results, should be used for design and installation analyses of the subsea cable system.

The design and assessment process is only one element in assuring safe and reliable solutions. It should be supplemented by adequate manufacturing (Sec.5), installation (Sec.6) and operation / maintenance (Sec.7).

### 2.3.2 System analysis

#### 2.3.2.1 General

Items of a cable system are subjected to a range of demands (or “loads”, “actions”), for which they have a certain capacity (or “resistance”, “strength”), resulting in a response (or “load effect”, “action effect”).

**Guidance note:**

Typical demand / capacity combinations for a subsea power cable include pulling force / maximum tensile load and overvoltage / lightning impulse withstand voltage.

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As long as demand remains below capacity, the item remains in a safe state, but for some types of demand or capacity degradation occurs. Over time, demand may vary and the capacity may deteriorate due to factors such as ageing, fatigue, corrosion or erosion. When demand exceeds capacity, a failure occurs and the system enters a faulty state. A ‘limit state’ divides the item’s condition between functional (available) and faulty (unavailable).

#### 2.3.2.2 System demands

Loads acting on items of a cable system can be classified as functional, environmental or accidental.

Functional loads arise from the physical existence of the cable system and its intended use between manufacture and decommissioning. Functional loads include, for instance:

- weight (weight of cable and attachments, buoyancy, marine growth)
- external hydrostatic pressure
- electrical stress
- heat (internal, external)
- short circuit induced forces
- reactions from components (clamps, terminations, cable protection systems, etc.)
- reaction from installation vessel (cable engine, rollers), static and quasi-static hydrodynamic forces during installation or recovery, reactions from burial tools
- reactions from seabed (friction, crushing, settlement)
- loads from cover (e.g. soil, rock, mattress) and infrastructure crossings.

Environmental loads are those induced by environmental phenomena acting directly or indirectly on the cable, not covered by functional or low-probability accidental loads. Environmental loads include, for instance:

- waves (e.g. slamming, slapping, buoyancy variations)
- currents (e.g. drag, vortex induced vibrations)
- ice (e.g. drifting)
- motions of offshore unit where cable connects.

Accidental loads are caused directly or indirectly by unplanned activities. Accidental loads include, for instance:

- extreme wind, wave or current loads
- seabed subsidence, mudslide
- earthquake loads (direct, indirect)
- dropped objects
- dragged anchor or trawling gear
- installation vessel positioning failure during installation or recovery.

For individual items of a cable system, the acting loads may be identified in order to analyse possible modes of failure.

**Guidance note:**

A load combination (i.e. a set of loads acting simultaneously), rather than single loads, frequently governs the design.
The cable system should normally withstand the most onerous combination of loads that can be predicted to occur simultaneously.

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2.3.2.3 System capacity

Items of a cable system have a specific capacity to respond to a range of demands they are subjected to during temporary or permanent phases. The capacity of an item can be described by a set of limit states covering the significant failure modes.

The following limit state categories can be of relevance for items of a cable system (see also [1.3.2]):

— serviceability limit state (SLS), e.g. damage to cable sheath (before or after installation) or armour (after installation)
— ultimate limit state (ULS), e.g. exceeding cable core emergency temperature rating or compromising minimum bending radius
— fatigue limit state (FLS), e.g. repeated cable bending and vortex induced vibrations in free spanning sections
— accidental limit state (ALS), e.g. objects dropped onto cables and anchor impact.

For individual items of a cable system, limit states may be analysed in relevant scenarios.

Guidance note:
A range of scenarios should normally be considered for items of a cable system, including temporary and permanent phases, and covering normal, ultimate and accidental situations.

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2.3.2.4 System response

Subsea power cables can fail during their service life due to electrical and thermal causes (predominantly in the operational phase). Examples are given in Figure 2-5 and Table 2-1.

![Figure 2-5](https://example.com/figure25.png)

**Figure 2-5**
Examples of subsea power cable failure mechanisms. (a) Electrical, (b) thermal

**Table 2-1** Examples of electrical and thermal failure modes of subsea power cables

<table>
<thead>
<tr>
<th>Failure mechanism</th>
<th>Demand characteristics</th>
<th>Capacity characteristics</th>
<th>Response characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation breakdown (ULS)</td>
<td>Voltage - average, peak</td>
<td>Electrical resistance of insulation</td>
<td>Full discharge between conductor and insulation screen</td>
</tr>
<tr>
<td>Treeing (SLS)</td>
<td>Voltage, moisture</td>
<td>insulation sensitivity to moisture, moisture barrier effectiveness</td>
<td>Electrochemical oxidation with moisture propagation</td>
</tr>
<tr>
<td>Partial discharge (SLS)</td>
<td>Voltage</td>
<td>Absence of micro-voids, insulation sensitivity to partial discharges</td>
<td>Partial discharge in small insulation voids or imperfections</td>
</tr>
<tr>
<td>Overheating (SLS)</td>
<td>Electrical current - magnitude, harmonics External heat, solar irradiation</td>
<td>Cable losses, thermal properties of cable components and surroundings, temperatures, insulation sensitivity to overheating</td>
<td>Increase of conductor temperature, soil drying (on land), ageing of insulation</td>
</tr>
</tbody>
</table>

Subsea power cables can also fail during their service life due to mechanical and chemical causes. Examples are given in Figure 2-6 and Table 2-2.
Examples of subsea power cable failure mechanisms. (a) Mechanical, (b) chemical

<table>
<thead>
<tr>
<th>Failure mechanism</th>
<th>Demand characteristics</th>
<th>Capacity characteristics</th>
<th>Response characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial tension (ULS)</td>
<td>Tensile force</td>
<td>Strength, stiffness</td>
<td>Elongation or compression, strain, bonding failure between conductor and insulation</td>
</tr>
<tr>
<td>Bending (ULS)</td>
<td>Bending moment</td>
<td>Strength, stiffness</td>
<td>Elongation (outside) and compression (inside), strain, bonding failure</td>
</tr>
<tr>
<td>Torsion (ULS)</td>
<td>Twisting moment</td>
<td>Strength, stiffness</td>
<td>Strain, opening or closing of armour, bird cageing, bonding failure</td>
</tr>
<tr>
<td>Lateral compression (ULS)</td>
<td>Clamping force and area</td>
<td>Strength, acceptable crush / squeeze load</td>
<td>Compression, strain, bonding failure</td>
</tr>
<tr>
<td>Impact (ALS, ULS)</td>
<td>Impact force and area</td>
<td>Impact resistance</td>
<td>Shear stress and strain</td>
</tr>
<tr>
<td>Abrasion (SLS)</td>
<td>Lateral and longitudinal forces,</td>
<td>Abrasion resistance, cable surface friction coefficient</td>
<td>Abrasion of cable sheath</td>
</tr>
<tr>
<td>Vibration (FLS)</td>
<td>Current - velocity, direction</td>
<td>Length of free span, cable stiffness</td>
<td>Fatigue of cable components</td>
</tr>
<tr>
<td>Sheath degradation (SLS)</td>
<td>Irradiation - wavelength (e.g. UV),</td>
<td>Adsorption</td>
<td>Ageing of outer cable sheath, cracking</td>
</tr>
</tbody>
</table>

Protective systems of subsea power cables can fail during the service life of the cable system. Examples of failure modes for burial protection and rock cover are given in Figure 2-7 and Table 2-3.

Examples of failure mechanisms of subsea power cable protection. (a) Burial, (b) rock placement
For individual items of a cable system, possible and credible failure modes should be identified. For those failure modes considered relevant, failure criteria (exceedance of capacity or critical threshold) may be formulated.

**Guidance note:**
Some failure modes may be allowed to occur repeatedly (generally in the SLS category), others are not acceptable even as a single occurrence (generally in the ALS and ULS categories).

For power cables, most credible failure modes are addressed by designing to applicable IEC standards and CIGRÉ guidelines, combined with mechanical / electrical type and routine testing.

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3 Concept development

3.1 General

The concept phase precedes the design phase and involves all activities to define the functional specifications and basis of design for a cable project (Figure 3-1).

Figure 3-1
Concept phase within the cable project life cycle

This section identifies and provides the basis for definition of relevant cable project characteristics.

3.2 Conceptual design

3.2.1 Systematic approach

An overall design philosophy and general design principles shall be established for the cable project, see [2.3]. This recommended practice promotes a lifecycle view which requires designing with all project phases in mind, including manufacturing, testing, storage, load-out, transport, installation, commissioning, operation and maintenance (including potential repair) as well as decommissioning.

Project hazard review should be based on a consistent risk management framework, see [2.2.3]. Hazard identification should determine potential failure modes, their causes and consequences. Design mitigation measures should then assure that an acceptable risk level is achieved for each section along the prospective cable route, see also [4.6].

The system design (cable, cable route) should be enhanced and optimised from early conceptual studies through feasibility assessments and preliminary design solution to more detailed solutions. Decisions made at each stage should be justified and documented to avoid detrimental effects on the project.

The overall requirement for systematic review in [2.2.3] should be reflected in an iterative concept evaluation. Identified hazards (other than related to health, safety and the environment) typically impact cost, schedule and performance (as a threat, but also as an opportunity) and may include, for instance:

- site conditions (e.g. timing of marine operations)
- design choices (e.g. cable, maturity of technical solutions, installation methods)
- supply and quality of material (e.g. timing, performance)
- constructability (e.g. site access, simultaneous operations with other site activities, vessel capacity)
- project scope changes (e.g. capability, flexibility)
- installation contractor availability and performance (e.g. competence, cost, construction timing, quality)
- market factors and prices (e.g. material, equipment, contractors)
- availability and cost of financing and insurance (e.g. commercial feasibility, risk transfer).

3.2.2 Project layout

Cable design is highly dependent on the conditions of the renewable energy project (e.g. offshore wind farm, see Figure 3-2) being developed. Important parameters include, for instance:

- overall number of turbines
- type and rating of turbine
- location of the individual turbines
- distance between generation site and shore
- location of onshore grid connection.

These boundary conditions determine, at least partially, the following:

- requirement for offshore substation(s) to step-up the voltage
- choice of the cable type(s)
- choice of cable route(s)
- feasibility of cable installation and burial.
3.2.3 Electrical system studies

Conceptual and feasibility studies should yield one or more preliminary system layouts such as shown in Figure 3-3 as an example for an AC connected offshore wind farm.

Electrical system studies should establish basic electrical design parameters. Appropriate design of the cables within the project depends on the required service conditions, which include the following operating conditions, see IEC 60183:

- operating voltage in the system
- lightning overvoltage
- system frequency, AC or DC operation
- type of earthing used
- current carrying capacity (normal, emergency)
- short circuit level (symmetrical, asymmetrical) and duration.

Furthermore, the service conditions include the installation data, i.e. the laying arrangement and conditions. With additional project information becoming available, more detailed electrical studies should be carried out, confirming the suitability and acceptability of the preliminary layout, e.g.:

- power flow simulation (static, transient, harmonics)
- grid code compliance assessment
- control and safety system (e.g. protection relay system) review for start-up, normal operation, emergency operation, shut-down
- reactive power compensation requirements.
3.2.4 Preliminary cable selection

3.2.4.1 Cable and accessory selection

Based on the cable service conditions, supplemented by cost data (e.g. for losses), the cable type and rating can be preliminarily determined as described below.

The use of existing cable and accessory designs can yield a lower risk solution, provided that they meet the basic functional requirements. Cable manufacturers and their published data sheets can be consulted to select suitable product ranges. This may involve a preliminary decision for the conducting material, either copper or aluminium.

**Guidance note 1:**
Both aluminium and copper are conductor materials which have been successfully used in subsea cables systems. Compared to aluminium, copper has higher conductivity and requires a smaller cross-section for a specific current rating, but metal prices can make aluminium preferable. Joints between copper and aluminium conductors are feasible.

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In some circumstances, a preliminary decision for an insulating (dielectric) material may be made.

**Guidance note 2:**
Most offshore wind farm cables (array, export) have used XLPE as insulating material. EPR is also used, e.g. in MV applications.

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3.2.4.2 Cable rating

The cable system should be analysed, e.g. through use of appropriate software tools, to demonstrate that it can safely transmit the required power without exceeding the maximum allowed temperature. This should include identification of constraints and requirements (including regulatory) for its installation and operation. This analysis should cover steady-state and transient operating conditions.

Use of up-rating / de-rating factors such as given in data sheets from cable manufacturers can provide a good overview of cable’s current rating at the planning stage. With design progress, more accurate calculations should be performed to confirm assumptions, e.g. for crossing of heat sources, see IEC 60287.

Temporary overload and emergency ratings of cables may be calculated according to IEC 60853.

The magnitude and duration of short circuit events determines the thermal energy to be dissipated through insulation / sheath materials adjoining the conductor / metallic screen, see IEC 60949 and IEC 61443. Manufacturers’ recommendations for temperature, current and/or time limits should be observed. Dynamic forces in cables and accessories during the short circuit event shall also be considered.

3.2.4.3 Earthing

Due to alternating magnetic fields in AC cables, circulating and eddy currents are generated in the metallic screens and in the armour. The associated losses generate heat and reduce the cable’s current rating. Onshore, these currents can be reduced or eliminated by single-end bonding or cross-bonding. Offshore these options are hardly practical and electrical bonding of metal coverings (screens or sheaths, armour) at both cable ends should normally be planned for.

**Guidance note:**
Single-end bonding of subsea power cables is possible, but insulation and high voltages at the non-earthed cable end need to be addressed. Cross-bonding is not practical as it requires cable joints and access to the cross-bonding positions.

Both-end bonding of array cables is commonly used. Single-end bonding is possible for cable designs with outer polyethylene sheath.

Both-end bonding of export cables is used also for longer lengths (Figure 3-4). Additional measures, such as a semi-conducting layer of the outer sheath of the single-core cable, may be used.
3.2.4.4 Reliability, redundancy and system layout optimisation

The preliminary layout of the cable system should be assessed with regard to its potential availability (including reliability, maintainability and maintenance support performance). Redundancy (e.g. parallel circuits) can increase overall dependability.

Guidance note 1:
For reported failure rates of \( \geq 60 \) kV AC and DC cable systems and joints installed onshore and offshore, see CIGRÉ Technical Brochure 379. Mean failure rates (expressed as failures per 100 circuit km per year) can be useful for order-of-magnitude comparisons. Due to the limited amount of supplementary information, the failure rates are not normally appropriate for availability calculations of newly planned, unrelated installations.

Guidance note 2:
After optimisation, array cable systems in large offshore wind farms often use two or three different cable cross-sections.

3.2.5 Preliminary engineering

Information gathered from the desk-based studies ([3.3]), investigations, site visits and fit-for-purpose surveys ([3.4]) shall be used to determine a feasible and, to the extent possible, optimised cable system and cable route. The (preliminary) cable operational conditions should be established (and collated in a design basis, see [4.2.4]), including:

— length of route
— installed conditions, e.g. type of protection, depth of lowering, proximity of heat sources
— temperature and thermal conductivity of soil / surroundings
— installation conditions, e.g. distance for pull-in operation, coilable vs. non-coilable cable design.

With additional information becoming available, more detailed assessments can be carried out, e.g. thermal studies for specific sections (e.g. J-tubes, cable with cable protection system, landfall).

The preliminary cable system / cable route design should be checked against the project objectives and functional requirements (see [4.2.3]). If objectives have been met, the project may progress to more detailed engineering (see Sec.4).
3.3 Cable route study

3.3.1 General

A formal cable route study determines initial information that is available on the project site as well as gaps in knowledge. A methodical approach should be used when evaluating a cable route, in the process of which the area under investigation is progressively narrowed down to the safest and technically most viable route (Figure 3-5).

Factors to take into consideration should, as a minimum, include those described in the following subsections.

Guidance note:
For details on minimum requirements in cable route studies, although written for the telecommunication sector, see ICPC Recommendation 9.

Factors can change with location (onshore, nearshore, offshore), some have distinct local effects, others vary little across a region. Factors can change over time on various timescales (e.g. hours, days, seasons, years), including those related to tides (e.g. tidal cycles, spring and neap tides). The spatial and temporal aspects of the factors and their effects on cable systems, interface points (offshore unit, landfall section) and installation spread should be taken into account.

Cable project specific requirements should be taken into account when conducting a cable route study. These should also include consideration of the construction phase, including marine operations for lay and burial, equipment to be used and envisioned burial depth.

Information shall be captured in a geographical information system (GIS) or similar database. The GIS system, maps and reports shall use the same horizontal datum, the same vertical datum and the same coordinate system. Reference data and coordinate system shall be documented in the design basis.

The output of the cable route study should include possible cable route(s) and the specification of the cable route surveys to be conducted.

3.3.2 Route selection and landing

The cable route should be selected based on the endpoints of the cable (e.g. at an offshore wind turbine, at an offshore substation, at an onshore grid connection point) and considerations given in the following subsections. The cable route study should investigate and validate a proposed cable route between these endpoints. The route may be subject to refinement and adjustments in an iterative process throughout the concept development and design phases.

When investigating offshore and nearshore cable route sections, the following should be taken into account:

- regulatory requirements ([3.3.3])
- commercial operations, restricted areas, obstructions ([3.3.4])
- geology and seismicity ([3.3.5])
- meteorological and marine conditions ([3.3.6])
- natural environment ([3.3.7]).

When investigating cable landing points, the following should additionally be taken into account:

- existence of designated cable corridors
- coastal conditions, including onshore topography and its stability
- sea defence systems
- installation considerations, e.g. landing type, length of shore section, onshore access.

Following investigation, the recommendation for cable / cable route design should favour low risk (feasible) options, highlight medium risk (critical or requiring further assessment) options and avoid high risk (infeasible) options. Areas may have to be avoided due to license restrictions, geo-hazards, environmental concerns, third party activities, “cable free” designations (see [4.7.2.1]), etc.
The route recommendations should include details such as the following:

- route position list (RPL)
- general survey corridor width and areas with extended corridor width (at landing points, near wind turbine locations due to the direction of cable entry, in close proximity to subsurface infrastructures, in navigation channels, in anchoring zones, etc.)
- third party activities ([3.3.4]) and related access restrictions, infrastructure crossings
- ground conditions ([3.3.5]) and anticipated burial depths along the route
- environmentally designated areas ([3.3.7])
- permit conditions or restrictions
- basic route engineering recommendations.

### 3.3.3 Regulatory requirements

#### 3.3.3.1 Factors

International and national laws and regulations as well as local administrative requirements which may impact the cable project shall be considered. These may include the following.

- Limits of national waters, the extent of the exclusive economic zone (EEZ) and disputed areas may influence cable routing. Administrative borders and ownership of land, beach and seabed may also influence cable routing.

**Guidance note 1:**

International law and policy regime framework set out a significant set of rights for subsea cables and obligations on nation states to protect those rights.

---end---of---Guidance---note---

- Distances (e.g. minimum) of planned cables and their safety corridors relative to existing infrastructure or boundaries may be prescribed.

- Local requirements for cable burial depth may apply.

**Guidance note 2:**

With regard to depth of burial for cables, countries may follow a prescriptive or a risk based approach:

- Germany: For wind farm export cables and interconnections in the North Sea, the required minimum burial depth is 1.5 m.
- United Kingdom: Burial depth may be determined employing a risk based approach.

---end---of---Guidance---note---

- Various species of flora and fauna may be protected leading to restrictions with regard to:

- timing of construction activities, e.g. seasonal restrictions
- disturbance of the ground, e.g. disallowing specific installation techniques
- introduction of materials, e.g. prohibition of rock placement on a larger scale or mitigation against potential spills.

- Entrance and import regulations may restrict the use of vessels, equipment or members of the workforce in certain areas.

- Notification periods for specific activities may apply.

#### 3.3.3.2 Information review

Statutory requirements (i.e. the approvals, licenses or permits required to engage in a certain activity) for planned marine and land-based activities shall be identified.

The effort and timeframes for obtaining permits should be assessed, e.g. based on similar projects under the same regulatory system.

**Guidance note:**

The permitting process for other, recent cable projects in the same area can provide valuable information.

---end---of---Guidance---note---

### 3.3.4 Commercial operations, restricted areas, obstructions

#### 3.3.4.1 Factors

Existing and planned activities in the vicinity of the planned cable route shall be investigated. Relevant operations, restrictions and obstructions may include the following:

- Navigation can impact cables, e.g. through various types of dropped or dragged anchors (inadvertently, routine, emergency). The risk of navigational impact will be influenced by the location of the following:
— controlled shipping channels (including plans for deepening) and shipping patterns
— anchorage areas
— harbour entry areas, including plans for modifications and channel deepening
— aids to navigation, e.g. oceanographic buoys.

b) Commercial and research activities may interfere with power cable projects by competing for space, e.g.:

— fishing (trawl board impact, net entanglement) and fish farming
— oil and gas exploration, including licensed areas and planned, in service or abandoned offshore units and pipelines
— pipelines for water intake or sewage outflow
— renewable energy installations, e.g. wind, wave and tidal farms
— exploration and dumping activities, e.g. dredging, mining, waste disposal
— telecommunication and power cables (planned, in service, abandoned) and construction or maintenance activities on these
— weather buoys.

c) Protected areas are of significance to the wider society and may have to be avoided, including:

— areas with environmental designations (see [3.3.7])
— archaeologically or culturally significant sites, e.g. historic sites and burial grounds onshore or specific wrecks and submerged prehistoric landscapes offshore
— recreation areas developed for tourism.

d) Restricted areas may be used in ways incompatible with subsea power cables and may have to be avoided:

— military exercise areas
— sound / undersea surveillance systems
— mined areas
— ammunition dumping grounds
— contaminated areas.

e) Obstructions impact cable routing. Larger objects should be avoided, smaller objects can sometimes be cleared:

— individual boulders and boulder fields (see also [3.3.5])
— artificial reefs
— anti-fishing blocks
— wrecks
— unexploded ordnance (UXO), specifically in former gunnery ranges, bombing ranges, testing areas and ammunition dumping grounds.

f) Coastal defence systems may require minimum distances to be kept.

3.3.4.2 Information review

Existing and planned third party activities and obstructions shall be investigated. Results from site investigations carried out previously should be taken into account. To the extent and detail necessary for the project, information should be captured by the developer in a GIS database.

Current data on third party infrastructure should be obtained, as far as practical, from official providers. The data should include, as a minimum, for all in-service, out-of-service or planned systems:

— type of system
— coordinates
— anchor exclusion zones
— safety corridor.

Guidance note:

Authorities and/or owners / operators of infrastructure may have to be identified and contacted early to inform them about the intended project and to obtain relevant information.

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A risk assessment should be conducted for third party activities and obstructions and mitigation measures should be identified.

Navigational risk (e.g. various methods of anchoring) and fishing risk (e.g. trawling) may have to be assessed through quantitative studies.

The potential for the cable route crossing culturally significant or protected areas should be evaluated. National and local regulations may require specific desk-based assessments, the findings of which have to be confirmed during the survey activities.
A transparent and robust assessment and management of UXO risk should be carried out in multiple stages with reviews on how to proceed between stages:

- desk-based assessment, general assessment of risk based on available data and historic information (potential types, probability of occurrence)
- broad assessment of anomalies during offshore geophysical surveys (using side scan sonar and magnetometers) and, where applicable, suitable onshore surveys, see [3.4]
- avoidance of specific areas, re-routing of cables, or, where these options are not feasible, assessment of identified objects through detailed UXO surveys (e.g. potential type, potential movement on seabed, risk)
- avoidance of specific objects, re-routing of cable sections, or, where these options are not feasible, clearance of specific objects.

3.3.5 Geology and seismicity

3.3.5.1 Factors

Ground conditions on land and at sea and related geo-hazards which have an impact on the construction and/ or operation of cable systems shall be considered.

Along and in the vicinity of onshore sections of the cable route geo-hazards may include, but are not limited to, the following:

a) Topography: Steep slopes and cliffs in the landfall area pose very challenging conditions for cable works.

b) Ground type: Influences construction activities. In horizontal directional drilling (HDD) applications, weak overburden or gravel may lead to collapse of a borehole, while larger stones / boulders cannot be flushed out and cavities can cause severe drilling mud losses (see [6.6.3]). Slope stability influences construction works such as open-cut trenching.

c) Thermal properties: Low thermal conductivity of the ground, e.g. in drying soils, adversely affects cooling of a cable in operation.

d) Ground water: A high water table may require dewatering measures for open-cut trenching. Artesian aquifers can cause problems for HDD when water enters the borehole, leading to destabilisation of the wall and deterioration of the drilling fluid.

Along and in the vicinity of the nearshore and offshore sections of the cable route geo-hazards may include, but are not limited to, the following (see also Figure 3-6):

a) Bathymetry: Uneven ground surfaces such as faults, slopes, ridges, ravines, crevices, canyons, mounts and rock outcrops can constitute difficult route conditions.

b) Ground type: The composition of the ground influences survey and installation activities. The presence of boulders, reefs (geogenic, biogenic), shallow gas pockets and other features at the sea floor and below can make cable routing difficult and have an adverse impact on cable project construction works. Slope stability can be a concern in some areas, also in applications like pre-lay trenching. Liquefaction, the temporary loss of strength of water-saturated, unconsolidated sediments, e.g. due to wave interaction or an earthquake, can undermine foundations and bases of equipment.

c) Thermal properties: Low thermal conductivity of the soil, e.g. in areas with organic material, can lead to undesirable temperature rise in the cable.

d) Sediment transport: A combination of gravity and fluid movement acting on the sediment particles can result, for instance, in scour around foundations of offshore units, loss of cover of buried cable, moving sand waves and high levels of turbidity. Beaches may erode through wave and tidal interaction and in storms, changing the conditions for or uncovering buried cables.

Figure 3-6
Potential geological features along a cable route

Seismic hazards may include the following:

a) Seismic activity: Release of energy in the Earth’s crust generates seismic waves which can lead to tsunamis and liquefaction.
b) Volcanic activity: Eruption of magma (or mud) onto the surface can be hazardous to cable installations in geologically active areas and can also be coupled with earthquakes.

3.3.5.2 Information review

Geological conditions at site shall be described, typically including the following:

— geological history and tectonic setting
— ground topography / bathymetry and characteristics
— ground lithology and morphology (bonded, cohesive, granular, containing organic matter)
— ground properties, including sediment mobility.

Seismicity should normally be described including the following:

— seismic activity - location, type, frequency and size of terrestrial and submarine earthquakes
— volcanic activity - location, type, frequency and size of eruptions.

The geological information identified should form the basis of a ground model. This model should be improved in an iterative process as additional information becomes available.

The geological (desk-based) study phase shall provide recommendations for subsequent ground investigations, comprising geophysical and geotechnical surveys, which in turn will provide all necessary data for a detailed cable system design.

The extent of ground investigations and the choice of investigation methods shall take into account the route / project layout, the cable protection requirements, the complexity of ground conditions, the actual type of deposits and intended or proposed installation methods. The area to be covered by ground investigations shall account for positioning and installation tolerances.

Guidance note:
The geological study, based on the geological history, forms a basis for selection of methods and extent of the site surveys. Geophysical survey results can be combined with the results from a geotechnical investigation to establish information about seabed topography and ground stratification for an extended area. A geotechnical investigation consists of in-situ testing of the ground and of sampling for laboratory testing.

For guidance on the scope of geophysical and geotechnical surveys, see [3.4] and an OSIG (2014) guideline.

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3.3.6 Meteorological and marine conditions

3.3.6.1 Factors

Environmental conditions on land and at sea which might have an impact on the construction or operation of a cable system shall be considered. These may include the following (see also Figure 3-7):

a) Wind: Strong winds (including gales, storms and hurricanes) can restrict vessel and crane operations, or make cables on floaters drift.

b) Surface waves: Can restrict vessel operations, in particular near offshore units, induce cyclic loading on cables partially in free span and erode beaches.

c) Internal waves: Gravity waves which oscillate in the sea in strata of different density may have an impact on subsea operations in specific areas.

d) Tidal / water level: Rise and fall of the sea level caused by tides, also combined with storm surges, are particularly relevant in shallow waters and at landing points, where they can impact navigation (also harbour entry) and cable laying and burial activities.

e) Currents: Can be caused by rivers or tides, induced by wind or density differences and created by storm surges or breaking waves (in near-shore regions). Currents can impact the position keeping ability of the installation spread and remotely operated vehicle (ROV) as well as diving operations. They cause scour, induce vibrations in exposed cable sections and may affect the stability of cables lying unprotected on the seabed.

f) Temperature (air, water, ground): Low temperatures may impact cable handling activities on site. Surrounding temperatures experienced during operation determine the current carrying capacity of the cable, especially inside J-tubes and in the landfall area.

g) Precipitation: Heavy forms of precipitation (including rain and snow) can have an adverse impact on site activities and lead to flooding of onshore areas including open trenches.

h) Fog: May impair visibility and thereby marine operations.

i) Sea ice: Includes ice sheets forming on the water surface in cold climate or ice bergs passing. Ice structures can exert mechanical loads on offshore units and the connected cables; ice bergs may scrape the seabed.

j) Turbidity: Haziness of the water caused by suspended solid particles in the water column may impact operations requiring visibility, e.g. diving or ROV operation.
k) Salinity: Dissolved salt content in water may have secondary effects on cables systems and their interfaces such as corrosion.

Figure 3-7
Marine and terrestrial conditions along a cable route

3.3.6.2 Information review

For the assessment of environmental conditions along the cable route, it may be divided into a number of sections, each of which is characterised by a given water depth, bottom topography and other factors affecting the environmental conditions.

The environmental data shall be representative for the area in which the cable system is to be installed. If sufficient data are not available for the area, conservative estimates based on data from other relevant locations may be used. Statistical data should be utilised to describe environmental parameters of a random nature (e.g. wind, waves). The parameters shall be derived in a statistically valid manner using recognised methods.

Guidance note 1:
For principles and methodologies to establish environmental conditions and loads, see DNV-RP-C205.

Environmental parameters should normally be described in the following way (if changing significantly with location, also for individual cable sections):

— wind - frequency distribution of wind speed vs. direction
— surface waves - frequency distribution of wave height vs. wave period, directional distributions
— water level - astronomic (predictable) tidal patterns and positive / negative storm surges
— currents - variations in magnitude with respect to direction and water depth (surface, mid-water, bottom)
— temperature - statistics of air, sea (surface, bottom) and ground temperature (at estimated burial depth), including representative high and low design values
— sea ice - statistics of ice berg development and passing (where relevant).

Seasonal variations and changes of patterns in recent years should be considered.

Guidance note 2:
Wind and waves frequently have a strong impact on construction activities, causing “weather delays”. Detailed long-term analysis of the climate can form a good basis for installation spread choices and operational assessments. Currents are generally more predictable, but their impact on construction and operation activities is often underestimated.

3.3.7 Natural environment

3.3.7.1 Factors

The impact of the cable project on the ecosystem along (and in the vicinity of) the cable route shall be assessed at the planning stage, covering survey, cable laying and burial, operation, possible repair and decommissioning phases, including mitigation measures.

Flora and fauna affected by cable projects may include species (referred to as “receptors”) such as the following, some of which may be endangered or protected (Figure 3-8):

— benthic (seabed) communities, including biogenic (biotic) reefs (e.g. tropical and cold water coral, oyster banks, *Sabellaria spinulosa*)
— fish, and their spawning or nursery areas
— other organisms living in the sea, e.g. plankton, turtles
— mammals, such as dolphins or seals
— birds, e.g. migrating or nesting.
Impacts on the environment encountered during cable system construction and operation can include:

a) Habitat loss: Degradation, fragmentation or destruction of habitat. Cable installation, in particular burial, may temporarily or permanently damage habitats offshore and in landfall areas.

b) Contamination: Presence or introduction of man-made chemicals and materials in the natural soil environment. If sediments in contaminated areas are disturbed during installation, contaminants may be moved in suspension to nearby areas. The environmental impact of certain materials may be prohibitive.

c) Introduction of foreign materials: Deposition of new substrates into the natural environment, thereby changing the environmental characteristics. Cable protection such as rock placement can lead to reef forming and coastal processes can be modified in its immediate vicinity.

d) Turbidity: Suspension, dispersal and subsequent deposition of seabed sediments, dependent on ground type and sediment grain. Cable burial activity can temporarily cause higher than natural levels of turbidity, leading to smothering of certain types of marine organisms.

e) Visual disturbance: During certain seasons, vessels and other temporary disturbances can distress birds and mammals.

f) Noise: Audible disturbance above background levels. Underwater noise during construction can distress certain species of fish and mammals with high sensitivity hearing. Breeding birds in landfall areas may be disturbed by onshore construction activities.

Guidance note 1:
Noise levels during cable related works offshore are generally very low compared to, for instance, foundation piling activities in offshore wind farms.

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g) Electromagnetic fields: In very close proximity, local or migratory fish that use the Earth’s electromagnetic fields for navigation may be affected (avoidance, repulsion) by strong magnetic fields from cables.

Guidance note 2:
The electrical field outside shielded power cables is zero. The strength of magnetic fields outside three-core AC cables in operation is very low and mitigation measures are, from an environmental point of view, not required. Where single cores of DC cables are laid in proximity, the external magnetic fields are minimised. Clear adverse effects of the remaining magnetic field on fish have not been demonstrated.

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h) Heat transfer: Heating of habitat above natural levels. Heat losses from subsea cables can cause a change of habitat conditions to local organisms.

Guidance note 3:
The environmental impact of a raised soil temperature in the direct vicinity of a subsea cable in operation due to cable losses is currently not known with certainty. In an evaluation, the temperature rise should be considered in the context of seabed / water temperature changes throughout the year, which can exceed 10 K in the North Sea. Countries may have specific requirements with regard to acceptable levels of thermal influence:

— Germany: Specific requirements exist with regard to the maximum value the seabed’s temperature may be raised by the presence of a cable in operation. Bundesamt für Seeschifffahrt und Hydrographie (BSH) guidance “Design of offshore wind turbines” applies.

— United Kingdom: No specific requirements. If the Environmental Impact Assessment (see [3.3.7.2]) identifies an adverse impact, mitigation measures could be required.

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Marine species can also directly or indirectly affect cable projects, in particular marine growth (fouling) on submerged structures, and should be assessed.
3.3.7.2 Information review

High level information can generally be extracted from existing literature and databases, covering physical and sedimentary processes and seabed features. The following data are commonly collected:

- marine condition data to establish relationships between waves, tides and sediment mobility
- bathymetric, geophysical survey and sediment composition data to ascertain the form of the seabed and sedimentary quality / processes
- water quality data
- benthic community data
- fish distribution data
- ornithological data.

Considering conservation interests, an ‘envelope’ of envisioned activities and their potential impact should be established. Data should be investigated in a formal environmental impact assessment (EIA), leading to an ‘environmental statement’ which details the nature and extent of potential (and allowable) impacts during each phase of the lifecycle of the cable project.

**Guidance note 1:**
In areas with high turbidity potential, a presence of sensitive species and the envisioned use of burial techniques such as chain cutting or jetting, a sediment plume study is advisable if the temporary turbidity increase is likely to be significant compared to background levels.

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When the EIA indicates that an unacceptable impact would be attained, possible mitigation measures shall be identified, making use of practical experience within the industry.

**Guidance note 2:**
Care should be exercised that the environmental statement does not unnecessarily limit or exclude potential solutions to project challenges.

The mitigation measures identified in the EIA process are typically transposed into consent conditions or requirements.

Permit restriction may not only apply to an area but also to times when access for installation and repair activities is not allowed (e.g. due to bird breeding; in Europe frequently between October and March). In such cases a route change involving longer cable lengths may be advisable.

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A potential mitigation measure is to avoid cable routing in designated conservation areas where possible.

**Guidance note 3:**
Areas of conservation interest include, for instance, Marine Protected Areas, European Marine Sites, Special Areas of Conservation, Special Protection Areas, Sites of Special Scientific Interest, Ramsar sites and Marine Conservation Zones.

Further buffer zones around protected areas, e.g. 500 m wide, may constitute exclusion areas for cable works.

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Where avoidance of sensitive areas is not an option, monitoring and mitigation measures for the relevant project phase should be identified, e.g.:

- pre- and post-construction monitoring
- method and/or timing restrictions for survey activities, installation works or repairs
- re-instatement of site to pre-construction condition
- other environmental compensation works.

3.4 Cable route survey

3.4.1 General

Detailed data shall be obtained for the total length of the planned cable route, covering a corridor of sufficient width to provide adequate information for design of the cable route as well as installation and operation related activities, taking into account possible route adjustments due to subsequent findings.

**Guidance note 1:**
Surveys in nearshore, intertidal and mud flat areas may be more difficult to conduct than in onshore or offshore areas. Minimum requirements to cover these areas adequately should be established.

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Data for the onshore part of a cable route can frequently be obtained from official sources. Data for the offshore part of a cable route should normally be obtained from national hydrographic institutions, supported by results from dedicated surveys.

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Guidance note 2:
Data on planned activities may be obtainable from trade organisations and market intelligence services.

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All survey data shall be geo-referenced to allow overlaying of subsequently obtained data, e.g. in a geographical information system.

3.4.2 Onshore surveys
Where the cable project includes shore landings or an onshore section, a site visit should normally examine:

— marine and terrestrial constraints like infrastructure, features, utilities and conflicting developments / activities along the prospective cable route and at the beach
— harbour / nearshore activities, e.g. fishing and marine traffic
— local ground conditions along the cable route and at the beach, including the need for setting up hard standing for machinery or temporary storage
— during any excavation work, consideration of archaeologically or culturally significant findings
— site accessibility, e.g. for road transportation and available storage / working space
— local facilities for construction and operations periods, including communication, transportation, fresh water, services
— potential for community involvement.

Onshore ground conditions may be available from local or national authorities. Where such information cannot be obtained, onshore ground investigations should be conducted to a level adequate for the project. Ground investigations should normally comprise the following types of investigation:

— site geological study (see [3.3.5])
— geotechnical investigations, e.g. standard penetration test (SPT) in weak rock, cone penetration tests (CPT) in soil
— borehole drilling with representative soil sampling and subsequent laboratory testing
— identification of ground contamination.

Guidance note:
Thermal conductivity of the ground is a significant design parameter which should be established through in-situ testing and/or laboratory analysis.

For HDD applications, penetration tests and borings should be made at entry and exit points. Depending on the geological conditions, penetration tests are typically made at least every 100 to 200 m along the route with additional investigation borings for every second penetration location. In order to avoid break-outs during horizontal drilling, borings should be offset horizontally from the planned HDD centre line. For all geotechnical tests, penetrations down to anticipated HDD trajectory plus at least 5 m should be achieved.

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Meetings with relevant local organisations such as fishermen’s representatives or environmental interest groups can be helpful in establishing a dialogue.

3.4.3 Offshore surveys
Ground investigations offshore should normally comprise the following types of investigation:

— site geological study (see [3.3.5])
— geophysical investigations of the bathymetry of the seabed using multi-beam echo-sounder, of the sea floor texture using side scan sonar and of objects on the seabed using side scan sonar and magnetometer
— geophysical investigation of the shallow geology using sub-bottom profiling
— geotechnical investigations, e.g. CPT
— soil sampling, e.g. by vibrocoring or grab-sampling, with subsequent laboratory testing for ground truthing
— specialist surveys, e.g. satellite imaging to collect information on the morpho-dynamics of an area, UXO surveys.

Guidance note 1:
The extent and content of a ground investigation programme are no straight-forward issues and will depend on the specifics of the cable project. An experienced geotechnical engineer who is familiar with cables and their installation and who represents the developer or owner should be present during the ground investigation surveys. Depending on the findings during the investigations, actions may be taken to adjust the ground investigation programme during its execution. This may include suggestions for increased depths of planned tests, suggestions for additional tests, and suggestions for changed positions of investigations and tests.

When non-homogeneous soil deposits are encountered or when difficult ground conditions are identified locally, it may be necessary to carry out more tests than the tentative minimum recommended below.
Compared to deeper water surveys, very shallow water surveys use different equipment setup for multi-beam echo-sounder, side scan sonar and sub-bottom profiling (e.g. refraction seismic). Therefore a specific shallow water survey may be required.

Guidance note 2:
Requirements with regard to competence of personnel on board the survey vessel may apply, e.g. with regard to geo-survey and/or archaeological qualification. Local requirements for geological surveys apply:
- Germany: Bundesamt für Seeschifffahrt und Hydrographie (BSH) guidance “Baugrunderkundung für Offshore-Windenergieparks” applies.
- Norway: Standards NORSOK N-004, Appendix K and NORSOK G-001 apply.
- UK: No specific requirements; European Norms and British Standards apply.

All features which may influence the cable route or seabed intervention shall be covered by the route survey, including:
- obstructions in the form of rock outcrops, boulder fields, etc., that could necessitate levelling or removal operations to be carried out prior to cable installation
- geo-hazards like potentially unstable slopes, sand waves, pock marks, significant depressions, and erosion in the form of scour patterns or material deposits
- existing and planned infrastructure such as submarine pipelines, power cables and communication cables and wrecks
- archaeologically or culturally significant findings
- high-current areas.

The entire cable route within a wind farm shall be covered by geophysical investigations. The survey width should be defined depending on the risk profile along the route. In the landfall area, offshore and onshore surveys should be suitably combined to achieve full coverage.

Guidance note 3:
For consenting purposes and general route identification, the geophysical survey width may be 1,000 m or wider. Typically, the entire area of a prospective wind farm site would be covered by a geophysical survey.
For design purposes, when basic cable routes have been identified, a typical geophysical survey in water depths up to 50 m may be 100 m wide for a single cable (but wider for several cables routed in parallel). In very shallow water, e.g. below 20 m, this width may be reduced. In areas with difficult ground conditions, sand waves or where many constraints are present, the corridor width should be increased so that potential re-routing of the cable is covered by the survey.

The line spacing of the seismic survey at a cable route section should be sufficiently small to detect all soil strata of significance for the design and installation of the cable.

Depending on the findings of the geophysical programme, the amount of geotechnical investigations should be determined which will gather sufficient information for design purposes. Geotechnical sampling density along the cable route should be established based on the ground model.

Guidance note 4:
Along export cable routes the investigations should be sufficiently detailed to identify the soils of the surface deposits to the planned/estimated depth of burial of the cables. Along a route with relatively homogeneous seabed, a geotechnical test spacing of 500 to 1000 m may be sufficient. In known, homogenous geology, the spacing may be increased to 2000 m, potentially more. In sections with more complex geology, the distance between samples should not be larger than 500 m, potentially significantly less.

In the shore approach, the spacing is typically reduced to 300 to 500 m. In areas of mobile sediments or where HDD is planned the spacing may have to be reduced further. River mouths typically require additional investigations. The choice of landfall design may influence the type and spacing of investigations for the onshore and nearshore sections.

In a wind farm area with very homogenous seabed, testing at 10% of the array cable routes (e.g. single test locations for 10% of array cables, midpoint, distributed across the wind farm) could already be sufficient. Investigation results from wind turbine foundation locations are only useful if the top 3 m have been carefully investigated in great detail. Often wind turbine foundation surveys do not yield any data suitable for cable route engineering and dedicated cable surveys are required within the wind farm area. In a complex area, one test location per array cable may not be sufficient.

For all geotechnical tests, penetrations to estimated burial depth plus at least 1 m should be achieved.
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A combination of several survey methods shall be used to facilitate the development of the ground model. The parameters used for the surveys should take account of the cable project specifics.

**Guidance note 5:**
Typical parameters of geophysical and geotechnical survey methods are given in Table 3-1.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Method</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geophysical</td>
<td>Multi-beam / swath echo-sounder</td>
<td>Sufficient data for maps with e.g. 0.5 m, or better 0.25 m resolution in shallow water; appropriate grid size in deeper water</td>
</tr>
<tr>
<td></td>
<td>Side scan sonar</td>
<td>Measurement range maximum 2 × 100 m, recognition of linear objects &gt; 0.5 m, positioning better than 10 m</td>
</tr>
<tr>
<td></td>
<td>Sub bottom profiler, chirp sonar or similar</td>
<td>Vertical resolution ≤ 0.5 m</td>
</tr>
<tr>
<td></td>
<td>Magnetometer, metal detection</td>
<td>Resolution &lt; 1 nT</td>
</tr>
<tr>
<td>Geotechnical</td>
<td>Cone penetration test</td>
<td>e.g. as per NORSOK G-001</td>
</tr>
<tr>
<td></td>
<td>Vibrocore</td>
<td>e.g. as per NORSOK G-001</td>
</tr>
<tr>
<td></td>
<td>Soil boring, sampling</td>
<td>e.g. as per NORSOK G-001</td>
</tr>
<tr>
<td></td>
<td>Heat conductivity measurement, heat flow probe</td>
<td>Note: In-situ measurement (e.g. combined with vibrocore); traditionally determined in laboratory tests.</td>
</tr>
</tbody>
</table>

Seabed samples should be taken for ground-truthing and the evaluation of scour potential.

For survey vessel positioning requirements, see e.g. IHO standard S-44.

Depending on the water depth range, different types of survey vessels may be required. Offshore vessels may not be able to operate in the intertidal area. Geophysical and geotechnical surveys can be combined if the survey vessel offers that capability. Some surveys are carried out by ROV.

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The required survey accuracy may vary along the proposed route. Obstructions, highly varied seabed topography, or unusual or hazardous sub-surface conditions may dictate more detailed investigations.

Soil samples obtained as part of a soil investigation programme shall be of a sufficient quality, allowing for adequate interpretation of soil parameters to be used in design. For requirements to soil sampling quality, see ISO 22475-1.

Additional route surveys may be required at landfalls to determine seabed geology and topography and to facilitate cable pre- or post-installation seabed intervention works.

In morphologically active areas with sediment movement erosion may occur. Special studies of the long-term seabed development may be required to:

— determine if seabed changes are likely to take place  
— quantify possible long-term seabed lowering, which may result in insufficient depth of cover and/or remedial works over the service life of the cable system  
— evaluate the risk of cable exposure, cable free spans, cable movement or excessive cover.

**Guidance note 6:**
Multiple geophysical surveys may be required over time in areas with mobile sediments.

Morphologically active areas where cable free spans can occur should generally be avoided or specific protection may have to be implemented and maintained. For guidance on free spans due to scour at offshore units, see [4.7.5]. For guidance on thermal implications of excessive sediment accretion, see [4.4.1.4].

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In areas where there is evidence of increased geological activity or significant historic events, which if reoccurring may impact the cable, additional geo-hazard studies should be performed. Such studies may include:

— extended geophysical survey  
— detection / investigation of boulders, cemented hard ground, faults or reefs  
— pockmark activity (indicating shallow gas), mud volcanoes activity, mud flow characteristics, seismic hazards  
— possibility of slope failure.

UXO risk should be addressed by general geophysical surveys and, if required, more detailed, dedicated UXO surveys, see [3.3.4].

**Guidance note 7:**
A wider survey area covered by geophysical methods increases the ability to avoid magnetic objects which could be UXO. Smaller grid sizes allow better identification of objects.
Detailed UXO surveys benefit from calibration of the magnetometer array with surrogate UXO targets matching the signature of the types of UXO expected in the surveyed area. This enables magnetic targets to be classed effectively by probability of being UXO.

Further surveys may be required to characterise the project area, including, but not limited to, the following:

- assessment of marine conditions, e.g. temperatures and tidal currents
- biological (benthic) sampling survey.

**Guidance note 8:**
In areas with strong tidal effects, on-site measurements of the current profile in the water column over a tidal cycle are advisable to inform scour assessment and installation analyses.

### 3.4.4 Determination of site conditions

Ground properties necessary for evaluating the effects of relevant installation and operational conditions shall be determined for the seabed deposits, including possibly unstable deposits in the vicinity of the cable. Ground properties may be obtained from generally available geological information, results from geophysical surveys, geotechnical in-situ tests and laboratory tests on sampled soil. Supplementary information may be obtained from visual surveys or special tests.

The geotechnical investigation at the site and subsequent analysis should provide data for all important layers, including the following:

- soil classification (according to ISO 14688-1, ISO 14688-2) and description
- shear strength parameters for clay, friction angle for sands
- other relevant (e.g. thermal) ground characteristics.

The laboratory test programme for determination of soil properties should cover a set of different types of tests and a number of tests of each type, which will suffice to yield data for a detailed cable protection design. These parameters should preferably be determined from laboratory tests or from specialist interpretation of in-situ tests. In addition, classification and index tests should be considered, to provide an extended set of data.

**Guidance note 1:**
Table 3-2 shows, by example, parameters which are typically derived for the different soil and rock types.

<table>
<thead>
<tr>
<th><strong>Table 3-2 Ground parameters applicable for cable routes</strong> 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>General description</td>
</tr>
<tr>
<td>Grain size distribution</td>
</tr>
<tr>
<td>Carbonate content</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Density</td>
</tr>
<tr>
<td>Plastic/liquid limits</td>
</tr>
<tr>
<td>Water content</td>
</tr>
<tr>
<td>Shear strength 2)</td>
</tr>
<tr>
<td>Compression strength</td>
</tr>
<tr>
<td>Friction angle</td>
</tr>
<tr>
<td>Liquefaction potential</td>
</tr>
<tr>
<td>Organic content</td>
</tr>
<tr>
<td>Thermal conductivity</td>
</tr>
</tbody>
</table>

1) Importance: H = Higher, L = Lower, - = not applicable
2) Static testing. Cyclic testing relevant in areas with liquefaction potential.

The characteristic value(s) of the ground parameter(s) used in the design shall be in line with the selected design philosophy, accounting for the uncertainties.

**Guidance note 2:**
It is primarily the characteristics of the upper layer of the seabed (accounting for sediment mobility) that are relevant for subsea cable burial design, typically the maximum local burial depth plus 1 m. The variations of the top soil between tested and untested locations add to the uncertainty of properties. Ground parameters used in the design
should therefore be defined with upper bound, best estimate and lower bound limits valid within defined areas or sections of the route.

Since the distance between ground investigation locations can be large, the assumed ground characteristics in a design situation at a specific point of the route should be the unfavourable of high and low estimates. For determination of the characteristic value of a soil property from limited data, see DNV-RP-C207.

Raw ground survey data may also be provided to cable installers, preferably in GIS format, for additional burial assessment and/or burial tool capability assessment.

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Additional investigation of the seabed material may be required to evaluate specific scenarios, as for example:

— challenges with respect to excavation and burial operations in areas with inhomogeneous ground conditions
— unstable subsurface when crossing post-glacial features like eskers or moraines
— possibility of mud slides or liquefaction as a result of cyclic loading, caused by waves
— challenges with respect to cable crossing
— probability of forming free spans caused by megaripples / sand waves or scouring during the operational phase
— high organic material content (e.g. peat) impacting trenching or heat transfer
— planned beaching of vessel or work in energetic inter-tidal areas.

Guidance note 3:
Detailed investigations may include trialling of burial equipment and techniques without cable or with a dummy, thereby effectively de-risking future cable burial.

---e-n-d---o-f---G-u-i-d-a-n-c-e---n-o-t-e---

The geological report should, as a minimum, contain the following information:

— brief project description
— terms of reference, reporting standards
— description of planned and executed investigation(s) including specifications / limitations of the survey tool used in the works
— results of the individual investigations
— combination and visualisation of results from geological study, geophysical survey, geotechnical survey and laboratory testing
— description of anomalies
— interpretation of the results.
4 Design

4.1 General

The design phase includes all activities associated with developing the cable project to the point ready for manufacturing and installation activities (Figure 4-1).

![Figure 4-1](design_phase_lifecycle.png)

**Design phase within the cable project life cycle**

Sec.4 provides requirements for the design process, including specifications of cables and accessories, design of the cable route and design of interfaces at offshore units and landing points.

**Guidance note:**

The manufacturer-specific cable designs are not the focus of this recommended practice. All cable design solutions should fulfill the standards, guidelines, and requirements of the specific project and comply with national laws and regulations.

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The design process of a cable project is often iterative, with results from previous stages influencing the following stages to achieve a life cycle cost optimised result.

4.2 Cable system design conditions

4.2.1 General

With conclusion of the conceptual phase of a project and prior to more detailed design and engineering, the project objectives and requirements should be suitably documented. Information may be divided into categories which are explained in the following subsections:

— project description ([4.2.2])
— functional requirements ([4.2.3])
— design basis ([4.2.4]).

4.2.2 Project description

A general description of the cable project should provide a high-level overview for project stakeholders and may include information such as the following:

— objective of project (purpose, use)
— geographic location of project
— cable system description with principal layout / arrangement and physical interfaces
— project stakeholders involved and interfaces between
— project plan and schedule, service life of operational system.

4.2.3 Functional requirements

Functional requirements are stated by a purchaser of a product or service by detailing the performance expectations / characteristics the cable system should have, e.g.:

— ability to meet health, safety and environmental objectives of the project
— capability to transmit power (and, if applicable, information) during the design life with the required dependability
— capability to operate under the stated envelope of environmental conditions during the design life
— capability to withstand specified design loads and load combinations
— composition of material compatible with the environment
— capability of being stored, installed, recovered, repaired and reinstated.

For individual parts of the cable system, specific design criteria can be developed, i.e. the specific requirements that a part must be able to fulfill during the individual phases of the project.

**Guidance note:**

Design criteria for cable system components are shown, by example (not exhaustive), in Table 4-1. Determination of optimal design solutions may require a trade-off between (initial) capital expenditure and (later) operational expenditure.
4.2.4 Design basis

A design basis shall be established, detailing all boundary conditions of the cable project, which, together with the functional specifications, enables a designer to pursue the design activities. Subjects covered in a design basis may include the following:

— system overview
— terms of reference
— site conditions
— technical interfaces
— manufacturing and storage aspects
— load-out, transportation and installation aspects
— operation and maintenance aspects
— decommissioning aspects.

For more detailed information on the content of a design basis, see [9.2.2].

4.3 Cable system design

4.3.1 Detailed design

Results from the preliminary design stages are used for more detailed design of the cable system in operation, yielding or confirming the operational parameters. Detailed design of the cable system and its interfaces ‘in operation’ is an iterative process which should address aspects such as the following:

— refinement of electrical system design
— determination of cable losses and thermal behaviour ([4.4])
— basic cable route engineering ([4.5]) and protection studies ([4.6]), yielding e.g. cable lengths, burial methods and burial depths
— if applicable, design of crossings ([4.5.4])
— design of interface with fixed offshore units ([4.7])
— if applicable, design of interface with the land-based power system ([4.8]).

Guidance note:

Static power cables covered by this recommended practice do not normally require fatigue assessments. An analysis could be relevant in specific cases, e.g. for a designed free span at an offshore unit / cable interface, subjected to wave or current interaction.

Sensitivity analyses are useful to ensure that the system configuration is robust. Sensitivity analyses may, for instance, be carried out for thermal properties of the soil to demonstrate that the power transmission capacity will be adequate.

4.3.2 Installation engineering

Information about the cable system, its interfaces and the installation spread is used to design the installation process, resulting in engineering analysis reports and ultimately in an installation manual. Detailed design of
the installation steps for cable system and its interfaces is an iterative process which should address scenarios, including contingencies and repairs, such as the following:

— cable storage, load-out and transport (see also Sec.5)
— cable laying, e.g. offshore, in landfall area and/or at infrastructure crossings (see also Sec.6)
— cable pull-in at offshore units and landfall (see also Sec.6)
— cable burial, including burial tools and their characteristics (see also Sec.6)
— cable protection by non-burial methods (see also Sec.6).

All phases of the cable installation operation shall be designed and analysed according to the principles stated in the applicable rules for marine operations and for the chosen operational limiting conditions, see [6.1]. The installation design shall demonstrate that the power cable system can be installed safely using the intended vessel and installation equipment and within the allowable limits, i.e. with acceptable risks to product and equipment.

The installation design shall provide an acceptable operations envelope used during the actual installation process in order to facilitate control over the cable configuration at all times. This may include, for instance:

— confirmation of cable system mechanical properties including, for instance, submerged weight, tensile strength, minimum bending radius
— definition of the operational limiting criteria with selected installation spread
— determination of laying parameters (e.g. minimum lay angle, maximum lay tension, minimum layback) to be maintained along the cable route
— detailed cable route engineering (including at offshore units, lay tolerances)
— verification of cable capacity in combined tension and bending and with respect to radial compression from cable engine tracks and chute contact.

Guidance note 1:
Static and dynamic installation analyses should ensure that the cable’s mechanical properties are adequate for the planned process. The analyses should provide the control parameters for managing the catenary during the laying process and pull-in, both for typical and worst-case scenarios.

Guidance note 2:
The loading capabilities of the cable installation vessel and the operational limiting criteria will also determine the maximum cable length that can be installed and the number of joints required in long cables.

In a burial assessment study the ground conditions along the cable route should be assessed and the final burial design determined ([4.6.3]). A tool capability assessment should determine the equipment most suitable for the operation and yield estimates for performance ([6.7.2]).

The extent of, and the requirements for, seabed preparation shall be determined and specified, taking into account laying tolerances and the potential for route changes. Required activities may comprise route clearance, pre-lay grapnel runs and pre-lay trenching ([6.5.2]).

4.4 Cable system

4.4.1 Power cables

4.4.1.1 General
Manufacturer and purchaser shall agree on the requirements for the cable design with regard to performance, testing, storage, load-out, transport, installation, operation, maintenance, repair and decommissioning. These may include the items listed in the following subsections.

Guidance note:
For preliminary cable selection, see [3.2.4]. For further guidance applicable to AC cables, see App.B. Taking the characteristics of DC transmission into account, the guidance provided in App.B may also aid the specification of DC cables.

Guidance note 2:
The purchaser should provide general project information to the manufacturer such as the following. For further details see [B.2]:

a) Project data: Name, location, water depth.
b) Project layout: Key information on cable interface points (e.g. at wind turbines, offshore substations, onshore grid connection).

c) Route length: Cable type, preliminary or final route length(s).

d) Cable system life: Design life (e.g. ≥ 25 years) and planned service life (e.g. 20 years).

Guidance note:
Cables “age” predominantly through deterioration of the insulation material under influence of electric stress, mechanical stress, temperature and chemical aggression (including humidity and UV irradiation). Well protected subsea power cables can achieve a service life of 30 to 40 years.

4.4.1.3 Electrical specifications

Voltage, frequency, short circuit ratings and the current / power carrying capacity (or the conductor cross-section, see [4.4.1.6]) should be provided by the purchaser. Reference should be made to the relevant IEC publication. With a finalised design, the manufacturer is able to provide cable parameters suitable for power flow simulations. For further details see [B.3].

a) System voltages: Nominal and maximum voltages used; lightning overvoltage / impulse withstand voltage levels required.

Guidance note:
AC system design voltages should be specified according to IEC 60183 in the format $U_0 / U (U_m)$, where $U_0$ is the rated rms power-frequency voltage between each conductor and screen (or sheath), $U$ is the rms power-frequency voltage between any two conductors and $U_m$ is the maximum power-frequency voltage between any two conductors (i.e. the highest voltage that can be sustained under normal operating conditions). Example specifications for cables used in offshore wind farms are as follows:

— 18 / 33 (36) kV - typical array cable voltage
— 36 / 66 (72.5) kV - potential array cable voltage for large wind farms with > 5 MW turbines
— 76 / 132 (145) kV - typical export cable voltage in the United Kingdom
— 127 / 220 (245) kV - potential export cable voltage for large wind farms.

b) System frequency: Nominal frequency, i.e. 50 Hz or 60 Hz.

c) Capacity: Rated current (or power) for continuous operation. Where known, specific current load profiles may also be used to determine cyclic or dynamic rating.


e) Earthing: Concept of screen/sheath earthing.

f) Electrical properties: Parameters of equivalent electrical circuit (DC and AC resistance; positive, negative and zero sequence impedances) and losses (by contributing cable element).

4.4.1.4 Thermal specifications

Current losses from conductors and metallic covers as well as dielectric losses in the insulation are transferred through the cable surface to the environment, e.g. soil, water or air. In steady state conditions, the temperature difference between conductor (limited by the maximum temperature of the insulating material) and ambient depends on the total loss per metre cable and the total thermal resistance.

The current-carrying capacity of the cable is largely determined by the thermal properties of its surroundings. Applicable cases should be assessed, e.g. cable in J- or I-tube (Figure 4-2 a), cable buried in the seabed (Figure 4-2 b) and/or cable inside conduit (Figure 4-2 c).

Guidance note:
Direct application of ‘steady-state’ IEC standards to ‘dynamic’ offshore wind applications can lead to very conservative cable cross-section choices when assuming steady state conditions at nominal power output. In the seabed it normally takes many days before steady-state conditions are reached; in a J-tube it normally only takes a few hours.

Typical hot spots can be found where the cable leaves the water, e.g. inside a J-tube or above the water table within the landfall area.
Figure 4-2
Thermal assessment cases for cables. (a) Inside J-tube in water/air, (b) buried in seabed, (c) inside conduit

Typically, the purchaser provides data as indicated in Figure 4-2 and explained below whereas the manufacturer calculates the current rating for a range of scenarios employing analytical and finite element methods. For further details see [B.4].

a) Ambient temperature conditions: Per cable section, e.g. in J- or I-tube at offshore unit (air, water), buried in seabed (water, soil), buried onshore (soil, air). Change of temperature over time (e.g. one year).

b) Other ambient conditions: Solar irradiation, air movement (e.g. wind), water movement (e.g. convection), as applicable.

c) Dimensions: Burial depth (minimum, e.g. for regulatory compliance and maximum, for worst case cooling assessment), tube / conduit diameter and thickness.

d) Thermal properties of materials: Heat conductivity (wet and dry, as applicable), thermal diffusivity, adsorption.

e) External heat sources: Other cables in proximity, pipelines, etc.

4.4.1.5 Mechanical specifications

The mechanical properties of the cable are strongly influenced by its armour and shall allow all required handling during the manufacturing, storage, load-out, transport, installation, operation phases as well as, if required, repair and decommissioning phases of the project. The anticipated handling should be specified by the purchaser and design properties, such as those listed below, should be specified by the manufacturer. For further details see [B.5].

a) Handling activities: Type and number of cycles, e.g. coiling or cable laying / recovery. Normally according to CIGRÉ Electra 171, see [5.2.2].

b) Dimensions: Outer diameter, roundness (also taking into account factory joints).

c) Weight: In air and water.

Guidance note 1:
Specific weight in kg/m is required for the assessment of storage and installation operations. Specific weight in kg/m³ is required for the assessment of trenching operations.

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d) Mechanical stress properties: Tensile strength, minimum bending radii at specified maximum tensile loads (also sidewall pressure), number of bending cycles. For installation analysis, axial / bending / torsional stiffness. For coilable designs, minimum coiling diameter and number of coiling cycles. Temperature dependency of properties, where relevant.

Guidance note 2:
Subsea power cables are qualified by testing using appropriate mechanical loading which represents worst handling conditions, commonly in accordance with CIGRÉ Electra 171. During installation (or repair) the worst combination of tension and bending will normally be experienced by the cable as it passes over the lay wheel or chute.

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e) Crush, squeeze and impact properties: Crushing / squeezing strength (e.g. for stacking, cable engine use, pulling stocking use) and allowable impact energy from falling objects (e.g. rock placement).
Guidance note 3:
Allowable squeeze loads in cable engines depend on the engine configuration and should be discussed between cable manufacturer and purchaser / installer.

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f) Friction and abrasion: Depending on the installation technique, the longitudinal and/or lateral friction coefficients for pull of the cable over installation equipment and/or across the seabed are of interest.

Guidance note 4:
Site-specific cable - soil friction coefficients may be derived based on survey results / standard laboratory testing of soil samples and the cable characteristics (outer diameter, weight, outer serving material roughness). Abrasion resistance may be relevant for e.g. second-end pull-in across rough seabed. Relevant parameters should be discussed between cable manufacturer and purchaser / installer.

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4.4.1.6 Cable construction features
The features of the complete cable should be specified by the manufacturer, most of which will be a result of the functional specifications.

Guidance note 1:
In some cases the purchaser may have a preference for certain design features, e.g. for conductor material, conductor cross-section and/or insulation material, which should be discussed with the manufacturer.

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Important parameters for typical cable features (see Figure 1-4) are shown in the following. For further details see [B.6].

a) Conductor: Material, cross-section, shape / type of conductor, overall diameter, longitudinal water blocking method.

b) Conductor screen: Material (commonly semiconducting), thickness.

c) Insulation: Material, thickness, maximum temperature.

d) Insulation screen: Material (commonly semiconducting), thickness.

e) Metallic screen: Material, thickness, cross-section, radial / longitudinal water blocking method.

Guidance note 2:
When an impermeable metallic sheath (e.g. lead sheath) is part of the design, the cable is sometimes referred to as “dry design”, otherwise as “wet design”.

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g) Fillers: Type, material, thermal conductivity.

h) Integral optical fibres: See [4.4.3].

i) Armour bedding: Type, material, thickness, thermal conductivity.

j) Armour: Number of layers; type (e.g. wire), material, nominal size, lay length, lay direction, corrosion protection for each layer.

Guidance note 3:
In offshore wind farms, single (unbalanced) armour is typically used, see also [4.6.2]. For double armour, the armour layers may be laid in opposite directions (“counter-helically”) to provide a torsion balanced (but non-coilable) design (Figure 4-3).

---c-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Figure 4-3
Cable armour. (a) Z- and S-lay, (b) forces, (c) unbalanced armour, (d) torsion balanced armour
k) Outer serving: Type, material, thickness, thermal conductivity, identification marks (labels, length marking, coloured stripes).

**Guidance note 4:**
The outer serving can also provide resistance against chemical failure modes including UV-related deterioration and corrosion. Corrosion impact of seawater onto armouring wires should be considered to retain the cable’s capability to withstand external forces and tensile strength for possible repair work.

---end---of---Guidance---note---

4.4.1.7 Testing specifications
Non-electrical and electrical manufacturing tests for the cables including the applicable standards should be agreed between purchaser and manufacturer, see [5.2].

In addition, the following should be discussed and, if applicable, the necessary information provided by the manufacturer:

— monitoring during load-out, inspection and testing after load-out, inspection and testing after transportation (see [5.3])
— monitoring during installation, testing after installation
— testing after commissioning (see [6.9])
— monitoring and testing during operation (see [7.3]).

4.4.1.8 Logistical information
The purchaser should specify logistical requirements for the cable project such as:

— place and time of delivery
— method of delivery (e.g. on drums / in basket / on turntable, individual cable lengths / continuous length)
— cable section lengths, sequence, identification
— installation aspects (cable supply only, installation supervision, turnkey supply).

The manufacturer should provide information on the ability to meet the request such as, for instance, production and testing capabilities, availability of production capacity and maximum continuous length of cable sections.

4.4.2 Power cable accessories
Subsea power cable accessories may include, but not be limited to, the following:

— joints (e.g. single-core / three-core, flexible / rigid), see also [1.3.2] and [6.4.3]
— terminations kits, see also [6.9]
— cable end caps
— hang-off modules, see also [4.7.2.6]
— pulling head / stocking.

Joints and terminations should be designed in accordance with applicable IEC standards and CIGRÉ guidelines.

**Guidance note 1:**
For general guidance on accessories for cables with extruded insulation, see CIGRÉ Technical Brochure 177.

---end---of---Guidance---note---

The joints and terminations shall have at least the same electrical strength as the cable itself. Mechanical properties of accessories can deviate from those of the cable and should be specified.

The design of the termination kit shall be compatible with the selected power cable design and switch gear design with regard to selected standards, dimensions and materials.

**Guidance note 2:**
The termination should also consider the connection of surge arresters, if required, and the connection of a test adapter.

---end---of---Guidance---note---

Normally, the joints and terminations should be of a proven technology. All joints and terminations shall be subjected to a test programme in accordance with the applicable standards, see [5.4].

The design or use of non-electrical accessories such as cable end caps, hang-off modules and pulling devices should be confirmed by the cable manufacturer.

4.4.3 Optical fibres
Three-core subsea power cables and some single-core designs may contain a number of optical fibres.
Guidance note 1:
Optical fibres integrated in cables are used for wind farm SCADA, communication, protection relays and cable monitoring purposes. Fibres for cable monitoring purposes may be of a different type than those for communication purposes.

Multi-mode fibres (typical wavelength 850 nm) are usable for shorter distances, single-mode fibres (typical wavelengths 1310 nm and 1550 nm) can be used at long distances.

The design specification for the integrated fibre optic package should be agreed between purchaser and manufacturer. Specifications may include, but not be limited to, the following:

— fibre type (single-mode or multi-mode) and operational wavelength
— number of fibres, including spare fibres
— dimensions and optical properties of single fibres, e.g. attenuation, bending loss
— construction of overall fibre optic package (e.g. fibres in metal tube, hydrogen scavenger gel, armour, sheaths), mechanical properties (e.g. maximum tension, crush load, impact, bending, torsion), water penetration
— hybrid solutions, e.g. inclusion of stress sensitive fibres for cable motion monitoring
— earthing of metallic parts of fibre optic package
— marking of individual fibres, i.e. colour coding scheme
— testing standard and special testing requirements.

It shall be possible to connect the optical fibres of different cables using a standard splicing tool.

Guidance note 2:
A general expectation for subsea cables is that continuous lengths of optical fibres are used which do not require splicing in the power cable factory.

Splices, connectors and splice/connection boxes shall be available for the optical fibres and suitable for the intended (e.g. offshore) application.

4.5 Cable route

4.5.1 General

Results from the general project layout phase ([3.2]), the desk-based study phase ([3.3]) the cable route surveys ([3.4]) and further pertinent information should be used in the detailed cable route engineering process.

Cable route engineering should refine the horizontal (x, y) position of each cable segment as well as its vertical (z) position (on the seabed, buried, protected). For details on cable burial and other protection methods, see [4.6], for details on landfall design, see [4.8].

Key parameters and constraints should be extracted from the design basis ([4.2.4]) or otherwise be defined, preferably in consultation with the installer, including:

— site constraints (slopes, rough terrain)
— minimum and/or maximum cable segment lengths
— cable constraints (minimum straight segment length between two alter course (A/C) points, on-bottom tension range)
— equipment constraints (minimum on-bottom radius, maximum A/C or arc angle)
— distance from existing cables, related to planned equipment and water depth
— avoidance of (unnecessary) crossings
— preference for straight cable pulls to / from offshore units
— temporary laydown areas, e.g. prior to jointing
— time restrictions.

Guidance note 1:
In general, bending of an armoured cable in one direction and after a short distance in the other direction should be avoided. To relax the cable, a minimum distance between bends of opposite direction may, for instance, be more than 5 m. Such an assumption should be confirmed by the cable manufacturer.

Based on the identified constraints, the cable route should be designed and optimised, preferably using a geographical information system (GIS) or similar route engineering tool. The preliminary route description should include, but not be limited to:

— route position list (RPL), acceptable tolerances for the as-laid cable
— estimations for burial depth
— crossing description, if applicable
— landing description, if applicable
— vessel access restrictions, e.g. draught.

**Guidance note 2:**
For a standardised format for cable route position lists, see ICPC Recommendation 11.

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Detailed cable route design and length calculations for each cable should take the following conditions into account, as applicable:

— end point locations (e.g. wind turbine, offshore substation, landfall, offshore / onshore joints) and tolerances of end point locations
— approach angles for offshore units (also considering “cable free” zones) and landfall
— lengths and overlengths required at offshore units (to termination point), cut-off lengths for pulling and preparation of cable end terminations
— length as laid and buried into the seabed, taking into account the bathymetry (slopes), positioning inaccuracies, potential deviation from / adjustment to the route
— crossings with existing infrastructure, commonly perpendicular
— installation method, e.g. first- and second-end pull-in
— burial method
— jointing of cable (or preference to have no joints) and laydown of bight.

The cable route should be further refined in the burial assessment study (see [4.6]), taking into account risks such as navigation. Specific aspects are addressed in the following subsections.

### 4.5.2 Parallel routing of power cables

When power cables are routed in parallel, the distance between them should be subject to careful evaluation.

**Guidance note 1:**
National or local regulations may require minimum distances to be kept between cables, specifically export cables. In congested areas of the sea, regulators may also have a preference for maximum cable distances to not unduly limit future developments.

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Optimum spacing of two or more power cables should be determined considering project internal and external factors.

**Guidance note 2:**
Factors that influence optimal cable spacing may include those listed in Table 4-2.

<table>
<thead>
<tr>
<th>Narrower spacing</th>
<th>Wider spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum corridor width</td>
<td>flexibility of route adaptation when encountering difficult ground conditions</td>
</tr>
<tr>
<td>accommodation of existing constraints, e.g. at approach to offshore unit or landfall</td>
<td>maximise utilisation of space, e.g. for subsequent cable installation</td>
</tr>
<tr>
<td>minimisation of interaction with existing or planned 3rd party infrastructure, avoidance of proximity or crossing agreements</td>
<td>adequate space for potential repair activities and laydown of repair bight</td>
</tr>
<tr>
<td>reduction of the magnetic field and the effect on the environment (in case of two HVDC poles which are not laid in the same trench or bundled, for thermal or other reasons)</td>
<td>greater flexibility in choosing vessel and equipment for intervention (burial, de-burial, cable pick-up)</td>
</tr>
</tbody>
</table>

Considering safety margins, parallel distances which have been realised in the past were, for instance, 50 m (Red Penguin, 2012) and 100 m. In very shallow waters, allowance may have to be made for the beaching of the cable installation vessel when deciding cable spacing. Due to the potentially large number of cables connected to an offshore substation, the distance between the cables may have to be reduced to several metres in the immediate vicinity of the offshore unit (see Figure 4-12).

Cables, in particular DC poles, may also be bundled and laid in the same trench (reduction factors to their current carrying capacity apply).

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Due consideration should be given to the potential repair of a cable. Laydown space requirements for the repair bight depend on water depth, repair vessel deck height, required deck length and crown radius of the bight. Space in addition to the repair bight height (Figure 4-4) may have to be foreseen for future intervention. When more than two cables are routed in parallel, consideration of laydown space for the repair bight become crucial.
4.5.3 Proximity to existing infrastructure

When new power cables closely approach or run in parallel to planned or existing infrastructure (pipeline, telecommunication cable, power cable, fixed or floating offshore unit), the potential consequences should be assessed. The assessment should consider the development, construction, maintenance (especially repair) and decommissioning activities of both parties.

Information about planned or existing infrastructure should be exchanged between the parties concerned as early as possible.

A written proximity agreement between the project developer and the owner/operator of the existing infrastructure may prove useful. The agreement should cover planned and possible activities of either party which may affect the other (e.g. anchoring or burial).

Existing offshore units may have designated exclusion zones in which no new developments can take place in order to avoid damage by third parties.

**Guidance note 1:**

The United Nations Convention on the Law of the Sea (UNCLOS) article 60 of 1982 allows a safety zone of up to 500 m around infrastructure which parties not related to the project or object must respect.

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Existing submarine pipelines may have designated exclusion zones.

**Guidance note 2:**

Pipeline design standards ISO 13623 and DNV-OS-F101 promote a risk based approach. Distance requirements are driven by the risk of incidents leading to loss of human life.

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Existing submarine telecommunication cables are commonly repaired using grapnel techniques to pick up the cable. Grapnel runs require safety distances to both sides of the telecommunication cable.

**Guidance note 3:**

ICPC Recommendation 13 discusses the distance required between offshore wind turbines and subsea telecommunication cables. Assumptions are provided for safety zones around wind farms, vessel length, grapnel length and run-on. For further, risk based considerations, see Subsea Cables UK Guideline 6.

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4.5.4 Crossing of existing infrastructure

Every crossing of existing infrastructure (pipeline, telecommunication cable, power cable) has its own characteristics and should be assessed separately.

Information about the proposed crossing shall be exchanged between the parties concerned as early as possible.

A written crossing agreement shall be reached with the owner/operator of the existing infrastructure. The agreement should cover the definition of the crossing area (including a safety zone, if applicable), the crossing design, the installation method description (including anchoring, burial), future maintenance requirements for each asset, liability of both parties and validity of the agreement.

**Guidance note 1:**

For guidance on design considerations for crossings between power cables and existing or new telecommunication cables, see ICPC Recommendations 2 and 3. Generic crossing agreements are available from ICPC.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---
Considerations concerning the exact crossing location and the design of the crossing shall include the following:

— location (and its uncertainty) of infrastructure
— site conditions, e.g. water depth, wave / current action and ground conditions
— type and protection of existing infrastructure, e.g. burial depth
— type and protection of planned cable
— mutual heating of planned cable and existing infrastructure, if applicable
— effects of magnetic fields from the new cable onto the existing infrastructure
— specific features of existing pipeline (e.g. anodes for cathodic protection) or telecommunication cables (e.g. repeaters, equalisers, branching units) which require minimum distances to be kept
— crossing at approximately right angle (90°) and never less than 45°
— service state (in service, out of service) of existing infrastructure and corresponding limitations (e.g. work near live power cables, pipeline in use)
— forming of artificial reef by using protection methods such as mattresses and rock placement
— local legislation protecting the existing infrastructure.

**Guidance note 2:**
New power cables may be laid on top of an existing telecommunication cable or underneath. The latter requires a cut and joint in the telecommunication cable. New telecommunication cables are generally laid over existing power cables.

---end---of---Guidance---note---

The design specification for a crossing shall state requirements concerning:

— minimum (vertical) separation between existing installation and the cable
— co-ordinates of crossing
— marking of existing installation
— confirmation of position and orientation of existing installations on both sides of the crossing
— lay-out and profile of crossing
— thickness of cover
— installation of supporting structures or gravel beds
— stability of protection, including methods to prevent scour and erosion around supports
— vessel positioning / anchoring
— installation / burial techniques and minimum distances including safety zones
— monitoring and inspection methods
— tolerance requirements, safety margins
— any other requirements.

**Guidance note 3:**
Suitably designed rock berms, also in combination with mattresses and/or bags, have been used for crossings with pipelines, power cables and telecommunication cables.

---end---of---Guidance---note---

### 4.6 Cable protection

#### 4.6.1 General

During installation, cables shall not be subjected to mechanical loads exceeding the cables’ design limits, including tension, bending, torsion and crushing, see [4.4.1.5]. After installation, for the service life of the project, cables should be suitably protected from hazards, such as the following:

— marine (waves, tides) and sediment conditions, e.g. exposure and movement of cable
— unsupported lengths of cable, e.g. in uneven terrain or due to sand waves
— movement of the cable between laying and protection (‘on-bottom stability’), potential for abrasion
— penetration of fishing gear, e.g. during bottom-trawling activities
— dropped or dragged ship anchors, intended or inadvertent
— invasive activities, e.g. dredging
— dropped objects, e.g. lost shipment containers or cargo transferred between vessel and offshore unit
— seismic activity
— ice scour.

Besides safeguarding from hazards, the design of cable protection along the proposed route should not adversely affect the required operational conditions of the cable (e.g. maximum temperature). Protection solutions may include the following, including combination of these:

— additional armour ([4.6.2])
— burial ([4.6.3])
— non-burial protection including tubular products, mattresses and rock placement ([4.6.4]).

**Guidance note:**
The external aggression risk profile along a cable route can vary to a large degree with burial generally providing the primary mitigation measure. The degree of protection provided by burial depends on a range of factors, including the risk of external aggression and the properties of the ground. Some guidance may be derived from the submarine pipeline sector, see e.g. DNV-RP-F107.

Of the damages reported world-wide for subsea power cables at voltages $\geq 60$ kV for the period from 1990 to 2005, almost half are attributed to external causes (CIGRÉ Technical Brochure 379). Most damages occurred on unprotected or insufficiently protected cables in shallow waters.

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### 4.6.2 Additional armour

Subsea cables are designed to be robust enough to withstand mechanical stresses due to handling, storage, transportation, installation as well as recovery for repair and redeployment, see [4.2]. This is achieved by the use of single armour or double armour.

**Guidance note:**
Most cables for offshore wind projects in shallow water require only single armour. Double armour could be useful for long pull lengths in landfall areas or for cable installation in deep water, see also [4.4.1.6].

In some occasions, specifically designed “rock armour” may enable the installed cable to withstand larger forces. Rock armour is similar to double armour, but the pitch angle of the armour is larger, the armour wires are typically of a larger diameter, and thick polypropylene beddings are used between the two armour layers.

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### 4.6.3 Cable burial

#### 4.6.3.1 General

Burial as the primary method of protection of a subsea power cable can provide mitigation against the potentially different hazards for array and export cables. Burial depth should be determined considering project internal and external factors.

**Guidance note:**
Factors which determine burial depth may include those listed in Table 4-3.

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#### Table 4-3 Considerations for optimum burial depth

<table>
<thead>
<tr>
<th>Shallower burial</th>
<th>Deeper burial</th>
</tr>
</thead>
<tbody>
<tr>
<td>— larger choice of installation techniques, equipment and operators, use of smaller vessels and less power</td>
<td>— better protection from external aggression</td>
</tr>
<tr>
<td>— less stress on cable and machinery during installation</td>
<td>— better protection in areas with mobile sediments</td>
</tr>
<tr>
<td>— less disturbance of the seabed (fluidisation, trenching) and fewer restrictions derived from the environmental impact assessment (EIA)</td>
<td>— meeting prescriptive regulatory requirements</td>
</tr>
<tr>
<td>— improved cooling of cable, higher current rating of cable</td>
<td>(where applicable)</td>
</tr>
<tr>
<td>— easier cable detection and recovery in case of required repair or end-of-life removal</td>
<td>— faster work progress</td>
</tr>
<tr>
<td>— faster work progress</td>
<td>— better protection in areas with mobile sediments</td>
</tr>
</tbody>
</table>

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

#### 4.6.3.2 Burial assessment

The burial assessment study provides input to the final cable route design ($x$, $y$, $z$ coordinates) by determining

— risks along the cable route
— appropriate depth of burial for the cable sections
— suitable (lay and) burial method(s) and resulting trench profiles
— additional protection that may be required.

**Guidance note 1:**
For the definition of ‘depth of burial’, see [1.3.2].

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The optimum depth of burial should be determined by applying a risk based approach, yielding an adequate and economical burial with a consistent level of protection. This may result in a varying burial depth along a longer route.
Guidance note 2:
Local regulations may require minimum burial depths and shallower burial may not be allowed. A risk based assessment may aid the discussion with the authorities and identify sections of the cable which should be buried shallower or deeper than the blanket requirement.

---end of Guidance note---

The risk based approach regarding external aggression in a relatively stable seabed comprises the following steps:
— determination of the external aggression risk along the cable route (dropped anchor, dragged anchor, fishing gear interaction)
— determination of the ground properties along the cable route to assess potential penetration depths
— for long cables, division of cable route into sections of similar risk profile
— application of a qualitative, semi-quantitative or quantitative method to determine a minimum burial depth which meets the cable project objectives.

Methods that may be useful in determining the burial depth include:
— review of long-term experience with similar infrastructure in the area, qualitative assessment
— burial protection index (BPI), semi-quantitative assessment, see Figure 4-5 a
— threat line, quantitative assessment, see Figure 4-5 b.

Guidance note 3:
Long-term data of existing infrastructure like buried power cables, telecommunication cables and pipelines can provide valuable insight in the achievable reliability levels. Simple application of failure statistics, however, can be misleading.

The BPI method (Allan, 1998) is generally considered a significant improvement over blanket burial depth requirements. The various types of seabed differ in the degree of protection they provide regarding penetration of locally used fishing gear and anchors. Depending on the identified risk of anthropogenic activities and the known ground properties, a required depth of cover can be deduced. The limitations of the BPI include that it was derived from ploughing tow force data with less-proven applicability for other burial techniques like jetting, that the concept was not sufficiently validated and that the factor of safety achieved is not readily apparent.

The “threat line” is the depth of penetration of a specific hazardous activity into the seabed. The risk can be assessed for various types of hazards (e.g. various types of trawling gear and anchors), after which the threat line can be defined to meet the cable system’s target reliability. The method requires appropriate data to be available for the assessment. It is suitable for inclusion of further hazards like sand waves.

---end of Guidance note---

Figure 4-5
Principle of risk based burial assessment. (a) Burial protection index, (b) threat line

In areas of unstable seabed (e.g. areas with mud slides, megaripples, sand waves, or erosion due to currents / waves /storms), the risk based approach should be expanded to account for the sedimentary processes. Data should be obtained or collected covering long periods (commonly several years, also distinguishing seasons) to assess the situation along the planned cable route. The information may be used to determine a corresponding threat line.

Mitigation measures in areas with unstable seabed may include the following, possibly in combination:
— avoidance of the area
— routing of cables perpendicular to the direction of megaripple / sand wave migration, burial below the megaripple / sand wave trough
— pre-sweeping / pre-lay dredging, disposing sediments and equalising the seabed
— specific rock berm designs, see [4.6.4.4]
— periodic inspections and remedial burial.

Guidance note 4:
In areas with megaripples or sand waves, a threat line could be assumed as the arithmetic sum of anchor penetration depth and height of mobile sediment layer. The corresponding burial depth may be reduced by site-specific mitigation measures.

Burial along the trough of megaripples / sand waves can provide good long-term protection, but may result in poor cooling due to excessive overburden and in difficult access for future repairs.

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4.6.3.3 Burial design

Burial design for cables should determine the trench geometry along the entire cable route including the main parameters, depth of lowering and depth of cover (see Figure 1-6). Time-dependent processes (e.g. natural backfilling) should be taken into account when designing the trench geometry.

Guidance note:
Where the selected trenching tool produces a narrow trench profile, ‘depth of lowering’ is frequently the primary requirement for protection. For wide trench profiles, backfilled ‘depth of cover’ could become a focus of burial design. The properties of the undisturbed soil and the backfilled material may be different. Due to the disturbance of the ground, the strength of the backfilled material is frequently lower. Settlement processes may increase soil density / strength again over time.

In general, varying burial depths along the route are more applicable for longer lengths of export cables than for array cables.

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Detailed engineering assessments should determine the feasibility of the design burial depths and whether pre-sweeping or pre-lay trenching may be required.

4.6.3.4 Burial techniques

The range of suitable burial techniques for a cable project should be assessed (Figure 4-6). Criteria for choosing one technique over another may include:

— water depth, marine conditions (specifically currents and waves)
— soil / rock properties including horizontal/vertical homogeneity
— environmental impact
— cable length, mechanical properties (e.g. maximum tension, stiffness) and specific weight
— burial depth requirement
— combination (simultaneous lay and burial) vs. separation (post lay burial) of cable laying and burial
— potential burial equipment (and support vessel) capability and availability.

Figure 4-6
Protection of cable through burial. (a) Jetting / fluidisation, (b) ploughing, (c) mechanical cutting, (d) open trench dredging

Guidance note 1:
No single method of burial will work in all ground conditions. Pre-mature decisions for or against one technique, e.g. during the permitting process, can negatively impact the feasibility of a project.

Self-burial of cables after laying on the seabed should not be considered an acceptable method of lowering.

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For guidance on burial tool selection, see [6.2.7]. Specification of burial depths and suggested burial technique should be reviewed, e.g. by an experienced installer, regarding feasibility and appropriateness.
4.6.4 Non-burial cable protection

4.6.4.1 General

Alternatives to burial protection or additional / corrective measures may be required in specific sections along the cable route and jointing areas including:

— at the interface between cable and offshore units
— in the immediate vicinity of offshore units where burial is not practical
— at infrastructure crossings, e.g. between power cable and pipeline
— across boulder, cobble or gravel fields or in very hard (rocky) seabed, including areas with insufficient sediment thickness, where trenching may not be feasible or economic
— in areas with mobile sediments
— where installation activities (e.g. ploughing) had been interrupted and cable was surface laid or minimum burial depth could not be reached
— at cable repair (joint) locations.

Where non-burial protection is required, the most appropriate technique (or combination of techniques) should be selected from the range of options available. These options may include tubular products, concrete mattresses and rock placement (or a combination of these), each having its own merits and detractions (Figure 4-7).

Guidance note:

Tubular products (including cable protection systems at offshore units) may not provide adequate protection against external hazards such as fishing or anchoring.

Non-burial protection techniques are less likely to be recommended for protection of cables over long lengths, except, for instance, in areas with very hard seabed.

The design of non-burial protection is driven by the specific application and should meet the requirements with regard to:

— primary functionality of the cable, e.g. acceptable reduction of current rating
— provision of protection, support and stability
— separation
— flexibility
— risks, e.g. acceptable hazard to navigation.

4.6.4.2 Tubular products

Tubular protection includes protective sleeves consisting of sections made of polyurethane or ductile iron. The segments typically comprise cylindrical half-shells (‘split pipe’) that overlap, interlock and fit around the cable. Some products provide a degree of flexibility (e.g. polyurethane), some are articulated structures (e.g. polyurethane, ductile iron). Tubular products can make the cable more susceptible to hydrodynamic loading or anchor / fishing gear drag. Tubular products are often used in combination with mattresses or rock placement.

The product should be designed to provide characteristics required for the specific site conditions (waves, currents, seabed, other hazards) and application. Design aspects may include:

— bend restriction, to prevent bending below the minimum bending radius of the cable, or bend stiffening
— impact protection, to safeguard the cable from dropped objects or other inadvertent impact
— stability improvement by mass addition
— abrasion resistance, to increase life of the cable in high energy / hard seabed environments
— durability (e.g. securing half shells by corrosion-free or corrosion-resistant material)
— heat conduction, to prevent overheating of the cable during operation
— hazard reduction (e.g. smooth outer surface, no protrusions).

**Guidance note:**
Standard polyurethane is comparably light (adding drag); high density polyurethane has specific weight similar to concrete. Ductile iron is comparably heavy (adding stability). The design of the tubular product can impact the cable installation.

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The installation method permitting, pre-assembly of longer tubular sections onshore can be advantageous. The installation of the tubular product around the cable should be carried out on board the vessel, not by divers (except for remedial work).

4.6.4.3 Mattresses and bags

Mattresses are lattices of segmented, mould-produced blocks of concrete or bitumen connected by polypropylene ropes which can be laid over a cable to stabilise and shield it, often at cable crossings. Small sections of the cable or gaps between mattresses may also be protected by pre-filled grout bags or gabion (rock filled) bags. Concrete shields may be a suitable method of protection for extreme external aggression, e.g. in a landfall area.

The mattress protection should be designed to provide characteristics required for the specific site conditions (waves, currents, seabed, hazards) and application. Design aspects may include:
— hydraulic stability, e.g. through overall weight, increased density and configuration
— multi-flexibility, i.e. ability to bend over two axes
— over-trawlability through design of the mattress edges (e.g. butt, tapered)
— adaptation to scour at the periphery.

**Guidance note:**
The required density and thickness of a mattress depends on hydrodynamic loading and target impact resistance.

To encourage build-up of sediment material which is suspended and transported in the water column, synthetic frond mats (“artificial seaweed”) may be introduced on top of the mattress and simultaneously installed.

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Where multiple mattresses are to be installed, alignment and “butting up” criteria (tolerances) should be established. If applicable, it should be established how gaps between mattresses will be filled (e.g. by grout bags).

The method of deployment should be defined (commonly by crane). Intervention should be diverless; operational limits of remotely operated vehicles (ROVs) shall be taken into account. The required installation frame (or beam) should be designed, certified, inspected and, if applicable, tested according to applicable codes and standards and have a safe working load required for the dynamic conditions during installation.

4.6.4.4 Rock placement

Rock placement is the subsea installation of crushed stones of varying size to form a protective barrier over the cable. Rock placement is e.g. used for scour protection, at infrastructure crossings or where not reaching minimum burial depth left the cable insufficiently protected. Rock berms are relatively resistant against trawling and anchoring activities.

**Guidance note 1:**
Rock covers may be reef and habitat forming, which, depending on area and legislation, may be regarded as a positive or a negative environmental impact.

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The rock berm should be designed to provide characteristics required for the specific site conditions (waves, currents, seabed, hazards) and application. Design aspects may include:
— long-term hydraulic stability
— over-trawlability and protection against dragging anchors (e.g. through choice of slope, rock size)
— rock impact energy during installation
— adaptation to displacement, e.g. due to weak soil, and scour at the rock berm edges and related maintenance requirements (e.g. by means of a falling apron)
— environmental impact (e.g. limitation of chemical reactions through choice of rock material)
— availability of rock, loading facilities, transportation options and times.
**Guidance note 2:**
Rock berms can be described by their geometry (length, width, profile) including acceptable tolerances, see also CIRIA Guideline C683. Layers and grading of rock are typically specified in accordance with EN 13383-1.

The method of rock installation should be suitable for the product to be deployed with the required profile and accuracy in the water depth at site. The impact of the falling rock onto the cable (or the cable protection system) should be confirmed to not compromise the cable integrity.

**Guidance note 3:**
The rock falling speed in the water column depends on installation method, rock grading and density.

---end---of---Guidance---note---

### 4.7 Cable interface at fixed offshore units

#### 4.7.1 General
The design of the interface between a subsea cable and a fixed offshore unit shall take conditions and limits during installation (primarily mechanical) and after installation (electrical, thermal, mechanical) into account.

**Guidance note:**
Offshore units comprise offshore platforms (e.g. AC transformer station, HVDC converter station) and offshore renewable generators (e.g. offshore wind turbines). Examples of interfaces shown, e.g. in Figure 4-8 and Figure 4-11, are for illustration.

---end---of---Guidance---note---

#### 4.7.2 Offshore unit

##### 4.7.2.1 Field layout
In the vicinity of offshore units where cables terminate, the cable layout should be optimised, avoiding congestion of cables and enabling installation, including burial and non-burial protection.

**Guidance note 1:**
A layout optimised for installability does not necessarily result in the shortest cable lengths. The de-risking nevertheless normally lowers overall project cost as a reduction in vessel time can more than compensate for a small increase in cable length.

The direction of approach to offshore units should take other users of the interface area at/near the offshore unit into consideration. A perpendicular approach often eases installation and minimises installation forces, see also [4.7.3].

---end---of---Guidance---note---

Restrictions at / near offshore units like jack-up “cable free” zones shall be respected. Conversely, “no jack-up” zones should provide adequate space for cable routing.

**Guidance note 2:**
Punch holes left by jack-up vessels can make routing of cables across difficult and should be avoided, where possible. Furthermore, scour may be encouraged around the jack-up legs and in the area of the punch holes. After cable installation, the use of jack-up vessels in close proximity to the cable increases the risk of damage and should be avoided where possible.

---end---of---Guidance---note---

##### 4.7.2.2 Access
Access of personnel and transfer of cable installation, termination and testing equipment to the offshore unit should be considered in the design.

**Guidance note 1:**
Access to the offshore unit can often be a limiting factor for installation progress. Reduction in requirements to access the offshore unit or improvement of the access system / method can result in more cost effective projects.

A davit or other type of crane with a source of power is normally required on each offshore unit to safely transfer any cargo such as equipment, tools and parts.

---end---of---Guidance---note---

Different design options should be considered. The choice of design should meet the objectives described in Sec.2.

**Guidance note 2:**
Different design options exist for the interface between the seabed-mounted substructure and the topsides. When a cable deck is part of the substructure (Figure 4-8 a), the subsea cables can be pulled in prior to installation of the topsides, decoupling installation steps. Typically cables cannot be pulled to final length in one step, but attachment of an approved pulling stocking and pull of additional length will be required. Laydown space should be provided,
respecting the bending radius for the three-core AC cables, single-core AC cables or DC cables, as required. For guidance on intermediate connections, see [4.7.2.4]. Additional steelwork may be required and should be designed considering cable weight, wind loads and the offshore environment. Mechanical protection and sealing of the cable ends may be required for the period until topsides installation. The design should permit future repair (including replacement) of a power cable with topsides installed.

When the cable deck is part of the topsides structure (Figure 4-8 b), the subsea cables can only be pulled in after installation of the topsides. The design of the cable path may allow pull of the cable to final length in one work step. Depending on the stabbing design, the J-tubes may not be allowed to protrude above the substructure and “filler” sections may have to be inserted after topside installation to bridge the distance to the cable deck.

Figure 4-8
Offshore unit / substructure design and installation

Where entry into confined space is required, this should be considered for persons and equipment to be used, including potential requirements for emergency escape.

4.7.2.3 Space and support requirements

At any offshore unit where subsea power cables connect (e.g. offshore substations, offshore wind turbines), the following recommendations apply:

a) Location of subsea cable entry points and relative positions of equipment should also consider a suitable and safely accessible cable path. Preferably, the equipment where the cable connects should be placed close above the hang-off while enabling necessary cable handling and termination activities.

b) Interference of cable pathways with other appurtenances on the offshore structure (e.g. boat access systems, cathodic protection systems) should be avoided.

c) Suitable pathways, locations and support systems for transferring, placing, operating and removing pull-in, termination and testing related equipment should be identified, including, for instance, winch, winch foundation, anchor points, pulleys, load-monitoring device. The space should be sufficient for safe execution of all work steps.

Guidance note 1:
Pull-in equipment should be sized to account for expected installation forces including applicable factors of safety (see also [6.5.1]). Permanent fixtures and/or pulling equipment (with contingencies) are preferable over temporary fixtures, also facilitating possible future repair works.

A straight pull up through the offshore unit’s structure is preferable. A pad eye suitable for cable pulling should be available above the hang-off flange, located as high as possible. The pad eye should be designed for the expected pulling / lifting forces, which may be in the range from 5 to 10 t for wind farm array cables and from 10 to 20 t for wind farm export cables. The space between hang-off and pulling point should be free, e.g. at a diameter of 0.6 m. If any cable ladder, beam, pipe or other structure crosses this space, it should be easily dismountable.

d) Adequate space for the pull-in operation, laydown, temporary fixing and permanent fixing of required cable length and overlength should be provided.

Guidance note 2:
Temporary or permanent provisions may be required to safely maintain the pulled-in cable’s minimum bending radius. Temporary storage of the cable should normally be possible without having to strip down the cable to the power cores.

Excessive overlengths can result in difficult handling and considerable offshore work effort; therefore overlengths should be kept to a minimum.
a) Computer modelling and/or mock-ups should ensure that the steel support structure, pipework and similar does not interfere with cable access or installation equipment (such as winch lines).

At offshore substations specifically, the following recommendations apply:

a) The clearance between cable deck and main deck shall be sufficient to carry out the cable pull-in and handling operations.

**Guidance note 3:**
The deck height will frequently be required to significantly exceed the minimum bending radius (at maximum pulling force) of the armoured three-core AC cable or armoured DC cable, as applicable.

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b) Congestion of cables and J- or I-tubes should be avoided to aid installation and maintain cable temperatures within acceptable limits.

c) When cables are pulled into an offshore substation, these should normally be planned as a “first pull”, not as a “second pull” (see [6.5]), in order to avoid interference in the congested seabed area (see also Figure 4-12).

At offshore wind turbines specifically, the following recommendations apply:

a) It can be advantageous if cable installation is possible with and without turbine tower installed on the substructure.

**Guidance note 4:**
For repair purposes, cable pull-in should be possible with the wind turbine tower present. For cases where the turbine tower is not yet installed, the flange of the substructure (e.g. transition piece of a monopile solution) should permit the mounting of pulling equipment and installation of the power cables. Davit crane and laydown area available should facilitate pulling equipment transfer.

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b) For relatively flexible structures (e.g. monopile designs), the effect of dynamic loading and cable movement may have to be evaluated.

4.7.2.4 Routing and fixing of cables
For routing power cables inside offshore units, the following recommendations apply:

a) Segregation: Low voltage (< 1 kV) power cables should not be bunched together with, or run through the same conduits as, or be terminated in the same box as cables for high voltage (≥ 1 kV). Cable should be installed well clear of substantial heat sources unless it is ensured that insulation and current rating are adapted to the actual temperatures at such locations.

b) Support: Cables should be installed so that they are not likely to suffer mechanical damage. The spacing between supports or fixing should be suitably chosen according to the type of cable, short-circuit forces and the probability of offshore unit movement and vibration at the point of installation.

c) Accessibility: Safe access ladders and work platforms should be provided for points of the cable run where later inspection or maintenance is planned or foreseen.

d) Cable sectioning: Power cables may be electrically terminated directly at the switchgear or at an intermediate connection above the hang-off system. If part of the design, the cable connection may be suitably located at the cable deck. The connection points of power cable cores and optical fibres may not be co-located and require different cable lengths above hang-off. An interface panel for optical fibres near the hang-off may be required.

e) Corrosion protection: Fixing devices should be made of steel adequately protected against corrosion or non-metallic materials with appropriate properties. Braid or armour of lead, bronze or copper should not be installed in contact with aluminium alloy structures, except in dry indoor spaces.

f) Bending: The minimum bending radius for power cables shall be in accordance with the manufacturers’ recommendations.

**Guidance note:**
A rule of thumb for the minimum bending radius is $20 \times d_o$, where $d_o$ is the outer diameter of the 3-core AC cable. A static cable with no tensile forces applied may allow bending to $15 \times d_o$ or $10 \times d_o$. Planning with larger than the minimum values recommended by the cable manufacturer will ease installation activities.

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4.7.2.5 Penetration of walls and decks
Where cables penetrate walls or decks (above the water level), the following recommendations apply:

a) Integrity: Penetrations should meet the fire and watertight integrity of the wall or deck.
   Guidance note:
   Use of cables with low emission of smoke in case of a fire should be considered for all indoor sections. The risk of fire and other environmental harms should be evaluated in a project-specific risk assessment.

b) Thermal insulation: Cable runs should not be laid in or covered with thermal insulation, but may cross through such insulation.

c) Chafing: Penetrations of walls and decks should be such that the cables are not chafed.

d) Mechanical support of penetrations: Except for cable hang-off, penetrations should be designed so that they do not take up forces caused by the offshore unit’s movements, vibrations and temperature variations.

e) Temporary seals: Penetrations through outer walls should be adequately sealed for temporary phases until cable installation.

4.7.2.6 Cable hang-off
Where cables are secured by hang-off systems, the following recommendations apply:

a) The hang-off should securely anchor the cable by transferring all mechanical loads from the armour to the structure for the design life of the cable system without compromising the integrity of the cable. The stress on the armour wires should remain in a range avoiding premature wear and yielding.
   Guidance note 1:
   Hang-off modules are often split into a temporary part (based on friction between a clamp and the outer sheath of the cable, installed first) and a permanent part (based on e.g. bending and clamping of the armour wires, installed later), see Figure 4-9. The temporary hang-off can quickly secure the cable after pull-in (and normally stays in place afterwards), while the permanent hang-off supports the cable for its operational lifetime. The temporary hang-off secures the cable sufficiently for cable installation works to proceed. The permanent hang-off is required prior to electrical termination of the cable.

b) The hang-off design should allow the implementation of the earthing design, see [3.2.4.3].

c) The device should account for the cable-integrated or bundled fibre-optic cable.

d) The hang-off should be designed to provide the required level of sealing.
   Guidance note 2:
   Air-tight sealing may be required for health and safety reasons (to avoid gases from below entering work areas) or to prevent the exchange of air (to limit the oxygen content below and reduce corrosion rates).

e) The hang-off should be easily installable.
   Guidance note 3:
   No scaffolding should be required for the installation of the hang-off system, see also [4.7.2.3]. The hang-off weight and dimensions should preferably be in a range so that installation without a crane is possible.
4.7.2.7 Single-core cables
For routing single cores of AC circuits (and for DC installations with high “ripple” content) at an offshore unit above the hang-off, the following recommendations apply:

a) Armour on single-core cables should normally be of non-magnetic type. Typically the non-magnetic armour is earthed at one end.

b) Single-core cables belonging to the same circuit should be laid as close as possible and preferably in a triangular (trefoil) formation. They should be contained within the same pipe, conduit or trunk. Clamps that fix them should, if possible, include all phases.

c) Phases belonging to the same circuit should not be separated by magnetic material and be run together in a common wall penetration (multi cable transit), unless the penetration system is of non-magnetic material.

d) In order to guard against the effects of electro-dynamic forces developing on the occurrence of a short circuit or earth fault, single-core cables should be firmly fixed, using supports of strength adequate to withstand the dynamic forces.

4.7.2.8 Cable termination
All equipment shall be provided with suitable, fixed terminals in an accessible position with sufficient space for dismantling and connection of external incoming cables.

Optical fibres contained within the power cable should be terminated in suitable boxes / cabinets which provide adequate space for splicing and are designed for offshore use.

At the location where cables are terminated, the following recommendations apply:

a) The layout at the cable interface shall not compromise the minimum bending radius of the cable, allow for access as required and provide sufficient and safe working space.

Guidance note 1:
The design should avoid using scaffolding or temporary ladders for installation and/or maintenance activities on the high voltage cores or optical fibres as they complicate logistics and increase health and safety risks for termination personnel, see also [4.7.2.3].

b) Cable entry into the enclosure should provide effective sealing.

c) All connections for current-carrying parts and earthing connections should be fixed so that they cannot loosen by vibration.

d) Disconnectable power cable terminations should preferably have the female part of the termination and insulator included in the switchgear cable chamber, facilitating hermetical sealing of the switchgear chamber.

e) Suitable earth connection points should be provided for fixing bonding leads from cable terminations or cable screen.

f) Electrical testing of cables should be facilitated by inclusion of suitable bushings or cable test sockets in the design.

Guidance note 2:
Where clearances required for an open terminal bushing cannot be achieved, power cables may potentially be tested through the connected switchgear.

In order to carry out certain high voltage tests on cables, it may be necessary to disconnect switchgear voltage transformers and surge arrestors. If required, this should be incorporated in the design.

4.7.3 Interface between cable and offshore unit
4.7.3.1 General
When designing the interface between cable and offshore unit, the following shall be considered:

— cable’s (and cable protection system’s) mechanical and thermal properties
— heat build-up in the cable guiding systems due to cable losses and exposure to direct sun light
— adequate sizing of tubes and their supports to achieve acceptable cable pull-in forces and cooling of the cable
— preference for straight path and avoidance of multiple bends, to minimise installation forces
— smoothness of the surface the cable will be in contact with during pull-in, chafing-proof tube ends
— operational and accidental impacts, e.g. from service vessels
— stiffening of substructure the tube is mounted to (requiring sectioning of the tube)
— corrosion protection of the cable armour and cable supporting elements
— seabed changes (accretion or depletion) and the possibility of the cable entrance being covered or positioned too high above the seabed
— current acceleration due to presence of the structure, vortex induced vibrations.

4.7.3.2 Cable path

Various potential solutions for the path of the cable from the seabed to the hang-off can be considered, which may include, but are not limited to, the following (see Figure 4-10):

a) Fixed external J-tube: External route of the cable through J-tubes which are fixed to the substructure. The cable enters through a bellmouth and is routed up to near the hang-off point.

b) Moveable external J-tube: External route of the cable, similar to fixed J-tubes, but adjustable in height and/or angle to achieve optimal positioning relative to the seabed, e.g. to account for scour hole development.

c) Fixed external I-tube: External routing of the cable with a free catenary curve between seabed and the bellmouth of the I-tube.


Guidance note 1:
“Free hanging cables” on the outside of the structure, exposed to waves and currents, require dynamic capabilities and are not covered by this recommended practice.

An optimum path of the power cables should be determined considering factors applicable for the specific project.

Guidance note 2:
Factors that influence the determination of an optimal cable path may include the following:
— exposure to wind, current and wave loads
— protection from vessel impacts
— location of cable entry into support structure, local stress concentration
— air or water exchange in structure and associated corrosion rate.

4.7.3.3 Interface design

The cable may be routed inside fixed (J- or I-) tubes (Figure 4-11 a) or through a flexible (J-tube-less) interface (Figure 4-11 b). The interface shall be suitably designed to transition the cable from a location on / in the seabed to the substructure of the offshore unit. The interface should:

— allow adequate heat dissipation
— stabilise and protect the cable in the vicinity of the offshore unit’s substructure, taking into account scour, dropped objects, abrasion and vortex induced vibrations
— be easily installable.
The interface may be comprised of components (described further in [4.7.4]), some of which are optional, fulfilling a range of functions:

- prevention of over-bending during cable installation, damping / prevention of cable movement
- alignment and securing of cable / cable protection system at the structure
- dynamic bend restriction for bridging a free span, adequate for vibration and erosion over the service life
- static bend restriction providing anchorage, shallow burial protection, on-bottom stability and supporting the ground - free span transition over the service life.

**Guidance note:**
The interface design should be capable of accommodating the full range of expected scour development, including the case of no scour, unless site-specific information allows for designing with a narrowed range of scour development.

---end---of---Guidance---note---

Depending on the type of substructure / foundation, specific issues should be considered for the interface design, including:

**Monopile / transition piece:**
- impact of pile driving on appurtenances (fatigue or cracking of welds)
- little flexibility for driving of pile with regard to final location of cable entry hole relative to the seabed
- corrosion inside monopile if cable entrance cannot be adequately sealed
- dynamic behaviour (deflection) of substructure and impact on cable, if any.

**Jacket structure:**
- reduction of number of bends in tubes, to ease cable pull-in
- distribution of cables between legs to reduce drag and increase space for cable pull-in.

**Gravity based structure:**
- avoiding collapsing of internal tubes when filling (ballasting) the structure offshore
- current acceleration at foot of structure and impact on scour and cable entry.

In order to allow for smooth cable installation, the following should be considered:

- onshore installation of all elements guiding the cable (e.g. J-tubes, I-tubes)
- location of lower cable entry point (pull-in catenary, build-up of sand)
- location of upper tube exit and hang-off relative to the cable termination point (alignment)
- access to installation / inspection space before and after installation of topsides structure / wind turbine
- availability of deck space
- installation time requirements (e.g. pre- or permanently installed pulling equipment)
- clear labelling of guiding elements (e.g. J-tubes, I-tubes)
- pre-installed, labelled messenger line
- ROV versus diver use, attachment points
- sequence of multiple cable installation (e.g. allowing any sequence).
4.7.3.4 Multiple cable interfaces
For routing multiple cables up a structure, the following shall be considered:

a) The distance between multiple tubes should be adequate to aid installation and to avoid thermal constraints and excessive wave loads.

b) The distance and orientation between the bellmouths of multiple tubes near the seabed should be adequate to facilitate cable installation and burial.

**Guidance note:**
When multiple tubes are attached to an offshore unit, the distance between their centre lines should be at least 1 m. This will improve cooling and reduce wave loads. The bellmouths of multiple J-tubes should be spaced widely, at least by 2 m, and, space permitting, by as much as 5 m. Aligning bellmouths at increasing angular offsets (fanning) also improves accessibility for equipment and thereby cable installability (Figure 4-12). If multiple cables are pulled in as a “second-end pull”, then the spacing may have to be increased further.

![Figure 4-12](image_url)

**Figure 4-12**
Fanning of multiple J-tubes

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4.7.4 Interface components

4.7.4.1 J-tube and I-tube
Tubes (Figure 4-13) provide guidance and mechanical protection for cables and shall meet requirements including the following:

a) Tubes shall be sufficiently sized, shaped and have a smooth inner surface to allow passage of the pulling device, cable end and cable without exceeding cable integrity limits.

b) When mounted externally to a structure, the tube shall be able to withstand impact forces specified in the design basis.

c) Tubes should be made of steel or, alternatively, of material type tested for the application.

d) Welded sections of the tube shall have a smooth inner surface. This may be assured, for instance, by the welding technique, grinding, use of seamless tube or PE liner inside the tube.

e) Corrosion protection adequate for the design life should be provided.
Guidance note:

As a general rule, the inner diameter of the J-tube $d_{i,tube}$ should not be less than $2.5 \times \text{cable outer diameter } d_{o,cable}$ to facilitate cable cooling and avoid excessive pull-in forces. The bending radius of the J-tube $r$, measured at the centre of the J-tube, should not be less than $20 \times \text{cable outer diameter } d_{o,cable}$ or larger, if specified by the cable manufacturer, in order to facilitate cable installation. The sizing of tube and bending radius should be verified for passage of the pulling arrangement.

An angle of approximately $45^\circ$ between J-tube lower end and seabed allows for a wide range of scour development cases and flexibility in cable installation. The height $h$ of the J-tube bellmouth above the undisturbed seabed (or scour protection layer) depends on the chosen angle, the minimum bending radius and the installation design (Table 4-4). I-tubes require significantly larger distances to facilitate cable installation.

After the bellmouth, the minimum straight length of the J-tube should be at least 1 m to aid centraliser insertion and cable pull-in.

The distance between straight sections of the J- or I-tube should be e.g. $\geq 0.5 \times \text{tube inner diameter } d_{i,tube}$ (to facilitate convection), but not be greater than $5 \times \text{cable outer diameter } d_{o,cable}$ (providing smooth transitions for the cable), see Figure 4-14. Ventilation holes in the tube can improve cooling of the cable but reduce its strength and, if introduced after installation, increase the risk of corrosion.

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4.7.4.2 Bellmouth

The bellmouth is used at tube ends to provide guiding and bend limiting functionality and reduce the possibility of cable damage during pull-in operation (Figure 4-14 a). When designing bellmouths for an J- or I-tube end, the following shall be considered:

- maximum offset angle of cable
- minimum allowable bend radius
- adequate sizing of the bellmouth
- smooth transition between tube and curvature of the bellmouth
- lock-in facility for cable protection system
- cable installation method
- attachment points for ROV and divers
- (temporary) cover and simple release mechanism, to avoid internal build-up of marine growth or sediments
- clear identification marks.

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Table 4-4 Typical J-tube angle and distance values for array cables

<table>
<thead>
<tr>
<th>Angle to seabed</th>
<th>Height above seabed</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>45º</td>
<td>2.5 m ± 0.5 m</td>
<td>Suitable angle for cable protection in a wide range of scour development cases. Provides flexibility for installation techniques.</td>
</tr>
<tr>
<td>30º</td>
<td>2.0 m ± 0.3 m</td>
<td>Compromise between 15º and 45º scenarios.</td>
</tr>
<tr>
<td>15º</td>
<td>1.2 m ± 0.2 m</td>
<td>Suitable angle for cable pull-in with no scour development or subsidence. Larger static forces on J-tube in case of scour development.</td>
</tr>
</tbody>
</table>

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Figure 4-14
Bellmouth design. (a) Large size: J- or I-tube entrance, (b) small size: transition between tubes

Guidance note:
To avoid chafing of the cable, a round bar may be welded to the outer edge of J- or I-tubes made of steel (Figure 4-14 a).

The ends of the tubes should be designed to help guiding whilst avoiding chafing of the cable, e.g. through a simple bellmouth shape, see Figure 4-14 b.

4.7.4.3 J-tube-less interface
J-tube-less interfaces between cable (and its protection system) and structure of the offshore unit (Figure 4-15) shall meet requirements including the following:

a) Entry holes shall be sufficiently sized and shaped / have a smooth radius / surface to allow passage and fixing of the cable with cable protection system.

b) The angle of the entry hole relative to the seabed and the height above the seabed should be chosen to follow the natural catenary of the cable and to allow for smooth cable installation.

c) The position of the hang-off should be preferably diagonally across from the entry hole, as far back as possible.

d) Cable guides inside the structure should be avoided, where possible.

Figure 4-15
J-tube-less cable interface with structure

Guidance note:
A generally suitable angle of cable entry relative to the seabed is 45°. For array cables in offshore wind farms, a suitable installation height above seabed (or scour protection layer) is in the order of 2.5 m ± 0.5 m.

4.7.4.4 Bend stiffener
Bend stiffeners are mechanical devices which (primarily) increase the resistance to bending (e.g. progressively) and improve the dynamic behaviour of unsupported sections of a cable. They shall meet requirements including the following:

a) Design loads should be defined in terms of angle deviations from the mean and effective tension, covering all load cases.
b) The design methodology should consider possible failure modes, including rupture, ageing, fatigue and end-fitting failure.

c) The bend stiffener should be manufactured from materials selected for the specific environment, e.g. polymer (elastomeric) material.

**Guidance note:**
Bend stiffeners are often made of polyurethane. For design guidance on bend stiffeners, see ISO 13628-2, Appendix B.

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### 4.7.4.5 Bend restrictor

Bend restrictors are mechanical devices which limit the bending of a cable to a minimum value. They shall meet requirements including the following:

a) Design loads should be defined in terms of bending moments, shear forces and impact loads (where applicable, e.g. for rock placement).

b) The design methodology should consider ageing and end-fitting failure.

c) A bend restrictor shall lock before the minimum bending radius of the cable is reached. The device shall provide smooth support of the cable without sharp edges.

d) Bend restrictor elements may be manufactured from elastomers, fibre reinforced plastic or metallic materials, which shall be selected for the specific environment and have sufficient corrosion resistance.

**Guidance note:**
Bend restrictors are often made of polyurethane or ductile iron. For design guidance on bend restrictors, see ISO 13628-2, Appendix B.

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### 4.7.4.6 Entry seal

Where a power cable enters the structure of an offshore unit, a seal between cable and structure is sometimes used.

**Guidance note:**
Sealing can reduce seawater exchange inside the submerged part of the structure in order to lower corrosion rates. Sealing can make power cable installation and repair difficult, therefore designs without seals may be preferable.

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If used, the seal should meet requirements including the following:

a) Where the purpose of the seal is to limit or block seawater exchange to reduce corrosion, the allowed rate of exchange should be specified (depending on sealing differential pressure) and the design should be demonstrated to meet the specification.

b) The seal should be easy to fit during installation and allow exchange of the power cable in case of repair.

### 4.7.4.7 Latching / anchoring mechanism

A latching / anchoring mechanism may hold a cable protection system in place after installation. If used, the mechanism should meet requirements including the following:

a) The mechanism should maintain the cable protection system in place under the designed environmental conditions.

b) The mechanism should be easy to install. The latch should be removable, preferably without the use of divers.

c) The mechanism should not prevent an exchange of the power cable in case of repair.

### 4.7.4.8 Tube centraliser

Centralisers provide a local increase in cable diameter, limiting the cable’s lateral movement inside a tube. When used in the bellmouth of J- and I-tubes in power cable applications, centralisers should meet requirements including the following:

a) The centraliser should maintain the position of the cable within the tube.

b) Centraliser and J-tube bend should be designed together so that the minimum bending radius of the cable cannot be compromised during pull-in.

c) The centraliser should be easy to fit during installation. The clamping pressure shall not exceed the limits of the cable.
Guidance note:
For designs where the centraliser is fixed to the cable, cable overlength or bight shape on the seabed cannot be adjusted during cable pull-in.

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4.7.5 Scour and scour protection

4.7.5.1 General
The sea floor variation can commonly be characterised as a combination of the following effects, which shall all be considered:

— local scour, steep-sided scour holes around foundation piles
— global scour, shallow basins of large extent around a structure
— overall seabed movement (depletion or accretion) including megaripples and sand waves (see [4.6.3.2]).

The risk of scour around the foundation of an offshore unit should be assessed to aid cable interface design. In an analysis of scour, the sediment properties together with the effects of steady current, waves, or current and waves in combination should be taken into account as relevant.

Guidance note 1:
Scour in areas with sand is relatively predictable, see e.g. Sumer and Fredsøe (2002); scour in areas with mixed soils is less well understood. Scour in areas of cobbles or stiff clay is generally low. Project-specific scour assessments are strongly encouraged.

The extent of scour will depend on the dimensions of the structure and on the soil properties. Larger diameter piles like wind turbine monopiles lead to larger scour holes than smaller diameter piles as used for wind turbine jacket structures. In cases where a scour protection is in place, the form and extent of scour will also depend on the design of the protection.

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The effect of scour, where relevant, should be accounted for by at least one of the following methods unless it can be demonstrated that the cable interface will not be subject to scour for the expected range of water-particle velocities:

a) The structure - cable interface is designed for a condition where all materials, which are not scour-resistant, are assumed removed.

b) Adequate means of scour protection are placed at the structure - cable interface.

c) The seabed around the structure is kept under surveillance and remedial works to prevent further scour are carried out shortly after detection of significant scour.

Guidance note 2:
The speed of scour development over time can be a crucial factor for cable installation as conditions change. Depending on soil and marine conditions, a scour hole can fully develop in a single tidal cycle or take several years.

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4.7.5.2 Design choices
When designing solutions to accommodate for scour at the interface between structure and cable, the following should be considered:

— space available / required
— mechanical properties of cable with/without cable protection system
— timing of scour hole development including the potential of refilling (e.g. during storms)
— timing of installation of cable and/or (layers of) scour protection
— structure / cable installation sequence effects
— long-term stability of scour hole / scour protection and intervention required
— choice of statically or dynamically stable protection.

A range of potential solutions to accommodate for scour at the structure - cable interface exists, which include, for example, the following (see Figure 4-16):

a) No scour protection: The cable is fitted with an external protection system, spanning the scour hole. A range of forces is acting on the cable, including tension and lateral movement (cyclic loading).

b) Pre-lay and post-lay scour protection, cable inside the scour protection: The cable is laid on top of a scour protection layer (e.g. filter layer) and subsequently (in a timely manner) covered by the armour layer. Deflections of the structure will act on the anchored cable, possibly introducing axial loads.

c) Pre-lay scour protection only, cable on top of the scour protection: The cable is laid on top of the scour protection, making it susceptible to lateral movement and abrasion. Increased tension due to seabed lowering can be partly mitigated by laydown with slack.
d) Post-lay scour protection only, cable under the scour protection: The scour hole is allowed to develop after which the J-tube is lowered (if moveable). The cable is laid and covered by full scour protection.

![Diagram of scour protection design choices](image)

**Figure 4-16**
Scour protection design choices. (a) No scour protection, (b) cable inside scour protection, (c) cable on top of scour protection, (d) cable under scour protection

Scour protection may be achieved by covering of areas with material of sufficient weight (e.g. placement of rock and concrete mattresses), thereby resisting erosion (see also [4.6]).

Scour protection material is designed to provide both external and internal stability, i.e. protection against excessive surface erosion of the scour protection material and protection against transport of soil particles from the underlying natural soil.

**Guidance note:**
Scour protection for foundations typically consists of a filter layer of small diameter stones preventing washing out of smaller soil particles and an armour layer of larger stones ensuring stability in all conditions required by the design basis.

Global scour can lead to undercutting at the edges of scour protection and relocation of some of the material. In rock placement design this is accommodated for by a local increase of the height of the armour layer (see Figure 4-16 b), acting as ‘dynamic scour protection’.

Failure modes of scour protection should be defined in order to establish when and to what extent remedial measures will be required during the operational phase of the scour protection.

### 4.8 Landfall

#### 4.8.1 General

Onshore cabling requires solutions which differ from those for the offshore section. The interface between onshore and offshore sections may require more engineering effort and more equipment than the other sections.

From a project point of view, landfalls are high risk areas, e.g. due to changeable conditions in the transition between land and sea during the construction and operational phases. Adequate meteorological, oceanographic and geotechnical data shall be collected ([3.4]) and used in the concept selection and final design.

**Guidance note 1:**
For guidance on the management of beaches for coastal defence purposes, see CIRIA Guideline C685.

---end---of---Guidance---note---
Site access by land and sea shall be carefully reviewed and designed. Seasonal restrictions, e.g. for environmental reasons, may apply (see [3.3.7]).

In the onshore area of the landfall, there is commonly, but not always, a transition from the subsea cable to a land cable. The transition takes place in a transition joint bay (also referred to as ‘jointing pit’), see [4.8.4]. The decision whether to use a joint as part of the nearshore cabling should be based on project-specific considerations.

**Guidance note 2:**
Decision criteria for or against a joint in the nearshore area may include those listed in Table 4-5.

<table>
<thead>
<tr>
<th>No nearshore joint (no separate shore-end cable)</th>
<th>Nearshore joint (separate shore-end cable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(slightly) increased reliability of cable section</td>
<td>two first-end pull-in operations; avoidance of second-end pull-in in complex situations (e.g. congested area)</td>
</tr>
<tr>
<td>saving of jointing time</td>
<td>reduced pull lengths and forces</td>
</tr>
<tr>
<td>potentially smaller cable corridor (no laydown of bight)</td>
<td>potentially smaller cable installation vessel required; closer approach to shore possible</td>
</tr>
<tr>
<td></td>
<td>schedules of offshore and nearshore works decoupled with improved reliability in planning</td>
</tr>
</tbody>
</table>

Further factors such as permitting conditions, marine conditions, environmental constraints and pulling force can influence or swing the decision on nearshore jointing.

It is possible to joint two different cross-sections of the same conducting material and also of different conducting materials (copper, aluminium). Such joints can be made in the factory or on site.

Cooling of the cable during operation is an important design consideration for the landfall design. At the transition from saturated (offshore) to unsaturated (onshore) soil, thermal conductivity may reduce significantly and partial drying of the soil can occur. Design options include reduction of losses (e.g. increase of conductor cross-section in onshore section) and specific burial design (e.g. thermal backfill).

Depending on the specific shore situation and boundary conditions, different burial designs for crossing the shore area may be suitable, including an open-cut trench (Figure 4-17 a) and horizontal directional drilling (Figure 4-17 b).

**Guidance note 3:**
Other solutions, such as micro-tunnels may also be feasible in the onshore section of the cable, see CIGRÉ Technical Brochure 194.
Guidance note 4:
Factors influencing the decision for open-cut trenching or HDD may include those listed in Table 4-6.

<table>
<thead>
<tr>
<th>Open-cut trenching</th>
<th>HDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>— suitable for beaches that can be excavated</td>
<td>— suitable for shores with high cliffs, hard rock or highly erosive character</td>
</tr>
<tr>
<td>— use of standard construction equipment</td>
<td>— undercrossing of sea defence systems (e.g. sea walls, dikes, dunes)</td>
</tr>
<tr>
<td>— relatively inexpensive</td>
<td>— low environmental impact, avoidance of surface contaminated zones</td>
</tr>
<tr>
<td>— good access to cable in case of repair</td>
<td></td>
</tr>
</tbody>
</table>

The design should allow for long-term effects such as beach erosion when specifying target values. In the northern hemisphere, significant beach erosion can occur in winter.

4.8.2 Open-cut trench
Open-cut trenching is a cable protection technique where the trench is cut prior to cable laying. For geo-hazards and site investigation techniques which should be considered to lower risks to an acceptable level, see [3.4].

Potential trench paths should be evaluated considering boundary conditions such as the following:

— geological formation, strata, hazards in the area, water table, thermal properties
— existing infrastructure
— existing and future use of the area, e.g. for agricultural activities including ploughing
— site access, also for equipment
— environmental and permitting concerns.

Trench design in onshore sections is often guided by local regulations. Critical features shall be determined at the design stage, including the following (see also Figure 4-17 a):

a) Path: The trench routing should be relatively straight to keep cable pulling forces low. The use of powered, synchronised rollers can reduce or eliminate the concern.

b) Corridor width: The corridor should provide sufficient space for and adequate trench cross-section design, temporary storage of excavated material and a work access road.

c) Trench cross-section: The trench width depends on the number of cables laid into the same trench. Cable manufacturers’ recommendation for minimum separation should be followed. Electrical faults shall be contained to ensure safety of the public. Trench slopes should be designed for the site-specific ground conditions to avoid collapse.

Guidance note:
The depth of cover is frequently in the 0.6 m to 1.0 m range for land-based cables, but in shore areas more may be required depending on the identified risks. Covers of concrete mats have also been used, both in intertidal and nearshore areas.

d) Cable bedding: The immediate cable surroundings largely influence the cooling of the cable during operation. The bedding material should have suitable mechanical and thermal properties.

e) Warning measures: The risk of damage by third party excavation works should be assessed and suitable countermeasures be introduced. Depending on the location of the cable section and the identified risk level, these may include concrete covers, protection grids and (almost always) brightly coloured warning tapes (see Figure 4-17 a). Reporting of underground works is a common requirement in most countries.

Trench design is an iterative process. Location of the water table and potential drying out of backfill material are important design considerations. Cross-checks should be performed to confirm that the cooling of the cable will be ensured under operational conditions.

4.8.3 Horizontal directional drilling
Horizontal directional drilling (HDD) is a trenchless method of installing pipes and cables underground along a planned shallow arc trajectory. The geological formation of the landfall area shall be reviewed to determine whether HDD is technically feasible. For geo-hazards and site investigation techniques which should be considered to lower risks to an acceptable level, see [3.4].

Potential HDD trajectories should be evaluated considering boundary conditions such as the following (Figure 4-18):

— minimum, maximum distance to be drilled
— cable, pulling head and conduit size as well as maximum pulling forces
— geological formation, strata, hazards in the area, water table, thermal properties
— required distance under coastal defence system, existing infrastructure
— feasible entry points (commonly land based)
— feasible exit points (in onshore, intertidal or offshore locations)
— height difference between entry and exit points, possibility of seawater entry and/or drilling fluid exit
— operational limitations, e.g. rig capabilities, drilling fluid pressure
— environmental concerns, e.g. loss of drilling fluid.

**Guidance note 1:**
Entry point (launch pit, rig site) and exit point (reception pit, pipe site) should be considered not only with drilling and conduit pulling but also with cable installation in mind. At locations with high longshore currents, an offshore exit point should be located as far out at sea as practicable. Depending on the site and project conditions, it may be possible to pull the conduit from sea to land or land to sea, see [6.6].

**Guidance note 2:**
Although feasible HDD lengths exceed 2,000 m, the pull-in of the conduit into the borehole and/or the power cable into the conduit over such a distance can exceed the maximum pulling force of either conduit or cable. For typical HDD lengths see [6.6].

**Guidance note 3:**
Typical tilt angles of drilling rigs range from 5 to 15°. The larger the angle, the more onerous will the handling and the working conditions for the crew become. The exit angle offshore should also be considered when designing the protection for the installed cable.

**Guidance note 4:**
Polyethylene conduit may require a bending radius of at least 75 times outer diameter while steel pipes require a much larger one.

**Guidance note 5:**
Vertical bend at entry and exit: A vertical bend shall meet the minimum bending radius requirements of drilling string, conduit and power cable. The geological formation should have sufficient strength to withstand the lateral pushing forces. Smaller radii result in larger push force for the rig and against the borehole wall.

**Guidance note 6:**
Horizontal bend: A bend shall meet the minimum bending radius requirements of drilling string, conduit and power cable. Horizontal bends should preferably be avoided or limited to a single one.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---
The transition between saturated and unsaturated soil will typically occur along the HDD trajectory. At this point cooling of the cable may be poor due to low thermal conductivity of the conduit and soil as well as large burial depth. Thermal properties along the planned trajectory should be determined to aid power cable current rating calculations. The conduit properties to be determined should include (see also Figure 4-17 b):

a) Conduit material: Typical materials are polyethylene (light, flexible, less expensive, low thermal conductivity) and steel (heavy, stiff, more expensive, high thermal conductivity).

b) Inner diameter of the conduit: Most commonly only one cable is installed in a conduit. Considering parameters such as pulling arrangement, cable weight, pull length, friction coefficient and bends, the minimum inner diameter of the conduit should be determined.

Guidance note 5:
With a typical HDD curvature, an inner conduit diameter $d_{i,conduit}$ of $1.5 \times$ cable outer diameter $d_{o,cable}$ can be adequate, while factors close to 2.5 are rarely required.

---end---of---Guidance---note---

c) Conduit strength: Based on the required inner diameter, adequate wall thickness of the conduit should ensure that it can be installed with the predicted pull-in forces.

d) Borehole size: The borehole size should be adequate for the chosen conduit, also considering the expected geological conditions.

Guidance note 6:
Typical borehole sizes are in the range of $1.25$ to $1.5 \times$ outer conduit diameter $d_{o,conduit}$.

---end---of---Guidance---note---

HDD and conduit design is an iterative process. Cross-checks should be performed to confirm that the predicted pulling forces do not exceed the cable’s maximum tensile load (or whether additional armour may be required) and that the cooling of the cable will be ensured during operational conditions.

4.8.4 Onshore jointing location
The onshore jointing location (also referred to as ‘transition joint bay’, ‘joint transition pit’ or ‘interface joining pit’) is an important interface between onshore works and beach / offshore works. Functions of the joint transition bay may include:

— mechanical fixation of power cables
— interface joint between un-armoured land power cable(s) and armoured subsea power cable(s)
— splice point for optical fibres
— earthing point.

The jointing location should be designed to:

— provide a safe and stable temporary working area
— have space for winches behind the transition joint bay and for adequate overlength of cables to be pulled in
— allow securing the cables mechanically
— allow for the provision of a conditioned environment for jointing activities (e.g. dewatering, air conditioning)
— enable cable commissioning and testing
— if required, provide accessibility for future inspections.

Guidance note:
Location of the transition joint bay onshore and above the water table can facilitate installation activities, inspections and fault locating. A location below the water table or offshore can provide improved thermal performance, but installation and maintenance activities will be more difficult to perform.

---end---of---Guidance---note---

The design should be accepted by onshore and offshore installers, including the party responsible for jointing.
5 Manufacturing

5.1 General
The manufacturing phase includes all activities to produce the ready-to-ship power cable and any required accessories (Figure 5-1).

![Diagram of cable project life cycle]

Figure 5-1
Manufacturing phase within the cable project life cycle

This section provides requirements for the manufacturing processes, the testing of cables and documentation that shall be prepared and agreed between manufacturer and purchaser.

5.1.1 Quality system and workmanship
Parties involved in manufacturing of cables, cable components and associated / interface products shall have a documented and implemented quality system according to ISO 9001 or equivalent. The extent of the quality management system may depend on the size and type of the organisation, complexity and interaction of the processes and competence of personnel.

Guidance note:
Quality management is concerned with the quality of raw materials, intermediate and final products and the associated processes.

Workmanship shall be in accordance with written procedures accepted by the purchaser.
All work shall be executed with adequate control by the manufacturer. Repair work shall be carried out in accordance with written procedures accepted by the purchaser.
Prior to commencement of the work the manufacturer shall agree on a plan for testing, testing procedures and documents for acceptance by the purchaser. The programme shall contain information and documents for planning, controlling, reporting, etc. Acceptance criteria for testing shall be agreed between manufacturer and purchaser if they are not specified in the applicable standards.

5.1.2 Inspection
Inspections should be carried out by the manufacturer and purchaser in accordance with accepted inspection and test plans to confirm that all project requirements are fulfilled.
The inspections may cover items such as:
— correct identification, documentation and use of materials
— qualification and acceptance of manufacturing procedures and personnel
— inspection of preparatory work
— inspection of manufacturing work for compliance with specifications and procedures
— witnessing of testing
— inspection of repairs
— examination of testing equipment and/or measuring / recording devices vital for correct functioning of equipment and machinery used in manufacturing.

Due consideration should be given to the access and the time required for adequate inspection during manufacturing.

High non-conformity rates in execution of the work or in the product itself shall lead to root cause analysis and remedial action, e.g. requalification of personnel, change of design, change of material or change of process. Personnel involved in inspections should be qualified according to a recognised scheme and should be able to provide documentation of proficiency.

5.2 Cable manufacturing and testing

5.2.1 General
Subsea power cables are subjected to a comprehensive test programme before, during and after the manufacturing process. Relevant tests may include:
— development tests, supporting a specific product or project, e.g. analysis of thermo-mechanical behaviour
— prequalification tests, validating long-term performance of (HV) cable systems, e.g. prequalification of flexible or factory joints
— type tests, demonstrating satisfactory performance through mechanical testing followed by electrical and material testing, see [5.2.2]
— sample tests, representing the manufacturing process of the cable, see [5.2.3]
— routine tests, verifying that the product meets specifications, including tests on manufactured cable lengths,
tests on factory joints and ‘factory acceptance tests’ of delivery cable lengths, see [5.2.4]
— post-installation tests, verifying successful installation, see [6.9.2].
Table 5-1 summarises standards and guidelines for type tests of subsea cables generally applicable in European
projects.

<table>
<thead>
<tr>
<th>Table 5-1</th>
<th>Type test sequences for subsea power cables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum voltage</strong> $U_m$</td>
<td>≤ 36 kV AC</td>
</tr>
<tr>
<td>Typical insulation</td>
<td>Extruded (XLPE, EPR)</td>
</tr>
<tr>
<td>Mechanical test recommendation</td>
<td>(CIGRÉ TB 490), (CIGRÉ Electra 171)</td>
</tr>
<tr>
<td>Electrical test recommendation</td>
<td>(CIGRÉ TB 490, IEC 60502-2)</td>
</tr>
</tbody>
</table>

Guidance note:

Tests for power cables were standardised with focus on land-based applications and some adjustments may be
required when applying them to power cables for subsea applications. Subsea power cables may have integrated
optical fibre packages; for testing see [5.2.5].

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.2.2 Power cable type tests

Type tests are made to qualify a type of cable system design for the conditions of the intended application. Once
successfully performed, these tests do not have to be repeated unless changes are made to the cable system.

The programme of mechanical type tests should be specified in accordance with CIGRÉ Electra 171 and
CIGRÉ Technical Brochures 490 / 496 and commonly includes:

— coiling test (only for cables intended for coiled storage)
— tensile bending test
— tensile (pulling) test
— longitudinal and radial water penetration tests.

Guidance note 1:

The extent of the mechanical test programme should be specified. For example, the number of cycles is required for
the coiling test; the anticipated water depth is required for the tensile bending and water pressure withstand tests. The
tensile (pulling) test according to CIGRÉ Electra 171 may not have practical relevance for shallow water applications
covered by this recommended practice. Water penetration tests are described in CIGRÉ Technical Brochures 490.
Requirements for specification of additional parameters should be agreed upon, see [4.4.1.5]. According to CIGRÉ
Electra 171, a trial installation may form part of the test programme if the cable design differs significantly from
earlier established practice. For trial cable pull-in, see [5.6].

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The programme of electrical type tests should be specified in accordance with IEC standards and CIGRÉ
guidelines and commonly includes for AC cables:

— partial discharge (PD) test
— loss angle (tan d) measurement
— heating cycle test
— impulse test(s)
— high voltage AC test.

Guidance note 2:

For ≤ 36 kV AC subsea cable type testing, the range of type approval tests described in IEC 60502-2 should be
followed, with mechanical testing according to CIGRÉ Electra 171.

For $U_m > 36$ kV AC subsea cable type testing, CIGRÉ Technical Brochure 490 requires a system approach, i.e.
combined testing of cable(s), termination(s) and different types of joints. CIGRÉ Technical Brochure 490 makes
reference to the range of type approval tests described in IEC 60840 ($U_m > 36$ kV to 170 kV AC) and IEC 62067
($U_m > 170$ kV to 550 kV AC).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---
Power cable type testing includes further, non-electrical tests described in the IEC standard applicable for the specific voltage range.

The programme of optical fibre tests, if applicable, should follow the mechanical and electrical series of tests, see also [5.2.5].

5.2.3 Power cable sample tests

Sample tests are made on samples taken from components or the complete cable, at a specified frequency, to represent the manufacturing of the cable.

The programme of sample tests should be specified in accordance with IEC standards and CIGRÉ guidelines and commonly includes for AC cables:

— examination of conductor, insulation and metallic / non-metallic sheath(s)
— hot-set test for extruded insulation
— electrical tests, depending on voltage level
— examination of completed cable, e.g. armour wire inspection.

5.2.4 Power cable routine tests

Routine tests are made on each manufactured length of cable to demonstrate integrity of the manufactured cable and to verify that it meets the specified requirements within tolerances.

The programme of routine tests should be specified in accordance with IEC standards and CIGRÉ guidelines and commonly includes for AC cables:

— tests on manufactured lengths, e.g. PD test, AC voltage test
— tests on factory joints, e.g. PD test, AC voltage test, X-ray inspection
— ‘factory acceptance tests’ on delivery length(s), e.g. AC voltage test, (PD test).

Guidance note:

Cable supply contracts commonly specify tailored routine test programmes. Routine testing of ≤ 36 kV AC cables according to IEC 60502-2 requires inclusion of conductor electrical resistance measurement.

CIGRÉ Technical Brochure 490 covers the practicality of AC voltage routine testing of long cables and allows a frequency range of 10 to 500 Hz to be used, while VLF (very low frequency, < 1 Hz) testing should be limited to voltages ≤ 36 kV.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.2.5 Optical fibre manufacturing and testing

Type tests of optical fibres should include the connection technologies (e.g. splices, connectors). Applicable definitions and test methods are specified, for instance, in standards IEC 60793 (optical fibres), IEC 60794 (optical fibre cables) and ITU-T G.976.

The fibre optic package shall be routine tested after lay-up of the complete subsea power cable to ensure that no damage has occurred to the fibres.

5.3 Cable storage, load-out and transport

5.3.1 Cable storage

5.3.1.1 General

After completion of tests on delivery lengths, the cable shall be suitably stored until load-out is undertaken.

Guidance note 1:

Cables may be supplied on cable drums / reels, in liftable baskets (coilable designs only), into static cable tanks (coilable designs only) or on a powered turntable.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Adequate space shall be available at the manufacturing site considering planned onshore and offshore installation schedules. Storage space should be considered to accommodate for changes in installation schedules.

Storage conditions shall be defined and confirmed by the cable manufacturer, considering the potential for damage.

— limits of mechanical forces, acceptable stacking heights
— limits of exposure to solar (UV) radiation, temperature, humidity
— suitable protection of cable ends (capped and sealed in accordance with manufacturer’s recommendations)
— maximum time allowed for chosen storage solution.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---
**Guidance note 2:**
Shrink-on end caps rarely provide adequate protection of the cable for extended periods of time. When stored over long periods of time, cables may develop a “memory” which can impact subsequent installation.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The following shall be documented for storage facilities:
- adequate foundation for the weight of the cables
- adequate protection from environmental influences (e.g. low or high temperature, frost, solar radiation, wind)
- drainage of water
- icing potential and appropriate countermeasures.

Access to cable ends (including optical fibres) for testing purposes should be considered.

### 5.3.1.2 Specific requirements

For cables stored on drums / reels, the following shall be considered:

a) Drum dimensions should be agreed upon. Transport restriction should be taken into account.

b) Handling procedures for lifting (acceptable methods, approved lifting points) and spooling should be provided. When hoisting a drum, a spreader bar should be used.

c) Cable drums should be stored on a hard surface resting on the flange edges (flanges vertical, see Figure 1-5a) with blocks preventing rolling or on cradles. The duration of storage shall be considered when selecting a particular drum type.

**Guidance note 1:**
When stored outdoor, wooden drums deteriorate over time. For long-term storage, steel drums are preferable.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

For cables stored on a coiling pad, in baskets or in static cable tanks, the following shall be considered:

a) Only cables specified as ‘coilable’ shall be coiled. The minimum coiling ring diameter shall be specified by the cable manufacturer.

**Guidance note 2:**
Coiling is performed so that the armouring is opening up. The minimum coiling diameter MCD depends on the cable design and should be specified by the cable manufacturer.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

b) The coiling area shall have a flat surface.

c) Cable manufacturers and installers should review and agree on the coiling method to be used.

**Guidance note 3:**
During the coiling process, a linear cable engine (transporter) is often used to move the cable. A suitable height of the cable engine should be recommended by the cable manufacturer.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

d) The crushing load of the lowest layer of cable shall not be exceeded by cable stored on top, also, if applicable, considering accelerations during transport and installation.

For cables stored on powered turntables, the following shall be considered:

a) The inner barrel of the turntable (see Figure 1-5 e/f) shall be large enough not to compromise the cable’s minimum bending radius.

b) The turntable shall be verified to have adequate capacity (volume, tonnage) for the cable to be stored.

c) The crushing load of the lowest layer of cable shall not be exceeded by cable stored on top, also considering accelerations during transport and installation.

### 5.3.2 Cable load-out

Load-out conditions shall be defined, considering the potential for damage, see also [5.3.1].

A load-out procedure for the cable (and, if applicable, the cable protection system) shall be developed, considering all interfaces such as onshore / quayside conditions and transport / installation vessel conditions. The procedure shall also include ancillary components such as joints and terminations. Communication procedures and the responsibilities at each moment of the load-out procedure shall be clearly defined, including control and monitoring of loading operations and the agreed point of handover from manufacturer to installer / purchaser.
The procedure shall consider the following facilities, which should be inspected prior to commencement of activities:

- conditions - ambient temperature, cable temperature
- storage - system used, arrangements, handling restrictions
- handling / transfer system - system used, layout, interfaces with storage and vessel, limitations, control, monitoring
- vessel - draught, mooring and quayside requirements
- communication - arrangement, control.

**Guidance note 1:**

(Horizontal) transport of the cable over roller tracks is not covered by common mechanical type tests. The distance between rollers and the stiffness of the cable should be taken into account to ensure that roller spacing does not compromise cable properties.

---end---of---Guidance---note---

A detailed loading plan shall be produced well in advance of the loading campaign. Loading trials should confirm the suitability of the loading setup prior to loading of the actual cable.

Cable tests prior to load-out should be considered if the cable has been stored for a longer period.

**Guidance note 2:**

“Longer period” may be specified contractually or otherwise taken to mean 3 months (ISO 13628-5, Sec.14.5).

Tests / inspections on power cables prior to load-out (revealing major damage) may include:

- general visual inspection - outer sheath or armour damages
- electrical conductors (all cores) - DC resistance test, insulation resistance test, VLF test and/or time domain reflectometer (TDR) test
- sheath test - DC resistance on single-core sheath, if not semi-conductive
- optical fibres (if present, selected fibres) - optical time domain reflectometer (OTDR) trace, one end.

---end---of---Guidance---note---

Adequate support of the cable shall be provided when loading a drum, tank or turntable. Sufficient tension shall be applied during loading in order to ensure that the successive layers on the drum, in the tank or on the turntable are sufficiently tightly packed to prevent slippage between the layers. Tension shall be monitored. Adequate measures shall be taken to protect the cable surface during loading.

Transfer and lifting of cable shall be conducted safely to avoid injury or damage to equipment and product. The equipment used for transfer and lifting shall not impose damage to the cable:

a) Pulling / bending / crushing / twisting of cable: All mechanical loads imposed on the cable shall be less than the maxima specified for the product.

b) Transfer of cable across spans: At all times, the cable shall be supported adequately so that a catenary forming is within the specified limits. Suitable supports such as rollers, caterpillars, bend shoes, sheaves and chutes shall be employed.

**Guidance note 3:**

Forming of a catenary compensating for differences in speed between quayside facility and cable vessel handling systems can serve as a visual feedback for the handling system operators to control loading speed, but must not compromise the cable’s mechanical properties.

In ports with significant tidal differences care should be exercised to avoid contact of the cable catenary with the ground. Sufficient moorings should ensure that passing traffic will not cause excess movement of the vessel and the cable.

The cable twist induced during the load-out from the shore facility to the cable installation vessel should be monitored, e.g. by placing and monitoring suitable marks on the cable for the first hundred metres.

---end---of---Guidance---note---

c) Lifting of cable: Cable ends shall be lifted using methods (such as pulling head) designed in accordance with the cable specification. If it is required to lift / support a cable by crane, appropriate support (such as bend shoes) shall be used.

d) Lifting of cable drums / reels and auxiliary equipment: The lifting design should be independently verified.

Load-out operations shall be monitored. Visual examinations should be conducted during and after load-out. The results should confirm that the cable has not been damaged in the course of the operation. The loaded cable length shall be recorded.

Tests after load-out, if any, should be specified.
Guidance note 4:
Tests after load-out are typically done if responsibility transfers from one party to another. Cables on drums do not normally require testing after load-out if no irregularities have been observed during the operation. Tests on power cables after load-out (revealing major damage) may include:
— general visual inspection - outer sheath or armour damages
— electrical conductors (all cores) - DC resistance test, insulation resistance test, VLF test and/or TDR test
— optical fibres (if present, selected fibres) - OTDR trace, one end.

5.3.3 Cable transport
During transport, the properties of subsea power cables should be protected through suitable and careful loading. This requires:
— the cable storage system has sufficient strength to support the loads imparted by the stored cable during transport
— crush loads remain within the limits of the cable manufacturer’s specification, considering the vessel motions.

Depending on the storage system used on the vessel and the marine conditions during the voyage, the cable shall be adequately supported and secured. Acceptance criteria for seafastening should be established.

Guidance note:
Acceptance criteria differ for cable transport on drums, in tanks or on turntables.

Trans-spooling of cable between two vessels should be carried out in sheltered waters employing safe mooring to minimise relative movement. Considerations as for load-out apply.

5.4 Cable accessories
Power cable accessories may include joints, terminations kits, cable end caps, hang-off modules and pulling heads / stockings, see [4.4.2].
Quality assurance during the manufacturing process of accessories should be agreed between purchaser and manufacturer and may include review of the following:
— type testing of specifically engineered products
— traceability of material used for production
— routine and factory acceptance testing.

Guidance note 1:
Depending on the voltage range, AC cable accessory tests should be carried out in accordance with IEC 60502, IEC 60840 or IEC 62067. For further information on AC subsea cable accessory testing, see CIGRÉ Technical Brochure 490; for test procedures on HV transition joints, see also CIGRÉ Technical Brochure 415.

Key interface dimensions should be checked to avoid issues arising offshore. For new or critical items, an interface test should be performed prior to shipment.

Guidance note 2:
Integration tests are advisable for items that could adversely affect the installation schedule. Decisions regarding the testing programme are influenced by the criticality of the (few) export cables and the repetitiveness of the installation steps for the (many) array cables.

5.5 Cable protection measures
A specific quality control programme for external cable protection measures including inspection and tests shall be set up to monitor the quality throughout the different phases of the design and manufacturing.
Quality assurance for tubular products may include review of the following:
— type testing of specifically engineered products, including destructive testing
— traceability of material used for production
— consistency of fitting
— acceptable surface finishing
— representative deployment test, e.g. in combination with cable pull-in tests ([5.6]).
Quality assurance for concrete mattresses may include review of the following:
— correct mix of sand, gravel and cement
— quality and diameter of polypropylene rope
— curing process and timing, including protection from frost and rain, and sample cube testing
— fabrication traceability of each mattress
— storage conditions, especially exposure to ultraviolet light, and multiple handling.

**Guidance note 1:**
For quality assurance, see also locally applicable concrete fabrication guidance.

---end---of---Guidance---note---

Quality assurance for rock and gravel materials may include review of the following:
— correct type of rock
— correct grading (size or weight) of rock.

**Guidance note 2:**
For details on rock material specifications and quality control, see e.g. CIRIA Guideline C683.

---end---of---Guidance---note---

### 5.6 Offshore units

Prior to load-out, the cable interface at offshore units (wind turbine substructure and tower, offshore substation substructure and topsides) and the cable path from entry point to termination point should be reviewed by the purchaser and/or cable installer.

Where J- or I-tubes are used, inner diameter, roundness, and smoothness / cleanness of the inside and the correct application of the specified coating should be verified. For J-tube-less systems, the location / execution of the works should be inspected for compliance with the design drawings.

**Guidance note 1:**
Use of a gauge pig, possibly supplemented by a camera inspection, can ensure adequate inner diameter of J- or I-tubes, their roundness, smoothness and cleanness.

---end---of---Guidance---note---

Representative cable pull-in tests should be performed prior to load-out, in particular where J-tubes are used.

**Guidance note 2:**
For new designs, mock-up tests for cable pull-in and hang-off should be considered.

Full-scale cable pull-in trials may be performed so that the operations can be observed and optimised. Some tests can be performed onshore at a quayside (dry and/or wet), e.g. with a suitable piece of cable including the cable protection system and the pulling head.

---end---of---Guidance---note---

### 5.7 Spare parts

Spare parts should be planned and procured together with quantities required for the project.

Spare parts for a cable system may include the following:
— spare cable length, e.g. for repairs or exchanges, as applicable
— subsea repair joints, transition joint(s)
— terminations
— spare components for the optical fibres
— spare elements of cable protection systems.

**Guidance note:**
The number of anticipated repairs should be defined by the purchaser. A single cable repair offshore may require spare cable longer than twice the water depth (see also [4.5.2]). Where cables with several cross-sections are used in a project (e.g. for array cables), the spares should cover the larger cross-sections as some joint designs can accommodate cables of different cross-sections.

---end---of---Guidance---note---
6 Installation

6.1 General

6.1.1 General

The installation phase includes onshore (landfall) and offshore construction activities as well as transport (Figure 6-1).

![Figure 6-1](Installation phase within the cable project life cycle)

This section provides requirements for installation process analyses and documentation that shall be prepared and for the installation and testing execution of the complete subsea cable system. Additional requirements may be imposed by an appointed Marine Warranty Surveyor (MWS) on the basis of established guidelines and recommendations, see [2.2.5.2].

6.1.2 Planning of operations

Marine operations shall be planned to allow for safe and practical installation steps and developed into method statements and procedures. The rules to be applied for marine operations shall be defined.

**Guidance note 1:**
DNV Rules for Planning and Execution of Marine Operations may be applied, see DNV-OS-H101.

Risk assessments, including hazard identification (HAZID), hazard and operability study (HAZOP) and/or failure mode and effect analysis (FMEA), should be carried out for each step of the installation procedures.

**Guidance note 2:**
For guidance on risk assessment, see ISO 19901-6 and DNV-RP-H101.

Exclusion zones should be established for areas surrounding the installation activities. Day signals or navigation lights, compliant with local regulations, shall be visible at the appropriate times of the day. Information on construction activities should be posted on “Notice to Mariners.”

An installation manual shall be developed and agreed upon, see [9.2.5]. The installation manual should include the installation sequencing and methodologies for the individual installation steps. The applicable operational limiting conditions shall be defined, see [6.1.3].

Interfaces should be established with other parties that may be affected by the operations or may affect the operation. The responsibilities of all parties and lines of communication should be established.

6.1.3 Operational limiting conditions

Operational limitations shall be established based on the intended vessel’s capabilities, the planned installation techniques, the applicable weather windows and suitable contingencies. The installation operation shall be classified as weather restricted operation or unrestricted operation. An unrestricted operation is a temporary condition or permanent condition.

For weather restricted operations, operational limiting conditions for whole or partial operations shall be established and agreed.

The operational limiting conditions shall be based on detailed load effect analyses, vessel station keeping capability and FMEA / HAZOP data, and shall refer to objective, critical values determined by measuring devices. Continuous monitoring and recording of the measuring devices required for control of the operational limiting conditions shall be performed during all phases of installation activities.

**Guidance note 1:**
For principles of operational planning together with definitions of unrestricted and weather restricted operations, see DNV-OS-H101. Marine operations with a reference period less than 96 hours and a planned operation time less than 72 hours may normally be defined as weather restricted (Figure 6-2). Note that even if the total operation lasts more than 72 hours, the operation may be defined and designed as weather restricted, given that the cable lay operation is planned and performed based on ‘running’ weather windows, while ensuring that the operation can be suspended and the cable be brought into a safe condition if the weather should deteriorate beyond the lay criteria.
For weather restricted operations, planning of activities shall be based on an operation reference period. Further, the operational criteria shall account for uncertainties in both weather forecasts and monitoring of environmental conditions. Regular weather forecasts from a recognised meteorological centre shall be available on-board the cable installation vessel, and should be supplemented by historical environmental data. Start of weather restricted operations is conditional on an acceptable weather forecast for the required weather window.

**Guidance note 2:**
For reduction factors accounting for uncertainties in both monitoring and forecasting environmental conditions, see DNV-OS-H101.

More than one forecast from different providers are commonly used to reduce forecasting uncertainties. Use of a weather buoy / measurement located inside or near the project (e.g. wind farm) area can reduce monitoring uncertainties.

If the operational limits are about to be exceeded, preparations for stopping the work shall commence. If the critical condition is weather dependent only, and if weather forecasts indicate that the weather condition will subside, the installation may continue, subject to agreement.

The decision to resume cable lay shall be based on comparison of the forecasted (and, if applicable, measured) sea-state with the limiting (design) sea-state.

**6.1.4 Diver intervention**
Diving and underwater operations shall be performed in accordance with agreed procedures for normal and contingency situations covering applicable requirements.

As far as practicable, the use of divers should be avoided.

**Guidance note:**
The use of remotely operated vehicles (ROVs) is preferable for the analysis and rectification of incidents, but diver intervention can be useful in specific, unforeseen circumstances.

For diving operation details which are relevant in subsea power cable projects, see IMCA D 014 and IMCA D 042 (R 016). Specific guidelines, e.g. for nearshore areas, may apply.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---
6.2 Installation spread

6.2.1 General

6.2.1.1 Qualification of vessel and equipment

All vessels and equipment planned for cable installation shall be qualified to perform work and supporting operations within the determined operational limits.

**Guidance note:**

For vessel classification requirements, see [6.2.2]. Requalification is required if significant modification or alternation to the vessel, equipment or software has been made.

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Qualification should be

— done according to a qualification plan
— based on a systematic review of the specified operational limits for the selected vessel and equipment
— reviewed through a combination of desk-based assessments (e.g. HAZID, HAZOP, FMEA), analyses, simulations and tests
— documented for employer or Marine Warranty Surveyor review.

Vessels, cable handling / installation equipment and associated (e.g. survey / ROV) systems shall have a documented inspection and maintenance programme covering all systems vital for the safety and operational performance of the vessel, related to the operation to be performed. The maintenance programme shall be outlined in an operation and maintenance manual or similar document.

6.2.1.2 Personnel

The organisation of key personnel with defined responsibilities and lines of communication shall be established prior to start of the operations. Interfaces with other parties shall be defined.

All personnel shall be competent for their assigned work. Key personnel shall have sufficient verbal communication skills in the common language used during operations.

For marine crews the manning levels should comply with IMO Res. A.1047 (27) - Principles of minimum safe manning. Non-propelled vessels should have similar manning and organisation as required for propelled units of a comparable type and size.

For installation crews the staff levels should be adequate to execute the planned work in a safe manner.

6.2.2 Cable installation vessels

Vessels shall meet statutory requirements and in general have a valid class certificate with a recognised classification society or National Authorities. A vessel specification should state requirements for:

— general seaworthiness of the vessel for the region
— anchoring systems, anchors, anchor lines and anchor winches
— thrusters
— positioning and survey equipment
— dynamic positioning equipment and reference system
— alarm systems, including remote alarms when required
— cranes and lifting appliances
— cable management and installation equipment
— any other requirement due to the nature of the operations.

**Guidance note:**

Typical cable installation vessels can be distinguished into the following types:

— Shallow water barge capable of beaching, generally with anchor mooring positioning
— Cable laying barge, with anchor mooring system or dynamic positioning
— Cable laying vessel, with dynamic positioning.

Dependent on project scope and site conditions, more than one installation vessel type may be required. For instance, due to ultra-shallow draft requirements, nearshore construction activities may use purpose-built barges with lower seaworthiness categorisation for installation works in favourable weather conditions.

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Status reports for any recommendations or requirements given by National Authorities and/or classification societies and the status of planned / completed maintenance shall be available for review by employer and/or Marine Warranty Surveyor.

A vessel survey or inspection should, subject to agreement, be performed (typically by a Marine Warranty Surveyor) to confirm that the vessels and their principal equipment meet the specified requirements and are suitable for the intended work, see also [4.3.2].
Accommodation requirements, including for Marine Warranty Surveyor(s) and employer representative(s), shall be defined and met by the selected vessel(s).

The scale of fire fighting and lifesaving appliances on board is covered by its safety certificates and shall, as a minimum, be in accordance with the scales prescribed in SOLAS corresponding to the number of personnel on board the vessel.

6.2.3 Support vessels

Support vessels such as anchor handlers, crew transfer vessels and guard/escort vessels shall meet the minimum statutory requirements. For anchor handling vessel requirements, see [6.2.4.2].

Guidance note:
Beyond statutory requirements, assurance processes should be used to account for operational hazards. The transfer of crew to and from offshore units is a critical operation where vessel capabilities can be a limiting factor for installation processes.

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6.2.4 Positioning systems

6.2.4.1 General

The installation barge/vessel shall have a position/heading keeping system able to maintain a desired position/heading within the accuracy and reliability required for the planned operation and the environmental conditions.

The operation/installation shall be planned and executed with use of position/heading reference system(s) of suitable type, accuracy and reliability required for the operation(s) and type of vessel(s) involved.

The positioning/heading reference systems shall be capable of operating within the specified limits of accuracy and calibrated prior to start of the installation operations.

Installation in congested areas and work requiring precise relative location may require local systems of greater accuracy, such as acoustic transponder array systems.

Guidance note:
Suitable reflectors at fixed offshore units can improve the accuracy of local positioning/heading reference systems. Furthermore, the use of ROVs and/or real-time modelling during cable laying can assist the operations where operational limits permit.

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The positioning/heading reference system shall as a minimum provide information relating to:

— position relative to the grid reference system used
— geographical position
— heading
— offsets from given positions
— vertical reference datum(s).

6.2.4.2 Anchoring systems, anchor patterns and anchor handling

Anchoring systems for vessels kept in position/heading by anchors (with or without thruster assistance) while performing marine operations should meet the following requirements:

a) Mooring and anchor handling operations shall be monitored and controlled with an anchor management system continuously logging anchor positions.

b) Instruments for reading anchor line tension and length of anchor lines shall be fitted in the operations control room or on the bridge, and also at the winch station.

c) Remotely operated winches shall be monitored from the control room or bridge, by means of cameras or equivalent.

Anchor handling vessels (‘anchor handling tugs’) shall be equipped with:

a) A surface positioning reference system of sufficient accuracy. High accuracy is required for anchor drops in areas with strict requirements to control of anchor position, typically within the safety zone of existing installations, proximity of pipelines or areas of archaeological or environmental importance.

b) Computing and interfacing facilities for interfacing with lay vessel, trenching vessel or other anchored vessels.

c) Latest revision of (digital) charts for the whole area of operation.
Procedures for the anchor handling shall be established, ensuring that:

— anchor locations are in compliance with the anchor pattern for the location
— requirements of operators of other installations and pipelines for anchor handling in the vicinity of the installation are known, and communication lines established
— position prior to anchor drop is confirmed
— anchor positions are monitored at all times, particularly in the vicinity of other installations and pipelines
— any other requirement due to the nature of the operations is fulfilled.

**Guidance note 1:**
In order to ensure correct positioning of anchors, the line length measurements should be reset at the point of the anchor shackle being at the stern roller. Anchor dragging may be indicated by loss of anchor line tension.

All mooring equipment shall hold a valid certificate. Procedures shall be in place for handling and regular inspection of all mooring equipment.

For mooring systems using synthetic fibre lines, instructions for handling, use and storage as provided by manufacturer and/or stated on certificate shall be followed. Contact with the seabed shall be avoided at any time unless the fibre ropes have been certified for such contact.

Anchor patterns shall be predetermined for each vessel / barge using anchors to maintain position. Different configurations for anchor patterns may be required for various sections of the cable route, especially in the vicinity of fixed offshore units or subsea infrastructure.

Taking into account the site conditions during which the cable can be installed, the minimum allowable number of anchors to be used during cable installation shall be established.

Anchor patterns shall be according to the results of mooring analyses and shall be verified to have the required capacity for the proposed location, time of year and duration of operation. Safe distance to other installation and non-anchoring zones shall be established, and the possibility to leave the site in an emergency situation shall be considered.

**Guidance note 2:**
For weather restricted operations and mooring, see DNV-OS-H101. For non-weather restricted operations and mooring, see DNV-OS-E301.

The mooring system shall as a minimum be analysed for:

— an ultimate limit state (ULS) to ensure that the individual lines and anchors have adequate strength to withstand the load effects imposed by extreme environmental actions
— an ultimate limit state (ULS) to ensure that the individual lines have the adequate strength and the vessel/ barge is kept within acceptable positions for the environmental limiting conditions for the operation.
— an accidental limit state (ALS) to ensure that the mooring system has the adequate capacity to withstand the failure of one mooring line, or in case of thruster assisted mooring, failure of one thruster or failure in thrusters’ control or power systems.

Holding capacity of anchors shall be documented, and potential dragging anchors shall be assessed. The anchor holding capacity shall be based on actual soil conditions and type of anchors to be used.

Anchor patterns shall be clearly shown on a chart of adequate scale. The patterns should include allowable tolerances. Relevant existing infrastructure and other anchor restricted zones should be shown in the chart.

**Guidance note 3:**
Different types of anchor patterns should be considered:

— Anchor patterns for continuing operations: Vessel is moving along the cable route, anchor patterns are assessed and documented in a more general way to allow for flexibility.
— Anchor patterns for specific operations: Vessel is carrying out a particular, higher risk operation (e.g. in proximity of existing infrastructure) and the specific anchor pattern is assessed and documented.

The use of the anchor handling tug as a live anchor should be reserved for exceptional cases.

Station-keeping systems based on anchoring shall have adequate redundancy or back-up systems in order to ensure the cable integrity and that other vessels and installations are not endangered by partial failure.

**Guidance note 4:**
The station-keeping / power cable integrity check should, as a minimum, include the static and dynamic worst case scenarios for mooring failure.
Safe distances shall be specified between an anchor, anchor line and any existing fixed or subsea infrastructure, both for normal operations and emergency conditions.

The anchor position, drop zone and line catenary should be established taking into account the water depth, line tension and line length. Confirmation of anchor positioning after installation shall be confirmed at regular intervals depending on required accuracy and criticality, and counteractive measures taken when found required. Monitoring systems shall be considered.

During anchor running, attention shall be paid to the anchor line and its catenary, to maintain minimum clearance between the anchor line and any subsea installations and infrastructure or obstacles.

**Guidance note 5:**
The length of anchor lines depends on anchor type and size as well as soil conditions and sea state. For placement of anchors in the vicinity of subsea infrastructure, see DNV-OS-H203. Mid-line buoys may be required when anchor lines cross over existing subsea infrastructure (pipelines, cables), in particular when the infrastructure is not buried to sufficient depth.

All anchors transported over subsea installations and infrastructure shall be secured on deck of the anchor handling vessel.

### 6.2.4.3 Dynamic positioning

Vessels performing cable laying activities using dynamic positioning (DP) systems for station keeping and location purposes shall be designed, equipped and operated in accordance with IMO MSC/Circ.645 (Guidelines for Vessels with Dynamic Positioning Systems) and the corresponding class notations from a recognised classification society.

Selection of required DP equipment class for the operation shall comply with national requirements and in addition be based upon a risk assessment of the actual installation and location.

**Guidance note 1:**
The following DP equipment class typically apply:
- equipment class 1 for operations where loss of position would result in acceptable consequences for the project
- equipment class 2 for operations in close proximity to existing infrastructure which could get damaged
- equipment class 3 for manned subsea operations, e.g. diving support vessels.

Vessels with lower equipment classes may be accepted, subject to agreement by employer / Marine Warranty Surveyor, on a case by case basis. Elements to evaluate with regard to acceptance of lower equipment class include:
- the vessel does not exceed the size for which the facility is designed with regard to withstanding collision
- the consequences of single failures, including fire and flooding, will not increase significantly
- reliable positioning reference systems are available
- operation with open waters on leeward side is possible
- risk reducing measures such as extra DP manning, engine room manning and fire watch are foreseen.

Sufficient DP capacity shall be documented by capability plots. The plots shall be relevant for the planned project based on correct vessel lay-out, including project specific modifications. The plots shall cover normal operation as well as worst case single failure from FMEA.

**Guidance note 2:**
The capacity plots should be provided for two scenarios for the same weather conditions: (1) all system fully functional and (2) single worst case failure mode, or an amalgamation of the worst cases. For capacity plots, see IMCA M 140. For worst single failure concept, see e.g. IMO MSC/Circ.645. For DP vessel operation near an offshore platform, see IMCA M 125.

For critical operations monitoring/displaying of actual DP capacity for actual weather conditions at site are recommended.

Due consideration should be given to the reference systems limitations regarding reliability, accessibility and quality.

The DP operators shall be familiar with the vessel specific FMEA as well as the contingency plans for the operations.

Key elements of the contingency planning measures should be located in the vicinity of the DP operator station, so that situation specific required actions are immediately available to the DP operator.

**Guidance note 3:**
DP operation station and cable engine system operation station (see [6.2.5]) should be located in the vicinity of each
other or other means should ensure close communication between the operators and availability/monitoring of vital information.

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6.2.5 Cable handling equipment

6.2.5.1 Cranes and lifting equipment
Cranes and lifting equipment shall meet applicable statutory requirements. Certificates for the equipment, valid for the operations and conditions under which they will be used, shall be available on board for review.

6.2.5.2 Cable installation vessel arrangement
The vessel deck space and layout of cable handling equipment should:
- be adequate for temporary storage of cable and components required
- allow assembly of cable components required for the planned operation
- by means of suitably spaced / sized rollers, tracks or guides, allow the cable and its components to move axially while being sufficiently supported
- prevent damage to the outer surface of cable and components
- protect the cable minimum bending radius at all times during all cable handling operations through its design.

Guidance note 1:
Requirements with regard to space and layout for cable laying differ, in general, from those for cable repair. Where cable repair involves jointing, arrangements for handling two cable ends are required.

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Vertical and/or horizontal adjustment of supports may be required to ensure a smooth transition from cable storage along the cable highway and onto the chute and to maintain the loading on the cable within the specified limits. Where adjustable support configuration is used, it should be related to a clear and easily identifiable reference point.

The cable handling system shall allow control of pay-out / pay-in speed. The cable handling system shall operate in a fail-safe mode and shall have adequate pulling force, holding force, braking capacity and squeeze pressure to maintain the cable under controlled tension. The forces applied shall be controlled such that no damage to the cable will occur.

Guidance note 2:
A cable engine selection process with regard to type / size / forces applied should ensure that the integrity of the cable is preserved while avoiding product slippage. For linear cable engines, a suitable track / wheel arrangement and length should be chosen which keeps squeeze pressure within the allowable range for the chosen cable (see [B.5]).

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The cable handling system capacity should have sufficient redundancy to allow failure of individual components. In case of failure in the cable handling system, the cable installation should not re-start before the system has been repaired or have enough redundancy to allow for additional failures.

6.2.5.3 Laying equipment instrumentation and monitoring
A sufficient amount of instrumentation and measuring devices shall be installed to ensure that monitoring of essential equipment and continuous digital storage of all relevant parameters required for configuration control and control of the operational limiting conditions can be performed.

The following instrumentation and monitoring should normally be available; alternative methods for monitoring and control should be subject to employer approval:
- cable storage (drums, tanks, turntables):
  - drive system control, if applicable, e.g. turntable speed
  - loading arm control, if applicable, e.g. cable engine speed
  - back tension, if applicable.
- cable engine system:
  - cable pay-out / pay-in length and speed
  - actual tension, deviation from target range
  - squeeze pressure (or fixed set point).
- chute:
  - departure angle (i.e. cable, cable protection system or abandonment & recovery (A&R) line position with respect to the guide surface or last roller), frequently by means of a camera.
— lay configuration:
  — lay parameter monitoring and recording as applicable to the installation method, including independent
tension monitoring if required
  — touch down monitoring with appropriate systems capable of operating under the expected operational
weather conditions at the times / locations required
  — communication between devices.

— winches:
  — line tension and length recorder for A&R system
  — requirements in [6.2.4.2] for anchor winches.

— vessel:
  — vessel position
  — vessel movements such as roll, pitch, sway, heave
  — water depth
  — vessel draught and trim
  — wind speed and direction.

The functioning of essential measuring devices should be verified at regular intervals. Direct reading and
processing of stored records from all required essential instrumentation and measuring devices should
preferably be possible at the vessel’s bridge.

**Guidance note:**
Lay monitoring and control may also use real-time cable modelling software, taking input from vessel position, cable
engine and marine conditions and calculating / controlling cable catenary. Preferably the departure of the cable
overboard can be monitored by video recording during cable installation.

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All measuring equipment used should be provided with an adequate amount of spares to ensure smooth
operation.

6.2.5.4 Calibration and testing

All measuring equipment shall be calibrated in accordance with its manufacturer’s recommendations and
adequate documentation of calibration shall be available on-board the vessel prior to start of work and during
the whole operation.

Essential equipment shall be calibrated against a certified load cell. If essential components for the equipment
such as load cells, amplifiers or software are replaced or modified the equipment shall be tested and re-
calibrated. Indications of equipment out of calibration should trigger a re-calibration. The certified load cell
used for calibration shall have a certificate from a recognised certification body which is not older than one
year.

**Guidance note 1:**
Typical essential equipment can be, but are not limited to, cable engines, clamps, winches, cranes and lifting
equipment, positioning systems.

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Testing and calibration shall be done according to the test procedures. Test procedures shall be subject to
agreement. The test procedures shall provide documented acceptance criteria for the testing and calibration.
The acceptance criteria shall be evaluated and set according to the cable integrity. Any deviation from the
correct value shall be accounted for.

Calibration and testing should be planned and performed such that it can be witnessed.

During testing and calibration the complete load range should be covered. For linear trends at least five load
steps should be applied up to maximum expected dynamic loads, more steps are required when testing to
maximum capacity. Non-linear trends require higher numbers of load steps. Cyclic loading should be
considered.

**Guidance note 2:**
Cable engine system testing includes combinations of cable engine(s), clamp(s) and cable storage, and testing of
single cable engine failure when running more than one cable engine, test redundancy of single cable engines, fail safe
actions, loss of main power and loss of signal.

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The calibration and testing of essential equipment should as a minimum be performed on an annual basis.
For each specific project, testing and documentation of vessels and equipment shall as a minimum include:

- in-field dynamic positioning system test (DP acceptance test)
- maintenance and calibration records of critical/essential equipment, including testing equipment
- maintenance and calibration records of critical/essential equipment on support vessels
- pull and fail safe test of the cable holding system to verify sufficient squeeze pressure and friction
- A&R test.

A modification should be evaluated and documented regarding its potential to invalidate calibration. Re-testing should normally be performed in the following cases:

- if the annual testing was performed with a different setup (e.g. different clamps or pads or cable diameter)
- after equipment has been maintained in a way that affects calibration
- when equipment is exchanged or significantly modified.

6.2.6 Mobilisation
Before mobilisation, procedures for safe operations shall be in place.
In accordance with the mobilisation manual, all equipment needed for the operation shall be mobilised. During mobilisation,

- the vessel spread is fitted with all equipment necessary for the intended activity / operation
- the equipment is checked, serviced and adjusted and necessary tests / calibrations are carried out
- seafastening of equipment and, after load-out, cable / components is carried out.

On the cable installation vessel, the cable path / highway should be adjusted to the correct configuration. If adjustable, the cable supports and/or chute should be verified.
Handling and storage of cables and materials on supply, laying and support vessels shall ensure that hazards to personnel, cable and accessories are avoided. Slings and other equipment used shall be designed to prevent damage of the handled products. Equipment and material (permanent and temporary) shall be controlled and records maintained. For temporary storage and transport of cable, see also [5.3].

All equipment, cables, accessories, consumables, etc. shall be seafastened to withstand transportation loads within the operational limits expected for the location (sea voyage, project area) and time of the operation.
Trim and ballasting shall be verified to be according to procedures prior to start of operations.
All personnel shall be familiarised with the operations to be performed. Personnel involved in critical operations should participate in a risk assessment, safe job analysis and/or toolbox talk ensuring that risks involved in the operation are understood.

6.2.7 Cable burial equipment
6.2.7.1 Equipment characteristics
A diverse range of cable laying and burial equipment with differing capabilities can be used in the cable installation process. The selection of equipment best suited for the task is an iterative process involving the following review steps which may lead to different solutions for array and export cables:

a) Seabed conditions: Consideration of general feasibility of cable burial, achievable burial depth and suitable burial method.

   **Guidance note 1:**
   
   Figure 6-3 indicates potential burial techniques depending on ground conditions. Scales for cohesive and cohesionless soils are mapped approximately onto the x-axis. The suitability of the tools is shown on the y-axis. Ploughing (solid line) is suitable for a wide range of ground conditions. Jetting (dashed line) is suitable for soft or loose soils. Mechanical cutting (dash-dot line) is suitable for hard or dense soils. The boundaries are indicative only with equipment options widening the range of application. Fibrous material such as peat can be challenging for any burial technique.
b) Cable properties and other boundary conditions: Consideration of lengths, mechanical properties and the limitations for handling of the cable or cable configuration; anticipated vessel size and capabilities; marine conditions.

c) Laying and burial combination: The combination (or separation) of cable laying and cable burial should be reviewed based on project boundary conditions. Simultaneous Lay and Burial (SLB) is a combined method where the cable is directly guided from the cable installation vessel into the burial device. Post Lay Burial (PLB) involves a temporary laydown of the cable onto the seabed and a later, separate burial operation. Prelay trenching may also be an option for some projects, such as in areas with hard seabed (e.g. by V-shape plough, mechanical cutter) or mobile sediments (e.g. by dredger, mass flow excavator).

Guidance note 2:
Table 6-1 provides some guidance on SLB vs. PLB approaches.

<table>
<thead>
<tr>
<th>Simultaneous Lay and Burial (SLB)</th>
<th>Post Lay Burial (PLB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>combination of work steps</td>
<td>decoupling of work steps</td>
</tr>
<tr>
<td>one (large) vessel for laying and burial</td>
<td>dedicated vessels for laying and burial</td>
</tr>
<tr>
<td>simultaneous control of laying and burial parameters (e.g. on-bottom tension)</td>
<td>fast progress of cable laying, shorter weather window required</td>
</tr>
<tr>
<td>cable laying speed governed by burial speed, large weather window required</td>
<td>cable unprotected for some time, on-bottom stability to be analysed, guarding may be required</td>
</tr>
<tr>
<td>immediate protection of cable</td>
<td></td>
</tr>
</tbody>
</table>

The quality of cable laying is vital for successful burial operations. The overall progress rate using a barge may be dictated by anchor handling and placement rather than by the performance of the burial tool.

d) Mode of movement / burial tool carrier system: Consideration of choices including:

- towed - movement of a passive tool by tow force exerted by a host vessel or shore-located winch
- bottom crawling - self-propelled or umbilical controlled vehicle, commonly on wide-track caterpillar tracks reducing ground pressure or less commonly on wheels; suitable to operate in higher currents; may put pressure on nearby buried infrastructure (e.g. other cables)
- free swimming - negatively to neutrally buoyant vehicle using thrusters for propulsion and manoeuvrability; not suitable to operate in very shallow water or high currents.

e) Anticipated performance: Achievable burial depth, trench stability, burial tool stability, advancement speed, power / tow force requirements, wear and maintenance.

Preliminary decision for a specific approach should be subjected to a systematic review of all risks.
Guidance note 3:

Table 6-2 provides some guidance on potential issues to be considered. The assessment of suitability can differ for specific tools, methods and applications.

### Table 6-2 Comparison of burial techniques

<table>
<thead>
<tr>
<th>Category</th>
<th>Factor</th>
<th>Hydro jetting</th>
<th>Ploughing</th>
<th>Mechanical cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capability in difficult site conditions</td>
<td>Range of suitable soil conditions</td>
<td>M</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Uneven bathymetry</td>
<td>H</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>High currents</td>
<td>L</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Low underwater visibility, high turbidity</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Very shallow water</td>
<td>L ²)</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Usage options</td>
<td>Simultaneous lay and burial (SLB)</td>
<td>M</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Post lay burial (PLB)</td>
<td>H</td>
<td>L ³)</td>
<td>M ³)</td>
</tr>
<tr>
<td></td>
<td>Maneuverability</td>
<td>H</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Multi-pass capability</td>
<td>H</td>
<td>L ⁴)</td>
<td>M ⁴)</td>
</tr>
<tr>
<td></td>
<td>Ability to bury bundled cables</td>
<td>H</td>
<td>L ⁵)</td>
<td>L ⁵)</td>
</tr>
<tr>
<td></td>
<td>Ability to bury loops or repair joints</td>
<td>M</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Burial operation</td>
<td>Safety of cable during burial operation</td>
<td>H</td>
<td>L ⁶)</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Suitability in close proximity to infrastructure</td>
<td>H</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Backfill quality</td>
<td>M</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Environmental benignity</td>
<td>M</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Rate of progress</td>
<td>M</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Logistics</td>
<td>Availability of suitable vessels</td>
<td>H</td>
<td>M ⁷)</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Mobilisation layout flexibility</td>
<td>H</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Ease of catenary / tow line management</td>
<td>H</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Reliability (low maintenance)</td>
<td>M</td>
<td>H</td>
<td>L</td>
</tr>
</tbody>
</table>

1) Assessment: H = High / more favourable, M = Medium / neutral, L = Low / less favourable, - = not applicable.
2) Requires water supply. Typical minimum water depths are 5 to 10 m for ROV based systems.
3) Requires subsea loading of cable if start and end point are offshore.
4) Single pass only, except for pre-lay trenching operations.
5) Suitable for pre-lay trenching. Very limited suitability for SLB or PLB operation.
6) A cable manufacturer may recommend not using ploughing as a burial technique.
7) Large bollard pull required. Due to size and weight of plough, generally launched over stern, not side.

There is no single technique or piece of equipment which is suitable for all ground and site conditions. Hybrid systems have been proposed to widen the operational envelope.

Some tools require a minimum water depth (e.g. jetting for water supply); most tools have maximum water depths in which they can be operated.

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### 6.2.7.2 Equipment selection

A wide range of tools has been used for cable burial, including the following:

- pre-lay trenching tools, including dredgers (grab dredger / backhoe dredger, trailing suction hopper dredger, cutter suction dredger) and V-shape ploughs
- water jetting tools, including trenching ROV with two jetting blades, jet sledge, hydro plough, vertical injector and (for specific applications) mass flow excavation tools
- ploughing tools, including cable ploughs and vibration ploughs
- mechanical cutting tools, including chain cutters (single chain cutter, V-shape chain cutter), rock wheel cutters and others (e.g. auger wheels)
- venturi systems, including water lift and air lift systems.

A project-specific assessment should be made to select an appropriate system, or combination of systems. Water jetting tools are described in [6.2.7.3], ploughing tools in [6.2.7.4] and mechanical cutting tools in [6.2.7.5].
6.2.7.3 Jet trencher

Hydro jetting systems commonly perform PLB operation, sometimes SLB operation, either on free flying or tracked ROVs. In very shallow water, towed jetting sleds can perform SLB operation. A combination of high flow / low pressure water jets (e.g. for fluidising and displacing granular sediment) and low flow / high pressure water jets (e.g. for cutting and transporting of clay lumps) opens a channel into which the cable is allowed to sink (Figure 6-4). When fluid motion has subsided at a distance, deposition and re-sedimentation occurs. The nozzles are arranged along one or two adjustable jetting legs which are lowered into the seabed.

![Figure 6-4](image)

ROV jet trencher. (a) Principal components, (b) PLB operation

Machine options to enhance capabilities may include:

— dredging unit (spoil removal, extension of use in inhomogeneous soil, e.g. in shell beds)
— depressor (forcing cable downward into the fluidised trench)
— manipulators (e.g. for gripping, cutting).

When working with jetting systems, key considerations should include the following (see also Table 6-2):

a) Site conditions: Hydro jetting is well suited for softer and loose grounds. Fast re-sedimentation can limit the achievable burial depth with stiffer cable. Higher-strength clay lumps remaining in the trench can adversely affect lowering of a cable. Fibrous material (e.g. peat) can prove extremely challenging. High currents can make free flying ROV applications infeasible.

b) Usage options: A minimum water depth is required for submerged pumps to work; alternatively water can be surface-supplied. Sleds are frequently used in very shallow water or, in lightweight configurations, where soil does not provide sufficient bearing capacity.

c) Burial operation: Water pressure may be surface generated (lighter vehicle, but losses in piping) or vehicle generated (heavier vehicle, more water power). Stiffer cables require particle suspension over longer distances and time to be lowered into the trench.

d) Handling, deployment and recovery: ROVs commonly have the umbilical for power supply and communication integrated with the lifting line (surface winch umbilical). Deployment may be as “free swimming” with a direct connection between surface winch and ROV or via a tether management system (TMS) where the TMS is inserted in between. TMS have particular advantages in very deep water.

Jet trenchers / the trenching spread should have a control and monitoring system for the position of the jetting arm(s) and the trencher frame, horizontally and vertically relative to the cable and seabed. Devices indicating jetting parameters as well as the depth of the jetting arms should be installed. Survey sensors at the back end of the trencher may help determining the cable burial depth.

Jet sleds are towed trenchers which should have a control and monitoring system for the position of the jetting arm(s) and the overhead frame, horizontally and vertically relative to the cable and seabed. Devices indicating tension in the tow line and showing the depth of the jetting arms should be installed.

6.2.7.4 Plough

A plough is a system towed along the cable route by a host vessel, commonly performing SLB operation. The pulling force is either provided by bollard pull (moving vessel) or winches (anchored vessel). At landfalls, ploughs may also be pulled by winches located onshore or nearshore, performing a PLB operation. Tracked ploughs do also exist. The plough’s share cuts into the soil, opening a temporary trench which is held open by the side walls of the share. The cable is guided through the plough into the opened trench and pushed down by a depressor before the soil naturally backfills over the cable (Figure 6-5).
Guidance note:
Ploughs for pre-lay trenching, sometimes referred to as ‘pipeline plough’ or ‘V-shape plough’, have a fixed share and multi-pass capability. Pre-lay trenching can alleviate proximity concerns close to offshore units.

Ploughs are typically designed using the ‘long beam’ approach whereby the cutting depth is hydraulically adjusted by the height of the front skids around which the plough body and share can rotate. The skids should slide along the seabed without significant sinkage. The tow force required derives from the plough contact with the seabed at share and skids.

Machine options to enhance capabilities may include:
— on-board fluidisation (jetting) system for sands (reduced tow force, increased burial depth, increased progress rate)
— vibrating share plough (liquefying and displacing the seabed with low-amplitude vibration, ensuring progress in difficult ground conditions like chalk and gravel)
— rock ripping system (extending usability into soft and fractured rock conditions)
— diverless loading and unloading of cable (health and safety risk reduction).

When working with ploughs, key considerations should include the following (see also Table 6-2):

a) Site conditions: Significant geological hazards can include steep slopes (risk of overturning), very soft soils (risk of sinking) as well as cemented soils. Large boulders can misalign the plough.

b) Usage options: Ploughs have very limited manoeuvrability, affecting their ability to operate in close proximity of obstructions or infrastructure. Cable loading in PLB applications may require diver assistance for some models or applications.

c) Burial operation: For a plough to be considered ‘stable’, the skids (on the seabed) and the share (at desired depth) need to operate as intended. Stability is governed by device characteristics (dimensions, submerged weight), the (undrained) soil bearing capacity and the resulting forces. Many ploughs require a longer horizontal transition distance to plough down to and up from intended burial depth.

d) Handling, deployment and recovery: When used in the (common) SLB mode, ploughs require careful cable tension and catenary management.

Ploughs / the ploughing spread should have a control and monitoring system for the position of the share relative to the seabed. A depressor may be installed to secure position of the cable at depth of burial. Control mechanisms indicating tow line tension, cable tension, and displays of the depth of the trench should be installed. Vibrating share ploughs should in addition have frequency and amplitude controls / displays.

6.2.7.5 Mechanical cutter

Mechanical cutters employ either a cutting wheel or an excavation chain to cut a narrow trench into compacted seabed or rock (Figure 6-6). They are used for pre-lay trenching and sometimes PLB operation, but have generally too low progress rates to be applied in SLB operation. Rock wheels have replaceable cutting teeth which are adapted to the specific ground conditions. Excavation chains have similar teeth as well as scoops to transport the material. In PLB operation, the cable is loaded with or without diver assistance and passes through an enclosed pathway before entering the trench behind the vehicle.
Machine options to enhance capabilities may include:

- conveyor / auger (moving cut material away from trench)
- eductor / dredging / backwashing system (keeping trench free of debris)
- cable loading manipulators.

When working with mechanical cutters, key considerations should include the following (see also Table 6-2):

a) Site conditions: Geological hazards include soft top soils (stability and bearing problems), trench collapse and fibrous material in the soil.

b) Usage options: Due to their low progress rate, mechanical cutters are commonly used for short distances in hard grounds.

c) Burial operation: Depending on the soil conditions, removal of material from the trench bottom can be inadequate. Large rocks remaining in the trench can cause point loads in cables laid on top.

d) Handling, deployment and recovery: In shallow water SLB applications the catenary management can be challenging. In PLB applications, cable management can be difficult and visual verification of the cable relative to the cutting device will be required at all times. In very hard grounds, the wear and maintenance rate of the cutting tool can be high.

Mechanical cutters / the trenching spread should have a control and monitoring system for the position of the cutting tool and the device frame, horizontally and vertically relative to the cable (if applicable) and seabed. Devices indicating cutting parameters as well as the depth of the trench should be installed.

### 6.2.7.6 Verification of equipment selection

Cable laying and burial equipment shall be selected to be suitable for the intended application. The equipment should be maintained in accordance with the manufacturer’s specifications and have valid maintenance records covering all systems of importance for the safety of its operation. Requirements to the equipment should be given in a specification stating requirements for:

- general offshore / shallow water / dry operation capability, for the project location and timing
- space and seafastening
- cranes and lifting appliances
- positioning and survey equipment
- power and control
- alarm systems, including remote alarms if applicable
- monitoring of installation parameters (e.g. pitch, roll, distance travelled, tension, depth of burial)
- any other requirement due to the nature of the operations.

Trials should confirm whether the trenching spread meets its operational criteria, including deployment and recovery of equipment, which can be executed in port. Sea trials may further be used to investigate effectiveness of a tool on site and to optimise operations.

**Guidance note:**

Sea trials for burial tools can normally only be executed on site. Limitations of survey data and variations of ground conditions along the cable route can limit the quality of output from a trial run.

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6.3 Pre-lay survey and route preparation

6.3.1 Pre-installation route survey
A pre-installation survey of the cable route should be performed in addition to the route survey required for design purposes covered in [3.4] if:

— the time elapsed since the previous survey is significant
— seabed level changes are likely to have occurred
— the route is in areas with heavy marine activity
— new offshore infrastructure is present in the area and as-built information is not available
— after the previous survey, seabed preparation work was performed close to the route
— a significant deviation from the originally planned cable route occurred, outside the area previously surveyed.

Where applicable, the extent of, and the requirements for, the pre-installation route survey shall be specified. The schedule of the survey should avoid interference with other on-site execution works.

Guidance note:
The pre-installation survey typically consists of a geophysical method which allows identifying hazards within the cable corridor. Visual (ROV) survey may be required to confirm specific features on the seabed.

The pre-installation survey should determine and/or verify:

— that the present seabed conditions match those of the survey required in [3.4]
— potential new/previously not identified hazards to the cable and the installation operations.

Results of this survey should be reflected in the project execution plans.

6.3.2 Cable route preparation
Cable route clearance may be required to remove obstacles (on seabed surface, sub-surface) and potential hazards interfering with the installation operations, for instance:

— boulders
— debris affecting lay and burial operations
— unexploded ordnance (UXO)
— out-of-service cables.

Guidance note 1:
The width of the corridor to be cleared should be consistent with the risk profile of the route. Routing around objects like boulders or suspected/identified UXO can be more cost effective than clearing. UXO clearance typically requires involvement of authorities/special services. For considerations of removal of out-of-service telecommunication cables, see ICPC Recommendation 1.

Cable route preparation may be required, for instance, to:

— prevent loads that occur as a result of seabed or shore area conditions (such as unstable slopes, sand waves, deep valleys, possible erosion and scour) from exceeding the cable system design criteria
— prepare for pipeline and cable crossings
— infill depressions and remove high spots to prevent unacceptable free spans
— dredge at cable entry points of offshore units, if sediment accretion/depletion is outside the design envelope, e.g. clearing of J-tube entrances
— excavate pre-lay trenches with a sufficiently smooth bottom profile
— carry out any other preparation due to the nature of the succeeding operations.

Cable route clearance and cable route preparation should be carried out according to the specification developed during the design phase (see [4.5.1]). If applicable, these works should be recorded and documented in a way adequate for as-built documentation (see [9.2.5]).

Cable route clearance and cable route preparation activities should be carried out well in advance of cable lay and burial operations to accommodate for unexpected difficulties. Where unforeseen activities are required, a risk assessment should be conducted and the required approvals be obtained.

A pre-lay grapnel run (PLGR) should normally be carried out as near in time as practical prior to the cable laying operation to assure a debris-free cable route. The potential for subsequent removal campaigns should be considered.

Guidance note 2:
Pre-lay grapnel operation can ensure that there are no recent physical obstructions. Physical obstructions may include
abandoned fishing tackle, ropes, hawser or wires introduced along the cable route. Grapnels are effective to a
penetration depth of less than 0.5 m, subject to soil conditions. The number of pre-lay grapnel runs required depends
on the site conditions. Single runs are common; multiple runs (e.g. with a separation of 10 m) have been used.

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6.4 Cable laying

6.4.1 Cable installation

A cable tracking system shall be used to maintain records of cable / drum numbers, cable lengths, cumulative
length, field joints and repair numbers.

The lay configuration and loads shall be controlled in order to ensure that these are within the design envelope
during installation (Figure 6-7). The configuration and loads may be controlled by various means. These should
be clearly described, including allowable ranges for the specific sections of the installation.

![Figure 6-7](Cable laying process)

The cable lay process shall be monitored and controlled. Parameters monitored may include water depth, top
tension, departure angle, lay back distance and touchdown point as well as environmental parameters and
vessel motion. Depending on the installation vessel and cable, the preferred methods may change.

The cable touchdown point should be monitored continuously for operations that are critical or represent a risk
for existing infrastructure. The monitoring system shall be capable of operating under the sea-states expected
for the planned operations.

**Guidance note 1:**

Critical operations may include laying along curves or over existing infrastructure. Continuous touchdown point
monitoring may be achieved, for instance, by use of a high resolution real-time sonar system or ROV, supplemented
by real-time catenary modelling. The use of ROV may not be possible in very shallow waters or high currents.

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The cable shall be laid within an acceptable range of top and bottom tensions and without violating the cable
minimum bending radius or maximum allowable cable crush / squeeze loads.

**Guidance note 2:**

An acceptable value of tension is subject to the specific condition at a particular point along the cable route.
Insufficient tension may lead to the forming of loops on the seabed and make burial operations difficult. Compression
in the cable should, as a general rule, be kept low and within the cable manufacturers’ recommendation and confirmed
by dynamic analysis and continuous monitoring during installation. Excessive tension can prevent reaching the target
depth in post lay burial operations, lead to free spans, pull the cable off route when laying in curves or damage the
cable.

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Cable lay operations shall be carried out using positioning systems with the required accuracy. Measures shall
be taken to avoid damage to existing infrastructure, specifically in congested areas, in the vicinity of existing
installations and at pipeline and cable crossings.

Laydown of the cable should normally be performed such that cable is placed within the tolerances of the
planned route and with the desired angle of approach to the end point. Deviations from the planned lay route
should be checked and verified or corrected before cable laying operations continue.

**Guidance note 3:**

The cable end storage procedure should be defined and accepted before start of cable laying operations. Requirements
with regard to sealing against water ingress and protection against the risk of cable damage apply. The end caps should
be fixed in accordance with the cable manufacturer’s specifications.
In certain site conditions (high currents, very shallow water with wave induced loads) a cable end may have to be laid down with an anchoring system (e.g. weight, grappling line, subsurface buoy) to prevent migration of the cable on the seabed.

When the offshore unit where the cable will terminate is not present, the cable end may have to be temporarily laid down off track to avoid cable damage during installation of the offshore unit.

The position of the cable shall be verified to be within its target area prior to departure of the lay vessel from site.

In the event of suspected installation damage a survey of the cable should be performed before repair to establish the extent of damage and feasibility of the repair procedure, see also [7.6]. After completion of the repair, a survey should be performed of the cable over a length sufficient to ensure that no further damage has occurred.

The consequences of loops and kinks shall be evaluated as part of HAZID/HAZOP assessments and mitigation measures should be defined. A form of kink detection should be used (e.g. improved control of parameters such as lay tension and touch down point monitoring, real-time catenary modelling, post-lay survey). In case the parameters controlling the lay configuration indicate that an unacceptable situation is experienced or a kink event is suspected, an inspection should be performed. The inspection should be carried out such that it can be confirmed that a kink has not been laid, i.e. the minimum bending radius has not been compromised.

Guidance note 4:
The assessment of the consequences of kinks will typically include recovery, availability of repair methods and material as well as time frames for repair. Detection and rectification of kinks during installation will have less schedule and cost impact than detection and rectification during the operational phase of the cable.

For cable sections remaining, for a period of time before burial, unprotected on the seabed, cable guard vessels may be required.

Guidance note 5:
The distance to be protected by cable guard vessels may vary depending on local conditions and circumstances. For example, high density vessel traffic or fishing activities may require narrow spacing of cable guard vessels. Communications with and involvement of local fishermen and fishermen’s associations is crucial.

6.4.2 Weather vaning, abandonment and recovery

When operational limiting conditions for cable laying are exceeded, but analysis and experience show that there will be no damage to the cable (e.g. exceeding tension or violating minimum bending radius), the cable laying operation should safely cease and the cable installation vessel should be positioned favourably to overcome the influence of wind, waves and currents and wait for the conditions to improve ("weather vaning"). The cable installation procedure shall provide the operational limiting criteria for suspension and for restarting of installation operations.

Guidance note 1:
In areas with strong tidal variations, weather vaning during high currents may be a normal part of the procedure. The forces on the cable, including vortex induced vibrations, should be evaluated during installation engineering. Weather vaning commonly incurs less cost and risk for a cable lay operation compared to cutting and abandoning the cable and recovering and jointing the cable once the weather has improved. During weather vaning, the cable installation vessel should avoid twisting and kinking of the cable and may have to keep adjusting position to avoid fatigue damage of the cable.

As a planned operation or in an emergency situation, the cable A&R system and procedure should allow safe abandonment of the cable if needed. During project preparations, the cable A&R arrangements shall be designed, including, for example, clump weights, grappling lines for recovery and marker buoys. The laydown arrangement should ensure on-bottom stability and that no parameters specified by the cable manufacturer are compromised.

Prior to planned cable abandonment, the cable end shall be sufficiently protected from water ingress so that it can be safely abandoned onto the seabed and subsequently retrieved. During planned abandonment, the cable shall be laid down in a controlled way without exceeding any of its mechanical parameters. The grappling line should be easily recoverable, independent of waves and current conditions.

Guidance note 2:
If abandonment is part of cable installation design (‘split campaign’), the cable end should be temporary protected against accidental impacts such as fishing. Shallow burial may be considered as an option.
Emergency cable abandonment may be have to be performed if the cable installation vessel loses position or if the weather is deteriorating beyond conditions where weather vaning is a safe option for the installation spread.

**Guidance note 3:**
Emergency cable abandonment is a safety measure with consequences for project schedule and economics. The procedure should allow for cable cutting and sealing the end, except for extreme cases where time may be insufficient for sealing.

---end---of---Guidance---note---

Prior to recovery, the cable should be surveyed over a length away from the A&R head, sufficient to ensure that no damage has occurred. Recovery shall be carried out in a way not compromising the cable’s mechanical parameters.

### 6.4.3 Jointing

Jointing activities require:

- detailed planning of the entire process
- (repair) joint kit
- qualified and well-trained crew
- for offshore joints, a suitable vessel and equipment (stability, length for cable laydown, handling of two cable ends, etc.)
- for offshore joints, an adequate window of favourable weather.

**Guidance note 1:**
A vessel intended for cable laying does not necessarily have sufficient deck space and/or cable handling equipment to carry out jointing work after an emergency abandonment.

---end---of---Guidance---note---

The technicians shall be qualified and trained on the type of jointing kit to be installed and in possession of the related certificate.

**Guidance note 2:**
For guidance on joints, see CIGRÉ Technical Brochures 177 and 490. For guidance on cable accessory workmanship, see CIGRÉ Technical Brochure 476.

---end---of---Guidance---note---

The jointing arrangements shall ensure that:

- cable ends are secured and, for offshore joints, relative motion of the two cable ends is eliminated
- actual jointing work takes place in a controlled environment with temperature and humidity within ranges specified by the manufacturer
- jointing of conductors, insulation and sheaths (metallic, lead, polymeric) is carried out in accordance with the manufacturers’ recommendations.

**Guidance note 3:**
During jointing activities offshore at least one of the cables is suspended from the vessel (the other cable may still be stored on the vessel). Should the weather deteriorate once the jointing activity has started, the cable may have to be cut and abandoned.

Once both cable ends are laid up in the jointing house, the jointing process requires one to several days depending on the cable and joint design. Jointing techniques may include field moulding and pre-fabrication. Field moulding replicates the factory process to restore the insulation, increasing the diameter of a single core slightly. Pre-fabrication joints use various tested elements, increasing the cable core diameter, but reducing installation time.

Jointing times are significantly shorter for pre-moulded joints used in rigid joints, but deployment of the rigid joint is more complex. Most offshore jointing activities for three-core cables employ rigid installation joints.

Considering the duration of the jointing operations, suitable measures may have to be implemented to avoid cable fatigue in the catenary, e.g. over the chute or at the touchdown point, for instance through additional suspension arrangements.

---end---of---Guidance---note---

For flexible repair joints, curing times of the taped insulation layer shall be observed. The armour of both cable ends shall be connected by joint armouring with adequate tension. The final joint assembly with outer sheath should be suitable for deployment over the cable highway and the cable laying chute / sheave.

For rigid repair joints, the pre-fabricated elastomeric sleeve should be pre-tested at the factory. The jointed cable ends shall be encased in the (commonly metallic) housing with the armouring secured to the housing. Bend restrictors / stiffeners shall be used for the transition between rigid joint housing and the flexible cable.

For jointing of subsea and land-based cables at the transition joint bay, see [6.6.5].

The individual fibres of the fibre optic package shall be spliced in accordance with the specification. The splice box is commonly integrated in the housing of a rigid joint.
6.5 Cable pull into offshore unit

6.5.1 General

Project specific pull-in procedures shall be developed. The procedure shall be based on pull-in design and analysis incorporating dynamic amplification factors, supplemented by pull-in tests (5.6), as required.

**Guidance note:**

Higher factors of safety generally apply for (vertical) “lifting” operations compared to (nearly horizontal) “pulling” operations. See also [4.7.2.3].

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Monitoring of the pull-in operation may involve:

— use of ROV or alternative method to observe cable (or cable assembly) entry into the offshore unit’s substructure and pull-in progress
— tension monitoring at offshore unit during cable pulling
— detection of loops and kinks
— close communication between operators on offshore unit (controlling pull-in) and on cable installation vessel (controlling cable pay-out).

6.5.2 Preparations

Preparatory activities on site should follow the approved procedures which may include the following:

— review of installation design and calculations
— confirmation of physical arrangement on offshore unit (e.g. position of J- or I-tube, clamps and support), identification of damages and rectification of these
— installation of pulling / lifting equipment, if not pre-installed
— preparation of the cable hang-off
— visual underwater survey of the seabed and the cable entry point including bight laydown area, if not previously performed
— verification (and rectification) of condition of pre-installed messenger line or, if not present, installation of messenger line
— (diverless) removal of blind cover or bung from cable entry point.

Where the cable entry point is suspected to be affected by marine growth, debris or obstructions, it should be inspected and cleaned, e.g. by gauging or brush pigs.

The messenger line should be used to guide the pulling line through the J-tube, I-tube or entry hole of the substructure.

**Guidance note 1:**

The messenger line should not be considered as the pulling line.

Pre-installation of the messenger line can decouple work on the offshore unit and on the laying vessel. Replacement of messenger lines may be necessary due to damage (corrosion, shearing). Messenger lines are typically made of marine grade steel (‘messenger wire’) or synthetic material (‘messenger rope’).

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The pulling equipment (winch, rigging, load-monitoring, test equipment) shall be placed as defined in the installation design.

**Guidance note 2:**

Typically, the pulling equipment is placed on the offshore unit, at a suitable distance above the hang-off system. Placing the pulling equipment on the cable installation vessel (“pull back” method) requires additional sheave arrangements on the offshore unit and is generally considered to be more hazardous from a health and safety perspective.

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On the cable installation vessel, the pulling line shall be securely fastened to the cable pulling head.

**Guidance note 3:**

The rigging should be carefully designed to reduce or eliminate snagging hazards. Steel wire ferrules have a tendency to snag; chamfered designs should be used (Figure 6-8). The use of synthetic ropes may be permissible, provided that their integrity can be assured.

The design of the rigging should be considered in conjunction with the design of a cable protection system which is to be pulled together with the cable.

A bearing swivel may be used directly in front of the cable stocking / pulling head to reduce torsion within the cable, pulling line and cable protection system (if applicable). Where used, the swivel should be of a design which poses low snagging hazards.

The methodology of pulling overlength should be addressed by the design of the rigging.
A cable protection system (CPS), where used, should be installed as intended by its design, which may include either or both of the following options:

a) Installation prior to cable: The CPS may be installed at the offshore unit prior onshore or offshore. The pulling line is guided through the pre-installed CPS.

b) Installation together with cable: The cable end is fitted with the CPS (at a distance in accordance with the design) and the pulling device on board the cable installation vessel. The design may include a “weak link” which breaks when the CPS is in place, after which the cable is pulled to final length.

**Guidance note 4:**
Installation of a cable protection system after cable pull-in (e.g. split pipe sections) should only be considered for remedial work during the operations phase, not as a normal installation method.

### 6.5.3 Cable first-end pull

The cable installation vessel should approach the offshore unit close enough for the planned operation, considering contingencies in case of unplanned events. The vessel position may have to be adjusted depending on the weather and relative to the cable entry point to produce the correct catenary curve while avoiding excessive pulling of the head / cable across the seabed.

The pulling head / cable end shall be lifted overboard, aligned in front of the entry point of the offshore unit and lowered toward the seabed in a controlled manner while cable is paid out from the cable vessel (Figure 6-9).

The entire pull-in operation shall be continuously monitored for all parameters to be within specified limits (for options, see [6.4.1]) including:

- departure angle, taking marine conditions into account
- pulling force (tension) monitoring at the offshore unit, e.g. by means of a load cell
- holding force (tension) at the cable engine of the laying vessel
- bending radii of the cable when going overboard, touching the seabed, being pulled across the seabed and entering the foundation, e.g. bellmouth of I- or J-tube
- length and speed of cable pay-out
- vessel position and movement.

**Guidance note:**
When an armour layer has been installed to prevent scour, it may be necessary to prevent the cable catenary from touching the rock to avoid abrasion.
The entry point of the pulling head into the offshore unit structure presents a snagging hazard and should be carefully monitored.

Continuous underwater monitoring at the interface between cable and offshore unit may be achieved by use of multibeam sonar system or ROV.

---end---of---Guidance---note---

Upon completion of the pull-in, the position of the cable should be confirmed, possibly as part of an as-built survey, see [6.8]. Potential damage shall be identified and mitigation measures taken, if required.

6.5.4 Cable second-end pull

Where cables have not already been pre-cut to length, the cutting length calculation of the cable should take the following into account:

— final position of cable on the seabed
— catenary of cable between seabed and foundation, considering scour development
— cable path inside offshore unit
— overlength for termination (possibly including a part impaired by pulling)
— contingency.

Guidance note 1:
Excess cable lengths can lead to significant cable displacement from the planned route, resulting in difficulties to bury the cable. When a quadrant is used, excess cable can lead to formation of loops when the quadrant is released.

---end---of---Guidance---note---

Second-end pull-in operations are commonly carried out as one of the following two methods:

a) Bight laydown: During installation design, survey results should confirm the laydown area to be free of rough seabed, boulders, rock outcrops and other obstacles that may cause damage to the cable during pull-in. The installation analysis should also confirm acceptable friction and soil build-up when the cable is pulled over the seabed. At the time of installation, the cable end is laid down on the seabed in the form of an S-shaped or Ω-shaped bight by carefully navigating the installation vessel. Subsequently the pulling head with attached pulling line is lowered to the seabed and the cable is pulled into the offshore unit (Figure 6-10). Installation parameters (see Figure 6-7) and cable movement shall be monitored during pull-in.

Guidance note 2:
The pre-determined laydown target route may be adjusted by the captain of the cable installation vessel to take account of meteorological and marine conditions, anomalies or other factors. ROV monitoring during cable pulling can confirm that debris build-up on the inside of the pull-in loop remains within design limits.

---end---of---Guidance---note---

Figure 6-10
Second-end cable pull into offshore unit - Bight laydown on seabed

b) Deployment quadrant: The cable is placed over a deployment quadrant which is supported by a crane, winch system or the vessel’s A-frame. The quadrant is lowered towards the seabed while the cable is being pulled in at the same time (Figure 6-11). On the seabed, the quadrant is laid down in a monitored process to disengage the cable. This method requires careful coordination of cable lowering and cable pulling.
Guidance note 3:
When a cable protection system is fixed to the cable, a bight will remain on the seabed. When a pull through / weak link system is used, the bight can be pulled out.

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(a) Side view
(b) Top view

Figure 6-11
Second-end cable pull into offshore unit - Deployment quadrant

Guidance note 4:
Besides the methods described above, alternative methods of second-end pull-in have been used. For example, buoyancy elements can keep the cable at a distance to the seabed. The cable can also be laid down first and subsequently picked up and handled with a quadrant.

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For pull-in monitoring and survey requirements, see [6.5.3].

6.5.5 Cable fixing
Once sufficient length has been pulled up the offshore unit, the cable should be temporarily secured. Suitable options include:
— clamping the cable, typically by means of temporary hang-off, see [4.7.2.6]
— temporarily securing a mechanical (pre-) termination device pulled in together with the cable.

The permanent hang-off of the cable can be achieved by a range of solutions including:
— permanently securing a mechanical (pre-) termination device attached to the cable
— mechanical termination of the armour wires of the cable, see [4.7.2.6]
— resin encapsulation of the wires.

For electrical works and termination, see [6.9.1].

6.6 Landfall
6.6.1 General
Landfall activities include equipment mobilisation, landfall preparation, positioning of cable installation vessel, cable pull in, cable burial and demobilisation.

Risks to persons and the environment shall be considered, as well as the presence of third parties (e.g. recreation). Appropriate security measures and communication shall be established. In accordance with regulations, the construction area shall be clearly marked with warning signage and fenced off as appropriate to assure safety of the public.

The site layout, transport of equipment to the site and landfall preparation works (open-cut trench installation, horizontal directional drilling) shall be executed in accordance with the design.

For any marine operation works, operational conditions according to [6.1.3] shall be defined.

Guidance note:
In very shallow and sheltered waters, categorisation of the area may not warrant full application of offshore rules and dispensation may be sought from and should not be unreasonably withheld by the Marine Warranty Surveyor. Reduced weather conditions can allow for beachable barges, beachable vessels and small support vessels to be used, but will limit the available weather windows.

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After burial of the onshore sections, restoration works at the beach and in the surrounding areas should be carried out.
6.6.2 Open-cut trenching

Excavation plant shall be suitable for the works. Conventional, land-based plant may be used in onshore areas, while amphibious-grade plant may be required in beach and intertidal areas.

The soil conditions shall be considered to avoid collapse of trench walls posing a large safety risk for crew members. Stabilisation of the trench walls may be required, e.g. by temporary trench shields or, in severe cases, by permanent sheet piling panels. At the beach, the cable entry point may be stabilised by cofferdams. Requirement for dewatering should be subject to the local water table.

Temporary storage of excavated soil shall meet the design and permit requirements.

Guidance note:
Topsoil storage next to the trench is common, but requires a wider construction corridor. Offsite storage may be a permit requirement but is in general expensive.

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For backfilling, the following should be considered:

a) Surplus soil should be appropriately disposed of. Some excavated material may be too coarse to be suitable for backfilling and should be similarly disposed of.

b) In onshore areas, backfill should be compacted to meet design requirements.

c) Where the trench is excavated in vegetated ground, the topsoil should be stockpiled separately and re-used as the upper layer in backfilling to restore the trenching area.

6.6.3 Horizontal directional drilling

The decision where to place the horizontal directional drilling (HDD) entry site should be thoroughly evaluated taking into account points such as the following:

— drilling profile
— rig / pipe site space requirements, availability and accessibility
— risk of high water, erosion and damage to the equipment
— environmental factors, e.g. drilling fluid and soil management.

Guidance note 1:
The size of rigs is distinguished by its drilling and pulling capacities. Common designations are ‘mini’, ‘midi’ and ‘maxi’ with corresponding ranges of approximately 200 m, 1,000 m and 2,000 m and drilling holes sizes of up to 1.6 m. Landfall borings frequently use rigs in the ‘maxi’ range, requiring an area of 50 m \times 50 m of hard standing.

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The rig site commonly includes the following facilities:

— rig, storage of drill pipes
— drilling fluid preparation and recycling, high and low pressure pumps
— electric and hydraulic power units
— storage area, office space, workshop, welfare facilities.

After mobilisation and arrival of the HDD equipment on site, it shall be set up in accordance with the design layout, connected and tested.

The first step of HDD is the drilling of a pilot hole from entry site (also referred to as rig site) to exit site (also referred to as pipe site). The actual trajectory should be within the tolerances of the planned trajectory (Figure 6-12 a). This is achieved by a combination of the following:

— pushing of drill string and adding drilling rods
— rotation of entire drill string and/or drill / jet head by ‘mud motor’, rock cutting
— jetting at drill head through supply of drilling fluid (‘mud’)
— removal of cuttings through back-circulation of drilling fluid
— steering of the drill head (e.g. by magnetic system or optical gyro system).

The second step is to widen the pilot hole by reaming, commonly toward the rig site (Figure 6-12 b). Drill stem (‘pull-back pipe’) is added at the pipe site to maintain a continuous string inside the drilled hole. Reaming may have to be carried out multiple times with increasing diameters.

The third step is the pull-in of the conduit, normally from the pipe site (Figure 6-12 c), but pulling/pushing from the rig site is also possible. In order to maintain an acceptable catenary of the conduit, lifting at entry and exit points is normally required.
Guidance note 2:
There are many variations of the basic HDD process. The direction of work is an important consideration. Permitting of a land to sea operation will focus on land-based waste management for the cuttings, for a sea to land direction a marine license will be required.

A washover pipe may be used in weak, non-cohesive soils. In weak soils, pilot drilling, reaming and conduit pull-in may all be done in a single process from the rig site.

If the exit location is underwater, pilot drilling may stop before the exit and reaming be carried out from the rig site. This avoids marine operations and significant loss of drilling fluid. Eventually the assembly drills through the exit and conduit is pulled in from sea to land. In some cases, a pontoon raises the conduit end above water level for cable pull in.

Pushing or pulling in the conduit from the rig site may be required if the space is severely constrained at the opposite end.

Commonly the drilling fluid consists of a mixture of freshwater, naturally occurring powdered bentonite clay and additives.

Guidance note 3:
Additives to the drilling fluid may be required in case of drilling in salt water environments, acidic soils or sticky clay. Commonly used additives include caustic soda and soap.

The drilling fluid contributes to cutting of the softer soils, transport of cuttings, lubrication of the drilling string, cooling of the drilling equipment and stabilising the borehole walls. Drilling fluid management should cover the following aspects:

— monitoring of volume and pressures, as well as density, viscosity, pH value
— containment of the fluid at entry point, along the trajectory (avoiding fluid break-out) and exit point (e.g. by means of a cofferdam)
— recycling of the fluid (removal of cuttings, monitoring of properties) and disposal after completion of works.

Connection of conduit segments shall ensure a smooth inner surface, allowing for a cable pull-in without damage to its outer sheath.

Guidance note 4:
Common techniques for connecting the conduit pipes include welding of steel pipes and heat fusion techniques for polyethylene pipes.

A messenger line shall be installed inside the HDD conduit. This may be done during the conduit installation process or after the conduit pull-in has been completed.
6.6.4 Cable pull-in

Detailed requirements for the execution, inspection and equipment testing of the shore pull shall be specified, considering the nature of the particular installation site.

Guidance note 1:

Cables are generally pulled in the direction from vessel to shore. Due to onshore transportation constraints, a pull of any significant length of cable from shore to a nearshore positioned cable installation vessel is rarely practicable.

In comparison, first-end pull-in operations have simpler logistics. Second-end pull-in operations are more complex to execute due to the temporary laydown, but the vessel carries less weight and may approach closer to the shore.

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Pulling heads and other equipment shall be dimensioned for the anticipated forces (not exceeding the mechanical specifications of the cable) and provide a secure connection.

Monitoring and measuring devices shall be used during execution of the shore pull. Continuous monitoring of the cable tension and pulling force shall be performed to be within allowable limits.

Depending on the site conditions, messenger lines may be used to establish the pulling arrangement or the pulling line (wire or rope) can be passed directly between cable installation vessel and the shore.

The winches shall be equipped with sufficient line and indicators / recorders for line tension and length paid out. All measuring equipment shall be calibrated, and an adequate amount of spares to ensure uninterrupted operation should be provided. Prior to actual cable pull, the winch unit’s pulling force should be verified through testing.

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Where beaching of the cable installation vessel is planned in tidal areas, the following shall apply:

— the vessel is approved for beaching operation by its classification society
— the seabed will not damage the vessel or hold it down when attempting to re-float
— suitable methods are in place holding the vessel on location when beached and floating off, without damaging the cable
— the operational limiting conditions are met.

Guidance note 2:

The tidal range can be a significant design parameter. If a spring tide is required to position the cable installation vessel closer to the beach, the scheduling risk can increase due to a tight installation window.

ROV use for monitoring purposes in very shallow water areas is not normally foreseen, especially when cables are floated or pulled to shore. Use of divers may be acceptable in specific circumstances.

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In offshore and nearshore sections, buoyancy aids (‘floaters’) supporting the cable may be used as a means to keep pulling tension within allowable limits (Figure 6-13). Wind, waves and (particularly longshore) currents at the coast shall be taken into account in order to keep the floating cable within the tolerances of the planned cable route.

Guidance note 3:

Support by buoyancy aids is also referred to as ‘wet pull’. Depending on the cable installation vessel layout, buoyancy aids may be attached on-board the vessel or where the cable enters the water. Buoyancy aids are removed where the cable comes ashore.

When floating cable bights are long and/or lateral environmental forces (wind, waves, longshore currents) are strong, the bight may need additional support mid-way. Suitable solutions include pontoons which guide the cable with the floaters attached or small vessels ‘pushing’ the surface bight. In the latter case, point loads or excessive bending below minimum bending radius must be avoided.

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In beach and onshore sections, the cable may be supported on roller guideways located near or in the trench. If
the design includes a horizontal bend in the shore area, a beach quadrant or alternative method complying with the minimum bending radius shall be used to alter the cable course.

**Guidance note 4:**
Support by roller guideways is also referred to as ‘dry pull’. The roller blocks should be of a stable design and have no sharp edges. Support on three sides ("U" shape) rather than two sides ("V" shape) is advantageous, in particular when the cable is not torsion balanced. The roller design should ensure that the cable is not sliding but rolling. The beach rollers should be placed at such a distance from each other that mechanical parameters of the cable are not compromised.

Where powered and synchronised cable pulling machines are placed along the cable path, the pulling distance can be increased to several kilometres.

A roller cradle supported from an excavator can be used to position the cable into an open-cut trench.

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Friction forces during pull into HDD conduit may be lowered through the use of lubrication (mineral slurries, gels or bio-degradable oils) or by filling the conduit with water or drilling fluid.

After the cable has been secured in the transition joint bay ([6.6.5]), the cable rollers may be removed and the cable installation vessel can continue laying the remainder of the cable ([6.4.1]).

Depending on the specific design, the HDD conduit may be filled with fluidised thermal backfill after cable pull-in.

### 6.6.5 Interface with land-based system

The transition joint bay area shall be constructed in accordance with the design documentation. Depending on its location, temporary measures for dewatering may be required.

When the necessary length of subsea cable has been pulled in, the cable shall be mechanically secured (anchored) in / at the transition joint bay.

The jointing of subsea and land-based cables at the transition joint bay shall be carried out in accordance with the procedure developed for the particular cables and approved by the cables’ manufacturers.

After jointing of subsea and land-based cables, the transition joint bay should be closed and secured. Where feasible, accessibility to the pit should be retained for the operational life of the project in order to ensure its maintainability.

Following cable installation works, the site may have to be restored.

### 6.7 Cable protection

#### 6.7.1 General

The requirements of this subsection are applicable to the protection of cables, e.g. direct burial including trenching and backfilling, and other methods such as gravel and/or rock placement, grout bags, concrete mattresses, etc. It is also applicable to free span rectification.

A specific survey of the work area should be performed or supplement the pre-installation survey if conditions listed in [6.3.1] apply.

#### 6.7.2 Cable burial

In preparation of burial operations it should be confirmed that:

- the required cable trench depth is defined relative to the mean surrounding seabed
- the trenching method for the given cable submerged weight, soil properties and near-bed hydrodynamic conditions does not cause cable floatation during the trenching and backfilling operations
- during burial operations of cable bundles, strapping arrangements will not interfere with the operation.

Where pre-lay trenching is performed:

- the required trench geometry should be defined
- it should be documented that the trench is stable and will not be backfilled above the design level before cable installation
- the trench should be cleaned if excessive backfill develops prior to cable installation.

Where simultaneous lay and burial (SLB) is performed:

- cable catenary management ([6.4.1]) should not be adversely affected by operation of the burial device
- direct feedback from the burial device should be used for positioning and heading of the cable installation vessel.

Where post lay burial (PLB) is performed:

- the trenching equipment shall be designed so that it does not place significant loads on the cable and that it minimises the possibility of cable damage
— the loading of the cable should preferably be performed without divers
— cable tension in front of the trenching equipment should be understood / managed to avoid cable damage
— in beach areas, self-burial of the cable can occur, therefore the cable location may require recording / marking.

Where mechanical backfilling is performed:
— it should be carried out in a manner that minimises the possibility of damage to the cable
— the operation should be suitably monitored.

The trenching spread shall be equipped with sufficient instrumentation to ensure that excessive cable contact and damage to cable (outer serving, internal) are avoided. The burial equipment monitoring system shall be calibrated and may include:
— devices to measure trenching and cable depth relative to the seabed and relative to the applied datum (with quantified uncertainties for horizontal and vertical position)
— a monitoring system and control system preventing horizontal loads on the cable or devices to measure and record all vertical and horizontal forces imposed on the cable by trenching equipment, and devices to measure the proximity of the trenching equipment to the cable, horizontally and vertically relative to the cable
— underwater monitoring systems enabling the trenching equipment operator to view the cable and seabed profile forward and aft of the trenching equipment, as applicable
— measuring and recording devices for trenching equipment tow force, if applicable
— devices monitoring pitch, roll, depth, and the absolute underwater position of the burial equipment.

An allowable range of values, indicated by the measuring devices of the burial equipment, shall be established, see \[4.6.3.4\]. During trenching operations the measuring devices shall be continuously monitored. Records should be produced for future reference.

A post-burial survey should be performed in order to determine if the required depth of lowering and depth of cover have been achieved and if any remedial work is required, see \[6.8\].

### 6.7.3 Non-burial protection

#### 6.7.3.1 Tubular products

Tubular products shall meet the design specifications, see \[4.6.4.2\], \[4.7.4\] and \[5.5\].

Where the cable with fitted tubular product is transported on rollers, tracks, guides, chutes or quadrants, the design shall ensure smooth and controlled movement. Deployment of the cable assembly should be tested before installation commences, see \[5.5\].

For installation designs where cable and tubular product are deployed together, assembly on deck of the cable installation vessel shall ensure that the product is secured around the cable before deployment.

Upon completion of the installation works, a post-installation survey should be performed to confirm correct location and compliance with other design requirements, see \[6.8\].

#### 6.7.3.2 Mattresses and bags

Concrete / bitumen mattresses and grout / rock bags (‘gabion bags’) shall meet the specification with regard to size, shape and flexibility of the units and the specific gravity, composition and grading of the filling material (see [4.6.4.3]).

Placing of mattresses and bags shall be performed in a controlled manner, such that the mattresses or bags are placed as required. Restrictions on vessel movements during the operation shall be given.

During the placement operations, inspections shall be performed, e.g. with an ROV-mounted video camera, to determine the completeness and adequacy of the installation.

Mattresses with added frond systems should be installed using the same methods as conventional mattresses. Roll-out fronded mattresses require specific engineering and risk assessment.

**Guidance note:**
For details on diver and ROV based concrete mattress handling, deployment, installation, repositioning and decommissioning, see IMCA D 042 (R 016). The use of divers should be avoided.

Upon completion of the placing operation, an as-built survey should be performed to confirm compliance with the design requirements, see [6.8].

#### 6.7.3.3 Rock placement

Material used for rock installation shall meet the specified requirements for specific gravity, composition and grading (see [4.6.4.4]).
Rock installation shall be performed in a controlled manner. Existing infrastructure should not be disturbed or interfered with.

The rock installation operation shall ensure protection of the cable and/or rectification of all free spans to meet the specified requirements.

If the fall pipe technique is used for rock installation, minimum clearances shall be specified such that the fall pipe cannot touch the cable or any other subsea installation or the seabed. Deployment operations shall be performed well away from the cable or any other subsea installation. Before the fall pipe is moved to the installation location, the clearance beneath the fall pipe shall be verified. The clearance shall be continuously monitored during gravel installation.

The completed rock installation shall leave a mound on the seabed having a profile within the design envelope (e.g. with regard to steepness) and a smooth contour.

If the rock installation is performed over infrastructure crossings, the rock mound shall provide the specified height of cover over both the crossing and the crossed infrastructure. During the rock installation inspections should be performed, e.g. with a sonar survey system or with video, to determine the completeness and adequacy of the installation.

Upon completion of the rock installation, a survey should be performed to confirm compliance with the design requirements, see [6.8].

6.7.4 Infrastructure crossings

Prior to commencement of installation works the location of the existing infrastructure (pipeline, cable) should be verified, e.g. visually by ROV / sonar or, if buried, by tracking methods.

**Guidance note:**
ICPC Recommendation 3 suggests a minimum notification time of 2 weeks to telecommunication operators prior to commencement of any operational activity that may affect the performance of in-service infrastructure.

Preparations for crossing of pipelines and cables shall be carried out according to a specification detailing the measures adopted to avoid damage to both installations, commonly described in a crossing agreement (see [4.5.4]).

The operations should be monitored visually to confirm correct placement and configuration of the supports. Support and profile over the existing installation shall be in accordance with the accepted design.

Special precautions shall be taken when transferring the cable burial tool from one side of the existing infrastructure to the other.

6.8 As-built survey

6.8.1 General

An as-built survey covering the complete subsea cable system should be performed to verify that the completed installation work meets the specified requirements, and to document any deviations from the original design.

The as-built survey should be performed after work on the subsea cable system (or parts of a larger system) and its end points, including laying and burial, crossings, rock placement, artificial backfill, etc. are completed.

Requirements for the vessel carrying out the survey, survey equipment and the extent of the survey should be defined.

6.8.2 Survey requirements

The as-built survey should include the following, as applicable:

- position of the cable, also with regard to permitted tolerances of the cable route
- depth of lowering and/or depth of cover, as applicable, if not ascertained during burial operations
- location of any areas with observed scour or erosion along cable route
- identification and quantification of any free spans with length and gap height
- description of previously unidentified wreckage, debris or other objects which may affect the cable system, if applicable
- location of damage to cable (if applicable)
- video documentation of the subsea cable system interfaces at offshore units, if applicable and required.

**Guidance note:**

Burial requirements (depth of lowering, depth of cover) can exceed post-burial survey capabilities of certain equipment. ‘Pipe tracking’ equipment detects cables buried to 1 m, but reliability decreases for low metal content / small outer diameter cables, particularly when buried by more than 1.5 m. Methods such as impressing a signal or magnetising the cable armour have been used to increase the detection range.

Evidence from burial equipment recordings may be useful in the review process. When a depressor was used during burial, a post-burial survey may not supply additional information determining the depth of lowering.
The cable horizontal and vertical position shall as a minimum be reported at agreed intervals. The format should be compatible with that of earlier surveys to aid comparison and build-up of a database. Reporting should also include special events (non-conformities) during installation activities, e.g. ‘weather vaning’ or cable damage.

For non-burial protection such as mattresses or rock berms, the as-built survey should also include:

- verification that the condition of cable protection is in accordance with the design specification
- confirmation that minimum separation distance (if applicable) and minimum required height of cover are achieved and that maximum height of cover is not exceeded
- recording of length and cross-profiles of the protection and adjacent undisturbed seabed at regular intervals
- video or alternative survey method of the cable length covered
- check of any existing infrastructure in close vicinity in order to ensure that the infrastructure has not suffered damage.

6.9 Commissioning and testing

6.9.1 Termination

For mechanical works and cable hang-off, see [6.5.5]. The termination location may be within an area which requires ‘confined space entry’ for which the necessary safety precautions shall be taken.

The armour wire termination shall be electrically earthed at the designed earthing point, using an appropriate earthing kit.

High voltage cables shall be fitted with ending or termination kits approved or recommended by the cable manufacturer and shall be suitable for the intended termination point / application. The termination kit shall be manufactured and tested for the specified voltage level ([5.4]).

The technician shall be qualified and trained on the type of termination kit to be installed and in possession of the related certificate.

Guidance note:
For guidance on cable accessory workmanship, see CIGRÉ Technical Brochure 476. For guidance on maintaining the integrity of XLPE cable accessories, see CIGRÉ Technical Brochure 560.

The installation manual shall be project specific to take account of:

- cable design (e.g. conductor cross section, semi-conductive outer layer)
- type of cable lug (e.g. crimping or bolted)
- screen wire overlength to connect the screen to the earth bar.

The technician shall pay attention to using the correct tools with the correct adjustment when removing the various cable layers.

Due to the combined electrical testing of HV AC termination kit components, only these approved parts shall be installed together.

After termination works, the power cable termination should pass a commissioning test.

The optical fibres shall be connected in a splice box in accordance with the design specification.

6.9.2 Testing

Before a cable system is considered ready for operation or put into service, it should be visually inspected and tested. Inspection and testing activities may include the following:

a) Visual inspection: May include routing and fixing in offshore units and termination (mechanical, electrical) of the cable in accordance with the specification. This also applies after modifications and alterations.

b) Non-electrical tests: May include an optical time domain reflectometer (OTDR) test after installation, provided that the power cable contains optical fibres or is bundled with a fibre optic cable. The number of fibres to be tested should be agreed.

c) Electrical tests: Should include a high voltage test after termination.

The combination of tests to use for a particular subsea cable system should be specified and the responsible parties should be agreed.

Guidance note:
Various methods can be employed to ascertain a damage-free installation of the cable system. A selection of those listed in Table 6-3 may be used for a particular cable system.

Electrical tests similar to those at the factory may not be possible offshore or even at the shore, due to the unavailability of test equipment. Commonly only one of the high voltage tests (soak, VLF or series resonance) is used for a particular cable; as a minimum a soak test (at \( U_0 \)) is frequently recommended for high voltage and/or long length cables. For further guidance, CIGRÉ Technical Brochures 490 and 496.
Table 6-3 Potential post-installation cable tests

<table>
<thead>
<tr>
<th>Method</th>
<th>Requirements</th>
<th>AC / DC cable</th>
<th>Cable parameters monitored</th>
<th>Limitations</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical time domain reflectometer (OTDR) test</td>
<td>Optical fibre inside / at / near cable, measurement system at one or both cable ends</td>
<td>AC, DC</td>
<td>Optical attenuation, discontinued or stressed optical fibre</td>
<td>High level indication of cable integrity, detects only severely damaged power cables and tight cable loops / kinks</td>
<td>High</td>
</tr>
<tr>
<td>Time domain reflectometer (TDR) test</td>
<td>Measurement access point at one or both cable ends</td>
<td>AC, DC (often export cable)</td>
<td>Discontinued or severely damaged conductor, “finger print” of installed cable</td>
<td>Detects only severely damaged cable</td>
<td>High</td>
</tr>
<tr>
<td>Sheath integrity check ¹</td>
<td>Non-conducting cable sheath material, access for electrical connection</td>
<td>AC, DC (often array cable)</td>
<td>Water ingress, damage to outer sheath</td>
<td>Disconnected cable</td>
<td>High</td>
</tr>
<tr>
<td>Soak test (e.g. 24 h)</td>
<td>Grid connection ²</td>
<td>AC, DC (often export cable)</td>
<td>Operating voltage (U_0) withstand capability</td>
<td>No testing at elevated voltage</td>
<td>High</td>
</tr>
<tr>
<td>Very low frequency (VLF) test</td>
<td>Test system</td>
<td>AC (often array cable)</td>
<td>Insulation failure</td>
<td>MV cables only</td>
<td>Medium</td>
</tr>
<tr>
<td>Series resonance circuit test</td>
<td>Test generator ³</td>
<td>AC (export cable)</td>
<td>High voltage (above (U_0)) withstand capability</td>
<td>Test generator capacity may be insufficient</td>
<td>Medium (subject to feasibility)</td>
</tr>
<tr>
<td>Partial discharge (PD) test</td>
<td>‘Very low noise’ environment</td>
<td>AC, DC</td>
<td>Insulation performance, termination quality</td>
<td>Up to several kilometres, limited use at HV</td>
<td>Low</td>
</tr>
</tbody>
</table>

1) DC voltage test between metallic screen and Earth / outer semi-conducting layer, e.g. 5 kV for 1 min.  
2) When energising the cable system, precautions are required to avoid overvoltage at the far end of the cable. When disconnecting the cable, discharging the cable system requires consideration.  
3) Mobile units may allow testing cables at the shore end, either with AC or DC. Long cables require an extensive charging time and a power frequency test may not be feasible at the installation site.
7 Operation and maintenance

7.1 General

Consideration of operation and maintenance (O&M) begins during conceptual design, while the execution phase starts when construction activities have been concluded and the cable enters the service life. The phase ends with decommissioning of the cable (Figure 7-1).

This section provides requirements for the safe and reliable operation of a subsea power cable system during its service life with the main focus on management of cable integrity.

7.2 Asset management

7.2.1 Asset management system

The cable owner / operator shall establish and maintain an asset management system which complies with regulatory requirements.

Guidance note:

In offshore wind farms, array cables may be covered by an asset management system covering the entire wind farm. Export cables may be covered by an asset management system covering the offshore transmission system.

For guidance on asset management, see ISO 55000.

An asset management system comprises a core management process and a number of support elements (Figure 7-2). The core management process includes activities to maintain cable system integrity, see [7.2.2].

![Asset management system](image)

The support elements commonly include the following:

- cable owner / operator policy - values and beliefs and how these are realised
- organisation and personnel - roles and responsibilities, interfaces between different organisations, training needs
- reporting and communication - planning, execution, maintenance
- operational controls and procedures - safety systems, start-up, monitoring, maintenance, testing
- management of change - procedure, documentation
- contingency and disaster recovery plans - evaluation of possible scenarios, development and maintenance of plans
- audit and review - focus, timing
- information management - collection of historical data, filing.

The cable system shall be operated in accordance with the design and operating premises. It shall be maintained to ensure adequate performance with regard to health and safety, the environment and required system availability.
7.2.2 Asset management process

A risk based asset management philosophy, which takes into account probability and consequence of failures within the overall cable system, should be applied.

The core asset management process consists of the following steps (see Figure 7-2):

a) Risk assessment and asset management planning: Operation and maintenance strategy and long-term planning, based on objectives, design and condition of the cable system and its components.

Guidance note 1:
A long-term asset management programme reflecting the overall objectives for the management of the cable system should be established and reviewed on a regular basis. The following should be considered:

— philosophy for maintaining the integrity of the cable system
— design and function of cable system
— operational conditions of the cable system
— probability and consequence of failures
— monitoring, testing and inspection methods
— spare part considerations (policy, inventory).

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b) Monitoring, testing and inspection: Detailed planning based on adopted operation and maintenance philosophy, execution and documentation of activities.

Guidance note 2:
All operation and maintenance requirements identified during the design phase as affecting safety and reliability during operation should be covered.

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c) Performance assessment: Integrity assessment using recognised methods and based on design data and operational experience.

Guidance note 3:
When a non-conformity or defect is observed, an evaluation should determine magnitude, causes and consequences, including uncertainties.

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d) Mitigation, intervention and repair: Assessment of the need for mitigating actions, intervention and repair activities and their execution.

Guidance note 4:
If an observed non-conformity or defect is not acceptable, this may lead to further investigations, temporary precautions, continued operation with changed operational conditions, remedial work and/or repair activities.

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Detailed procedures for asset management activities shall be established prior to start-up of operation. Design and operating premises and requirements shall be confirmed prior to start of operation and updated during the service life. These premises and requirements may be, for instance, linked to the following:

— voltage, current, power, temperature (overloading, insulation deterioration)
— cover of buried cable sections (inadequate or excessive cover)
— free spans length and height (associated stress).

Procedures covering non-routine or special activities shall be prepared as required, e.g. in case of major repairs or modifications.

7.3 Monitoring, testing and inspection

7.3.1 Monitoring and testing

Objectives for (continuous) monitoring are to record the status of the cable system, to detect changes in operating conditions and to take mitigation actions such as restricting operational parameters (e.g. electrical current, temperature). Conditions of the cable which are monitored may include:

— electrical - voltage, current, power
— thermal - temperature
— mechanical - tension, bending, vibration.

Where testing activities are specified to be carried out during the operational phase, the activities shall be planned, executed, reviewed and documented. Parameters which are tested may include:

— cable and cable environment temperature
— partial discharge
— cable sheath leakage currents.

The combination of measurements and tests to use for a particular cable system should be subject to a detailed analysis.

Guidance note:
Various methods can be employed to remotely monitor the conditions of cable systems, see Table 7-1.

| Table 7-1 Potential cable tests during the operational phase |
|---|---|---|---|---|
| **Method** | **Requirements** | **Online / offline** | **Cable parameters monitored** | **Limitations** | **Recommendation** |
| Power flow measurement | Voltage / current transformers at cable end(s), SCADA system | online | Electrical power, (estimated temperature rise) | Point measurement(s) | High |
| Distributed temperature sensing (DTS) | Optical fibre inside / at / near cable, measurement system at one/ both cable end(s) | online | Temperature \(^1\), current rating through real-time thermal rating, inference of degree of burial protection | Several tens of kilometres, resolution better than 2-3 m and \(\pm 1\) K \(^2\) | Medium \(^3\) |
| Distributed strain sensing (DSS) | (Special) optical fibre inside / at / near cable, measurement system at one cable end | online | Mechanical stress on cable, e.g. free spans | Several tens of kilometres, no established track record | Low |
| Partial discharge (PD) monitoring | Permanent or temporary measurement system, ‘low noise’ environment | online / offline | Insulation performance | Up to several kilometres, limited use at HV (except terminations), no established track record in this application | Low |
| Sheath integrity check | Non-conducting cable sheath material, disconnectable earthing, temporary measurement system | offline | Water ingress, insulation performance | Outage and access for measurement required | Low |

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1) Temperatures differ at the various construction elements within a power cable. Sensing by optical fibres within or near the power cable are indirect measurements of the conductor temperature. Calibration and modelling are required to establish the relationship between optical measurement and power cable core temperature.

2) Better resolution can be achieved for shorter lengths.

3) Commonly used in export cables.

Further or alternative methods, such as distributed acoustic sensing / distributed vibration sensing or low voltage radio frequency testing, can be employed for cable condition monitoring.

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Techniques and equipment for monitoring and testing shall be selected based upon:

— monitoring objectives, including requirements for accuracy and sensitivity
— risks for the cable system.

7.3.2 Inspection

A cable verification survey is a survey to determine the position and condition of the cable system and its components. Data from the as-built survey ([6.8]) can normally be used; otherwise specific inspections should be completed within one year from start of operations. In case of significant changes after this first inspection, the need of additional inspections should be determined.

Guidance note 1:
Due to the large size of some projects, operations may start in stages. The inspection planning should reflect this.
A detailed external inspection plan including specifications for the inspections shall be prepared for each survey. The detailed inspection plan should be updated based on previous inspections as required.

External inspection shall be carried out to ensure that the design requirements remain fulfilled and that no damage has occurred. The inspection programme should, as a minimum, address by means of general inspection under water:

— exposure and burial depth of buried or covered cables, if required by design, regulations or other specific requirements
— free spans including mapping of length, height and end-support conditions
— condition of artificial supports installed to reduce free span
— local seabed scour, settlement, subsidence or instability affecting the cable integrity
— megripple / sand wave movements affecting the cable integrity
— cable settlement in case of exposed sections
— the integrity of cable protection covers (e.g. mattresses, covers, sand bags, gravel slopes, etc.)
— mechanical damage to cable
— major debris on, or close to, the cable that may cause damage to the cable.

Guidance note 2:
General inspection frequently involves vessel-based geophysical investigation techniques such as side-scan sonar as well as the use of remotely operated vehicle (ROV) based systems. The use of divers should be avoided.

---end---of---Guidance---note---

The sections at the offshore units shall be part of the long-term external inspection programme for the cable system. In addition to the generally applicable requirements for cable inspection, special attention should be given to the following elements, by means of close inspection under water:

— functionality of supports and guides and integrity issues (e.g. cracks in welds)
— damage or displacement, e.g. due to vessel impact or foundation settlement
— corrosion, e.g. of J- or I-tubes
— damage to coating
— extent of marine growth.

Guidance note 3:
Close visual inspection of below water sections of offshore units frequently involves the use of ROV and, where this cannot be avoided, divers.

Infilling of scour holes after storms can obscure the extent of scour.

---end---of---Guidance---note---

The frequency of future external inspections shall be determined based upon an assessment of:

— authority and cable operator requirements
— degradation mechanisms and failure modes
— probability and consequences of failure
— seabed dynamics, e.g. megaripples or sand waves
— results from previous inspections
— changes in the operational parameters
— requalification activity and results
— repair and modifications
— subsequent cable laying operation in the area.

Critical sections of the cable system vulnerable to damage or subject to major changes in the seabed conditions should be inspected at suitable intervals.

Guidance note 4:
A risk based approach should be employed to determine the need for inspections. For example, in an area with sand waves, critical sections may require inspections on an annual basis. Less critical sections may be inspected ensuring a full coverage of the entire cable system within a suitable period, e.g. within 5 years.

---end---of---Guidance---note---

If mechanical damage or other abnormalities are detected during the periodic inspection, an evaluation of the damage shall be performed, which may include additional inspections.

7.3.3 Security surveillance
Depending on the risk profile along the cable route, active security monitoring of specific sections may provide effective mitigation.
Measures that may be considered include the following:

- electronic monitoring by means of radar (based on land or offshore unit), by review of vessel monitoring system data (e.g. fishing vessels) or by analysis of automatic identification system (AIS) data (e.g. larger vessels)
- sea patrol in high-risk areas
- terrestrial patrol of land cable section, e.g. during nearby construction activities.

Guidance note:
For post-installation, non-physical measures mitigating the risk of cable damage by human activities including fishing and anchoring, see also ICPC Recommendation 6.

7.4 Remedial work

7.4.1 Minimum cable protection
Minimum depths of cover for each section of the cable during its service life shall be derived from the design assumptions, see Sec.4, and the installation records, see Sec.6. The thresholds for remedial work shall be defined.

Remedial work plans shall be prepared, subject to local conditions and circumstances.

When thresholds are exceeded, remedial works should be carried out. Suitable methods may include:

- post lay burial activities (see [6.7.2])
- mattress or bag installations (see [6.7.3.2])
- rock placement (see [6.7.3.3]).

Results of remedial works should be surveyed and reported as described in [6.8].

7.4.2 Free span rectification
Free span rectification shall be required for all spans exceeding the specified acceptable length or height for the specific location. Rectification of other spans shall be considered if scour or seabed settlement could enlarge the span length and gap height above maximum acceptable dimensions before the first planned inspection of the cable.

Guidance note:
Some guidance on free spans and rectification may be derived from the submarine pipeline sector, see DNV-RP-F105.

The requirements applicable to the specific methods of span rectification and protection regarding execution, monitoring and acceptance criteria shall be documented. Requirements for vessels, survey equipment, etc. shall be addressed in the installation and testing specifications and procedures. The extent of procedures to be prepared and qualified shall be specified.

Adequate rectification of free spans shall be documented by a video survey.

7.5 Fault detection and location

7.5.1 General
Survey results and operational data of a cable should be reviewed for indications of problems. Measurement systems such as power quality and DTS may provide useful information on the operational history and overload conditions that could cause failure, see [7.3.1].

7.5.2 Cable location
The cable route shall be ascertained by the documented and charted as-built information, subsequently confirmed by inspections during the O&M phase.

The location of cables may be confirmed by as-built survey methods and/or geophysical methods.

Guidance note:
Common methods of cable detection include magnetometer, pulse induction and tone detection. The presence of magnetic fields from energised DC cores can adversely impact cable detection.

7.5.3 Fault location
Except where the fault location is obvious, several methods should be employed to locate a fault in a cable. Often a combination of coarse and fine location methods is advisable.

For coarse location of a fault, measurements from both ends of the cable should be performed, where feasible.
Guidance note 1:
Methods which can be employed for coarse location of a cable fault may include those listed in Table 7-2.

Table 7-2 Potential cable fault location techniques

<table>
<thead>
<tr>
<th>Method</th>
<th>Physical requirements</th>
<th>Online / offline</th>
<th>Cable parameter tested</th>
<th>Limitations</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation measurement</td>
<td>Multi-core cable offline</td>
<td>Insulation resistance</td>
<td>Identifies only which core is damaged</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Bridge measurement</td>
<td>Intact parallel cable or intact core in a multi-core cable offline</td>
<td>Conductor resistance</td>
<td>0.5-1% of cable length. Compensation required for conductor or temperature changes along the route</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Optical time domain reflectometry (OTDR)</td>
<td>Optical fibre inside / at / near cable, measurement system at one or both cable ends, reference measurement 1) online / offline</td>
<td>Discontinued or stressed optical fibre</td>
<td>Relies on constant (and known) ratio between lengths of optical fibre and electrical core. Improvement of accuracy with measurements from both cable ends</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Time domain reflectometry (TDR)</td>
<td>Measurement access point at one or both cable ends, reference measurement 1) offline</td>
<td>Discontinued or severely damaged conductor</td>
<td>Performs best on breaks and low-resistance faults. Relies on known impulse propagation velocity. Improvement of accuracy with measurements from both cable ends</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

1) Measurement of signal propagation parameter should be performed on (spare) cables of exactly known (and documented) length prior to installation. An in-situ measurement of the cable should also be performed. Propagation speed before and after installation has been reported to be slightly different, see CIGRÉ Technical Brochure 490.

On cables where the voltage shape is continuously monitored with exact time stamps, the fault location may be inferred from the fault recordings at both cable ends.

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Except for very short cables, fine localisation of the cable fault should be performed to reduce uncertainties.

Guidance note 2:
Fine localisation commonly employs current signal injection at one cable end and passing a vessel along / over the cable with a search coil monitoring the magnetic flux, yielding accuracies of twice the water depth for straight, unburied cables (Worzyk, 2009). Lowering the search coil by means of ROV can significantly improve the accuracy. To reduce interference, the signal should be different from the system frequency (50 or 60 Hz).
A high voltage impulse can create a flashover at the fault location which may be detected with microphones or other suitable receivers.

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Records of fault localisation should be kept for future use and analysis.

7.6 Repair work

7.6.1 General
Examples of intervention and repairs are:
— intervention: trenching, rock placement, other protection works
— repairs: replacement of entire cable, replacement of cable section including jointing.

Guidance note 1:
Intervention and repair strategies generally differ for array and export cables. Repair activities during the installation phase of a cable are often simpler and require less time to plan and execute, subject to suitability of the mobilised vessel spread and availability of qualified staff such as jointers.

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Intervention may, in special cases, be carried out on energised cables, depending on the nature of the work and the applicable legislation. Repairs of cables require the cable to be de-energised.

Guidance note 2:
Where energised cables are located in proximity of the intervention / repair location, they should be included in the task specific risk assessment.

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All repairs shall be carried out by qualified personnel in accordance with agreed specifications and procedures defined for the cable.

Spare cable, repair parts and material such as jointing kits shall be stored suitably protected to prevent deterioration or damage. Where applicable, expiration dates should be clearly marked on the parts and material. In specific circumstances, longer term storage of spare cable on or in the seabed (“wet storage”) may be allowable.

**Guidance note 3:**

When planning wet storage, the risk of damage by a third party should be considered, with burial being a potential mitigation measure. Cables may also get damaged during recovery. Cables should be pre-rigged for retrieval.

---end---of---Guidance---note---

### 7.6.2 Repair planning

Operational limiting conditions with regard to the sea-state, current and vessel movements shall be established. The level of uncertainty in weather forecast shall be taken into account, see [6.1].

The position of the repair shall be verified prior to start of operations. A survey shall be performed to establish that the location is free of obstructions and that the seabed conditions will permit the repair to be performed as specified.

**Guidance note:**

The planned repair bight may lie outside the previously surveyed corridor and thereby require additional inspection or survey work prior to repair execution.

De-burial of the cable should be adequately planned, in particular in areas where deep burial was accomplished or where mobile sediments led to significant accretion on top of the cable. In addition, artificial reefs that have formed in the meantime, e.g. on installed rock, will be disturbed and may require specific considerations.

---end---of---Guidance---note---

Potential anchoring requirements and the laydown of the repaired cable shall be carefully planned, see also [4.5.2]. The repair joint should, if possible, be laid in line with the cable, not within an arc.

Arrangements and equipment for lifting and lowering of the repair bight shall be analysed to determine the critical parameters and limiting criteria for the operation. Critical parameters / limiting criteria shall be monitored continuously.

### 7.6.3 Repair execution

If the damaged cable is of a short length only (e.g. array cable between turbines), a complete replacement of the cable may be the most economical solution. This involves securing the cable at one end and recovering it from the seabed after (or during) partial or complete de-burial. Installation of a new cable follows the steps of cable laying and burial (Sec.6).

If the damage of a cable is located close to a termination point, then a repair requiring only one inline joint may be feasible. In this case the cable section between termination point and damage location is cut out and a new section is jointed in. After laydown of the inline joint, the cable is laid and pulled to the termination point as a second-end pull operation.

If a cable repair is to be carried out further away from either cable end and assuming that the cable ([7.5.2]) and the fault ([7.5.3]) have been located with sufficient accuracy, a repair sequence typically involves the following steps:

- de-burial of the cable along a section of sufficient length which is to be recovered
- cutting of the cable at the seabed (e.g. by ROV)
- recovery of first cable end and attaching a buoy to the second end
- removal of impaired part from the first cable end, jointing of spare cable section to first end
- laydown of first joint (as inline joint)
- recovery of second cable end, removal of impaired part, jointing with spare cable end
- laydown of second joint (typically as an omega repair bight; joint deployed first, then the quadrant with the repair bight crown)
- protection of laid cable, e.g. by burial or rock placement.

Installation of joints shall be performed in accordance with the manufacturer’s procedure (see [6.4.3]). During all handling, lifting and lowering into the final position, the cable and the joint shall be protected against mechanical damage (tension, bending, etc.). Bend stiffeners and/or bend restrictors used at either side of the cable joint should be approved by the cable manufacturer.

It shall be verified that the position of the repair bight is within the target area prior to departure of the vessel from site. The cable stability shall be ensured and adequate protection of the cable provided.

After completion of the repair, a survey of the cable on both sides of the repair area, and over a length sufficient to ensure that no damage has occurred, should be performed, see [6.8].
All repairs shall be inspected and electrically tested by experienced and qualified personnel in accordance with agreed procedures. Testing personnel, equipment, methods, and acceptance criteria shall be agreed upon in accordance with [6.9.2].

All intervention and repair works shall be documented.

### 7.7 Requalification

#### 7.7.1 General

Requalification is a re-assessment of the design under changed design conditions.

Within the original design life, and without essential changes in the manner of use, the standard(s) under which the cable system was designed and built may apply when considering minor modifications or rectification of design parameters exceeded during operation. For major modifications, see [7.7.2].

**Guidance note:**
For revision of qualification procedures of AC extruded underground cable systems, see CIGRÉ Technical Brochure 303.

---end---of---Guidance---note---

#### 7.7.2 Change of design criteria

A requalification may be triggered by a change in the original design basis, by not fulfilling the design basis, or by mistakes / shortcomings having been discovered during normal or abnormal operation. Possible causes may be:

— change of the premises, e.g. environmental loads, scour
— change of operational parameters or utilisation (voltage, current, power, temperature)
— deterioration mechanisms having exceeded the original assumptions, e.g. excessive scour
— extended service life
— discovered damage, e.g. to cable protection.

All relevant deterioration and damage mechanisms should be evaluated. Typical mechanisms include insulation deterioration, accidental loads, fatigue, development of free spans, erosion and settlement. Accumulated damage experienced prior to the requalification should be included in the evaluation.

The parameters that trigger the requalification and the implication of changes in these parameters on different design conditions should be clearly identified and documented. The revised design conditions should form the basis for a re-assessment of the relevant parts of the cable system design according to Sec.2, Sec.3 and Sec.4.

#### 7.7.3 System test

An inspection of the cable system according to [7.3.2] should be considered. System testing may be required when:

— the original cable test or system test does not satisfy requirements at the new operating parameters
— a significant part of the cable has not been tested before, e.g. new cable sections as part of a modification or repair campaign.

**Guidance note:**
Testing of aged cables with voltages higher than nominal can increase the risk of insulation breakdown.

---end---of---Guidance---note---
8 Decommissioning

8.1 General

The decommissioning phase occurs at the end of the cable system’s service life with normally no intention to return it to service (Figure 8-1).

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Guidance note 1:

When decommissioning a cable system, it is important to consider the following aspects:
- Relevant national and international regulations
- Natural environment (benefits of not disturbing the seabed, possible pollution, future effects)
- Obstruction for surface navigation, also in comparison to existing installations, wrecks and debris
- Impact on fishing activities
- Mobility of sediments and change of the cable presenting a hazard over time
- Future management of an out-of-service cable system
- Technical feasibility and socio-economic benefits of cable removal.

Guidance note 2:

Experience with removal of subsea power cables is very limited and virtually non-existent for subsea power cables in offshore wind farms (except for repair purposes). For guidance on the management of decommissioned telecommunication cables and considerations for their removal, see ICPC Recommendation 1. For further guidance, see Subsea Cables UK Guideline 8.

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Where a future use of the cable is anticipated, decommissioning should be planned, conducted and documented in such a way that degradation mechanisms are reduced and the cable can be re-commissioned and put into service again, see also [7.7].

8.2 Withdrawal from service

Withdrawing a cable system from service comprises the activities associated with taking the system / or part of the system permanently out of operation and leaving it in place. An out-of-service cable cannot normally be returned to operation.

Taking a cable out of service shall be planned and prepared. Cable withdrawal from service evaluation shall include the following aspects:
- Relevant national and international regulations
- Notification to international and national charting authorities
- Liaison with local fishermen and other users of the seabed
- Alternative use of the cable, e.g. for research purposes
- Insurance cover.

Out-of-service cables shall be managed in accordance with regulations and the owner’s code of conduct.

8.3 Removal

Sections or complete out-of-service cables that are planned to be removed should be classified by their destination, i.e. “scrap” or “re-use”. This classification will to some extent define the failure modes, limit states and acceptance criteria which should be checked.
Agreements covering the decommissioning phase should make provisions for the recovery of (at least) limited lengths of cable. The agreement should consider future requests for partial cable removal from:

- developers of new cable or pipeline systems, to avoid a crossing
- developers of new offshore units, to avoid a cable in the immediate vicinity
- other users of the sea, to avoid interference with planned activities.

Cable removal shall be planned and prepared. Cable removal evaluation should include the following aspects:

- relevant national and international regulations
- health and safety of personnel
- minimisation of environmental impact
- competence, experience and insurance cover of salvage party
- scrap value of materials, in particular metals
- treatment and documentation of cable segments left in the seabed.

**Guidance note 1:**
For guidance on planning and execution of marine operations for removal of offshore objects, see DNV-RP-H102.

Partial removal of cable should not leave the remaining cable system in a more hazardous condition than prior to removal.

**Guidance note 2:**
Cable ends require specific considerations. Weighing down and burial may be required.
9 Documentation

9.1 General

This section specifies the minimum requirements to documentation needed for design, manufacturing, storage, load-out, transportation, installation, commissioning, operation, maintenance and decommissioning of a power cable system.

A design, manufacturing, installation documentation summary should be established with its main objective being to provide the stakeholder organisation with a summary of the most relevant data from those project phases. The preparation of the documentation summary should be carried out in parallel with, and as an integrated part, of the design, manufacturing and installation phases of the project.

Guidance note 1:
A common language, e.g. English, should be used for all documentation.
Symbols used should be explained, or reference to a standard code should be given. Measurement units defined by International System of Units (SI) should be used unless otherwise agreed.

Important documents which should be available at the specified times include the following:

— design basis and functional specifications - prior to design
— design calculations, reports, drawings - prior to manufacture
— reports of prequalification tests performed on the entire cable system - prior to manufacture
— manufacturing quality plan - prior to manufacture
— manufacturing and testing specification - prior to manufacture
— as-manufactured documentation and test reports - with supplied cable, accessories, offshore unit
— installation plan and method statements - prior to installation
— as-built documentation and test reports - after installation
— operations documentation - prior to operations start.

For the design, manufacturing and installation phases, all required documentation should be reflected in a master document register which is kept up to date.

Guidance note 2:
Unique revision numbers should be allocated to all issues of a document, including the first issue. For documents with multiple sheets, the revision number should be the same for all sheets. Updated documents should be marked to identify the revised parts.

An in-service file containing all relevant data achieved during the operational phase of the cable system and with the main objective to systemise information needed for integrity management should be established and maintained for the whole service life.

The required documentation for all phases of the cable system’s lifetime should be submitted to the relevant parties for acceptance or information, as agreed or required.

An overview of documents which should be established is provided in [9.2]. Further documentation requirements are contained within the individual sections of this recommended practice.

9.2 Documents

9.2.1 Concept development

The results of early concept development should typically be captured as follows:

— summary report and detailed analysis results including recommendations and supported by relevant maps, figures and tables.
— geo-referenced information database collated in a geographical information system (GIS).
— data presentations in the form of charts, including the proposed cable route together with pertinent features.

The reporting on the cable route surveys should contain detailed information on all aspects of the cable project, including, but not limited to the following (see also [3.3.2]):

— analysis of project area / route, geology, terrestrial and marine conditions, environmental impact, third party activities, regulatory requirements
— preliminary route assessment and route recommendations
— preliminary recommendations for cable protection design.

The report should also show the results of the surveys on accurate route maps and alignments, at a scale commensurate with required use. The route alignment sheets should include cable route, bathymetry, seabed features, subsea infrastructure, navigational aids / fairways, surface geology and interpreted subsurface geology, location of geotechnical investigation points and other relevant features.
Output from the concept development phase should typically be captured in:

— project description, including GIS database
— functional requirements
— design basis.

9.2.2 Design basis

Typical content of the design basis is listed in the following:

— system overview:
  — cable system overview including general arrangements and key operational parameters
  — project stakeholders with responsibilities, interfaces, communication lines
  — general project plan and schedule.

— terms of reference:
  — reference to detailed project description and functional requirements (including design and service life)
  — health and safety, environmental and quality objectives
  — hierarchy of applicable codes, standards and regulations
  — use of SI system, coordinate system and references
  — horizontal and vertical reference data, coordinate system
  — general design approach, methods to be used.

— site conditions (design values):
  — third party activities, restricted areas, obstructions ([3.3.4])
  — topographic and bathymetric conditions ([3.3.5], [3.4])
  — geological conditions, morphological aspects ([3.3.5], [3.4])
  — atmospheric and marine conditions ([3.3.6])
  — environmental constraints, permit and license restrictions ([3.3.7])
  — design loads and load combinations.

Guidance note:
The description of site conditions forms a major part of the design basis. Measured or estimated values should not be simply reported, but those values to be applied in the design (commonly employing a level of conservatism) should be defined.

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— technical interfaces:
  — coordinates of interface points, principal cable routing and lengths
  — description / drawings of offshore units and landfall area
  — mechanical interface conditions (e.g. cable joint or switchgear)
  — electrical interface conditions
  — optical interface conditions.

— manufacturing and storage aspects:
  — manufacturability conditions
  — material properties and quality, as applicable
  — cable sizing and handling data
  — testing requirements
  — storage (time, conditions).

— load-out, transportation and installation aspects:
  — access to site (onshore, offshore)
  — basic vessel spread capabilities and motion characteristics
  — installability conditions, sequencing, scope.

— operation and maintenance aspects:
  — monitoring and inspection capabilities
  — acceptable limits for free spans, external aggression
  — maintainability conditions, acceptable frequency and type of intervention
  — repair-ability conditions.
— decommissioning aspects:
   — traceability of buried cable
   — recoverability of buried / protected cable.

More detailed / specifically scoped design basis (sub-) documents may be required for certain design aspects.

9.2.3 Design
Design documentation suitable for third party verification shall be produced. It may include, but not be limited to, the following:

— systematic review of hazards, risk register, contingency measures
— materials selection
— electrical and thermal calculations
— cable system design details; including cable, joints, terminations
— cable route design
— cable end point interface design
— cable installation analysis
— general method statements for storage, load-out, transport, installation, commissioning, operation, maintenance, repair and decommissioning.

Guidance note:
A method statement is a written plan of work tasks to be carried out, documenting a ‘safe system to work’. It is an important means of controlling the health and safety risk, e.g. following a risk assessment. A procedure is commonly a more specific, step by step description of work steps.

GIS information and drawings provided for the manufacturing of components or installation of the cable system should include, but not be limited to:

— cable route drawings including information on topology, seabed properties, existing and future infrastructure, shipping lanes, etc.
— alignment sheets
— infrastructure crossings
— offshore unit layout with cable path and details of interfaces
— other components within the cable system (joints, terminations, etc.)
— cable protection (burial, non-burial protection)
— land ownership details.

9.2.4 Manufacturing
The documentation to be submitted for review prior to start of manufacturing should include, but not be limited to:

— quality plan
— manufacturer’s quality system manual
— manufacturing procedure including test requirements and acceptance criteria
— electrical / thermal / mechanical calculations demonstrating the suitability of the component
— component specifications and drawings.

The as-built documentation to be submitted after manufacturing may include, but not be limited to:

— quality control procedures
— inspection and test plan
— traceability procedure
— material certificates
— equipment calibration certificates / reports
— component specifications and as-built drawings
— test reports, including non-conformity reports
— storage, handling and installation procedures
— release certificates.

Guidance note:
For a more detailed cable specification template, see App.B. Cables should also be supplied with information identifying the position of power core joints along the length of the cable so these can be handled correctly during transport and installation.

Other components for which specifications / manufacturing documentation should be submitted include joints, terminations, cable end caps (short-term, long-term), hang-off modules, pulling heads / stockings, etc.
9.2.5 Installation

9.2.5.1 Documentation before installation

An installation manual shall be produced, which is defined as a document or collection of documents required for performing the project specific installation work including normal and contingency operations and acceptance criteria.

**Guidance note 1:**

The installation manual is prepared in order to demonstrate that methods and equipment used by the installer will meet specified requirements and that the results can be verified. The installation manual will hence include all factors that influence quality, reliability and safety of the installation work in normal and contingency situations, and will address all installation steps, including examinations and check points. The manual will reflect the results of the risk management studies performed for the installation and will state requirements for the parameters to be controlled and the allowable range of parameter variation during the installation.

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The installation manual shall contain the applicable procedures and corresponding drawings and should be submitted for review prior to start of installation.

**Guidance note 2:**

Typically a procedure describes the following:

— purpose and scope of activity
— responsibilities
— materials, equipment and documents to be used
— how the activity is performed in order to meet specified requirements and acceptance criteria
— how the activity is controlled and documented.

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Typical procedures include, but are not limited to, the following:

**General:**

— risk management plan
— hazard identification (HAZID) studies, hazard and operability (HAZOP) studies, failure mode and effect analyses (FMEA)
— simultaneous operations
— diver intervention, if applicable
— contingency (e.g. failure of positioning system) and emergency planning
— inspection and test plan
— qualifications and competence for personnel.

**Cable route preparations:**

— route survey
— route clearance
— route preparations
— pre-lay grapple run.

**Cable logistics:**

— cable storage
— cable load-out
— cable transport
— cable trans-spooling, if applicable.

**Cable installation:**

— cable installation analysis
— cable laying and catenary management
— cable pull-in preparation and cable pull-in
— cable protection and burial
— cable crossing, if applicable
— abandonment and recovery (A&R), ‘wet storage’
— cable jointing
— cable repair.
Guidance note 3:
Detailed instructions will be required for more complex operations, e.g. cable overboarding, cable pull-in or cable recovery.

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Landfall:
— landfall site preparation
— open-cut trenching
— horizontal direction drilling and conduit installation
— cable pull-in preparation and cable pull-in.

Commissioning:
— cable termination
— cable system testing.

Marine logistics:
— cable installation vessel suitability analysis, motion analysis
— vessel mobilisation
— navigation and positioning, including anchors / anchor handling and/or dynamic positioning, dynamic positioning trials
— access to and egress from offshore units
— operational limiting conditions.

9.2.5.2 Documentation during installation
Construction activities should be documented in a consistent way. The scope, content and format of the GIS information and documentation should be discussed and contractually agreed prior to the commencement of on-site works. Typically, the reporting should cover:
— project / activity overview
— vessels, equipment used
— health, safety and environmental performance
— daily progress report, log of events, non-conformities, variation orders, incident investigations (if applicable)
— position (as-built) data \((x, y, z)\)
— testing information according to inspection test plan.

The narrative should be supplemented by survey maps and, where applicable, video recordings (e.g. of cable interface with offshore unit).

Guidance note:
There may be a need to prepare preliminary as-built information during the installation operations, e.g. after cable installation to demonstrate that the cable is correctly pulled into the offshore unit.

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9.2.5.3 Documentation after installation
For guidance on reporting of as-built surveys, see [6.8.2].

The as-built documentation to be submitted after installation and commissioning should include, but not be limited to:
— survey reports
— installation, commissioning and test reports
— updated GIS information and drawings.

The location of cables shall be reported to international and national authorities for the purpose of updating navigation charts.
Awareness of the cables (and rock berms, etc.) should be increased by inclusion of cables in freely available “cable awareness charts” and proactive liaison with stakeholder groups such as:
— hydrographic offices / authorities
— port and local authorities
— environmental authorities
— military authorities
— commercial and scientific organisations (e.g. pipeline owners, dredgers)
— fishing industry
— maintenance parties.
9.2.6 Operation and maintenance

As a minimum, the following documentation shall be established:

— cable system integrity management strategy covering operation, inspection and maintenance
— operational envelope, parameters, constraints, decisions for the operation of the cable system
— emergency response strategy
— repair strategy.

In order to maintain the integrity of the cable system, the documentation made available during the operational phase should include, but not be limited to:

— personnel training and qualifications records
— history of cable system operation with reference to events which may have significance to design and safety
— installation condition data as necessary for understanding cable system design and configuration, e.g. previous survey reports, as-laid / as-built installation data and test reports
— inspection and maintenance procedures
— inspection and maintenance schedules and records of their results.

The in-service file should include, but not be limited to:

— operational data
— results and conclusions from the in-service inspections
— accidental events and damages to the cable system
— intervention, modification and repair.

In case of damage and repair, the documentation prepared should include, but not be limited to:

— description of the damage to the cable system or components with due reference to location, type, extent of damage
— plans and full particulars of repairs, modifications and replacements, including contingency measures
— further documentation with respect to particular repair, modification and replacement, in line with those for the installation phase.

Maintenance of complete files of all relevant documentation during the service life of the cable system is the responsibility of the cable system operator.

9.2.7 Decommissioning

Records of a cable system withdrawn from service shall be available and should include, but not be limited to:

— details of out-of-service cable on land including route maps, the depth of burial and its location relative to surface features
— details of out-of-service cables offshore, including navigation charts showing the cable route.
APPENDIX A HAZARD IDENTIFICATION

A.1 General
As described in Sec.2, no single hazardous event should lead to life threatening situations for personnel or members of the public, to unacceptable impact on the environment or to unacceptable impact on project quality, cost and timing. This Appendix provides generic lists of hazardous events which may be used for review of project-specific risk assessments.

Guidance note:
Hazards differ between projects and require project-specific assessment. The following tables can provide useful input to a hazard identification process but can neither be assumed to be fully applicable nor comprehensive enough.

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A.2 Health and safety risks
Table A-1 provides examples for events hazardous to humans (personnel, members of the public) which may be encountered in subsea power cable projects, together with possible causes, consequences and safeguards.

<table>
<thead>
<tr>
<th>No.</th>
<th>Hazardous event</th>
<th>Possible causes</th>
<th>Possible consequences</th>
<th>Typical safeguards</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transportation incident (roads, harbour)</td>
<td>Poor weather conditions, poor vehicle maintenance, tiredness</td>
<td>Injury, fatality</td>
<td>Reduce transportation distances</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Use safe work methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Training</td>
</tr>
<tr>
<td>2</td>
<td>Vessel operation in rough sea state</td>
<td>Change of weather</td>
<td>Injury, man overboard, escalation due to moving cargo</td>
<td>Select capable vessel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Adequate seafastening</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Define acceptable weather conditions</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Accurate weather forecasting</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Follow procedures</td>
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<tr>
<td>3</td>
<td>Vessel collision with other vessel or offshore unit</td>
<td>Inappropriate procedure/ design, weather unsuitable for performing operations, loss of power, lack of navigation aids, human error</td>
<td>Injury, man overboard, fatality</td>
<td>Suitable design and procedures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vessel maintenance</td>
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<td></td>
<td></td>
<td></td>
<td>Training</td>
</tr>
<tr>
<td>4</td>
<td>Inexperienced vessel crew</td>
<td>Limited resources, lack of training</td>
<td>Injury, fatality</td>
<td>Training</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Joint working of senior and junior resources</td>
</tr>
<tr>
<td>5</td>
<td>Slips, trips, falls</td>
<td>Slippery or uneven surface, weather unsuitable for performing operations</td>
<td>Injury</td>
<td>Adequate surface design and maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Use of safe work methods</td>
</tr>
<tr>
<td>6</td>
<td>Transfer between vessel and offshore unit</td>
<td>Personnel required on offshore unit</td>
<td>Injury, man overboard, fatality</td>
<td>Design for minimum number of person transfers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reduce or eliminate equipment transfers</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Work within acceptable weather conditions</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Use of PPE</td>
</tr>
<tr>
<td>7</td>
<td>Man overboard</td>
<td>Weather unsuitable for performing operations, substandard work procedures</td>
<td>Injury, fatality</td>
<td>Training</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Adherence to work procedures</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Emergency procedures</td>
</tr>
<tr>
<td>8</td>
<td>Diving operation</td>
<td>Divers required for cable installation or maintenance</td>
<td>Injury, fatality</td>
<td>Eliminate diving operations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reduce number of diving operations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Use safe work methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Emergency plan and facilities</td>
</tr>
<tr>
<td>9</td>
<td>Work at height incident</td>
<td>Poor design, substandard work procedures, lack of training</td>
<td>Injury, fatality</td>
<td>Safe design</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Use safe work methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Work within acceptable weather conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Use of PPE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Training</td>
</tr>
</tbody>
</table>
Table A-1  Hazard identification for subsea power cables - Health and safety (Continued)

<table>
<thead>
<tr>
<th>No.</th>
<th>Hazardous event</th>
<th>Possible causes</th>
<th>Possible consequences</th>
<th>Typical safeguards</th>
</tr>
</thead>
</table>
| 10 | Dropped object, swinging load | Inappropriate lifting design, weather unsuitable for performing operations, equipment failure, human error | Injury, fatality | — Appropriate design  
— 3rd party verification  
— Sound method statement  
— Toolbox talks |
| 11 | Night-time working incident | Poor work planning, insufficient lighting | Injury, fatality | — Preference for daytime working  
— Good work planning  
— Adequate lighting |
| 12 | Loss of communication to vessel, offshore unit or shore | Equipment fault, loss of power | Escalation potential | — Equipment backup  
— Equipment maintenance |
| 13 | High tension in pull-in line | Poor design, uncalibrated equipment, deviations from method statement | Injury | — Good pulling design  
— Load monitoring  
— Adequate safety distances |
| 14 | Confined space incident | Substandard work procedures, lack of training | Injury, fatality | — Eliminate confined space work  
— Use safe work methods  
— Training |
| 15 | High voltage testing incident | Poor design, deviation from procedure | Injury, fatality | — Design for testability  
— Sound method statement  
— Qualified personnel |
| 16 | Unexploded ordnance (UXO) | Inadequate pre-installation surveys, inadequate distances | Injury, fatality | — Perform adequate surveys  
— Choose appropriate cable route  
— Use clearing services if required  
— Use safe work methods |

A.3 Environmental risks

Table A-2 provides examples for events hazardous to the natural environment which may be encountered in subsea power cable projects, together with possible causes, consequences and safeguards.

Table A-2  Hazard identification for subsea power cables - Environment

<table>
<thead>
<tr>
<th>No.</th>
<th>Hazardous event</th>
<th>Possible causes</th>
<th>Possible consequences</th>
<th>Typical safeguards</th>
</tr>
</thead>
</table>
| 1   | Landfall habitat disturbance | Drilling, trenching, cable pull-in, backfilling, access of barges and machinery | Habitat loss in inter-tidal area, distress of birds, impact on feeding and breeding behaviour | — Choose alternative cable route / landfall  
— Choose lower impact periods of the year  
— Choose low-impact construction techniques |
| 2   | Seabed habitat disturbance, turbidity | Cable burial, cable de-burial | Disturbance of seabed habitat, suffocation of marine organisms | — Choose lower impact periods of the year  
— Choice of burial / de-burial process and equipment |
| 3   | Construction noise, landfall area | Installation equipment and process | Disturbance of birds | — Choose lower impact periods of the year  
— Select low noise equipment  
— Minimise noise during installation process |
| 4   | Construction noise, offshore | Installation equipment and process | Disturbance of mammals and fish | — Choose lower impact periods of the year  
— Minimise noise during installation process |
### A.4 Project risks

Table A-3 provides examples for events which may have detrimental effects on subsea power cable projects with regard to quality, cost and time, together with possible causes, consequences and safeguards.

<table>
<thead>
<tr>
<th>No.</th>
<th>Hazardous event</th>
<th>Possible causes</th>
<th>Possible consequences</th>
<th>Typical safeguards</th>
</tr>
</thead>
</table>
| 5   | Contamination   | Marine or landfall incidents, spillages of oil or chemical, disturbance of contaminated areas | Habitat impact | — Avoid contaminated areas  
|     |                 |                  |                      | — Use safe work procedures  
|     |                 |                  |                      | — Regular maintenance  
|     |                 |                  |                      | — Build awareness  |
| 6   | Introduction of new materials | Rock placement for cable protection | Impact on ecosystem | — Assess risks  
|     |                 |                  |                      | — Use of local or alternative materials  |
| 7   | Thermal radiation | Electrical cable losses | Increase of soil/seabed temperature, possible impact on benthos | — Appropriate electrical and thermal design  
|     |                 |                  |                      | — Adequate burial depth (Germany)  |
| 8   | Magnetic fields | Single-core DC cables laid at a distance to each other | Possible effect on fish orientation | — Suitable cable design and layout  
|     |                 |                  |                      | — Specific attention to fish migration pathways  |

Table A-2 Hazard identification for subsea power cables - Environment (Continued)

<table>
<thead>
<tr>
<th>No.</th>
<th>Hazardous event</th>
<th>Possible causes</th>
<th>Possible consequences</th>
<th>Typical safeguards</th>
</tr>
</thead>
</table>
| 1   | Lack of work standards | Developing industry, lack of knowledge or experience | Substandard designs | — Application of guidance from related areas  
|     |                 |                  |                      | — Creation of dedicated guidance  |
| 2   | Regulatory / license changes | Governmental changes, policy changes | Delays | — Following and anticipating developments  
|     |                 |                  |                      | — Clear agreed terms & conditions  |
| 3   | Lack of site data / information | Inexperience, perceived cost saving | Excessive risk, potential delays and cost overruns | — Conservative planning and site assessments  |
| 4   | Poor survey results | Inexperience, perceived cost saving | Excessive risk, potential delays and cost overruns | — Well-planned, targeted surveys  
|     |                 |                  |                      | — Adequate budget and survey scope  
|     |                 |                  |                      | — Work with experienced partners  |
| 5   | Megaripples, sand waves | Mobile sediments, currents, waves | Unburied cable section, free spans, deeply buried cable section (overheating) | — Avoidance of area  
|     |                 |                  |                      | — Consideration of future movements  
|     |                 |                  |                      | — Deep burial avoiding free spans  |
| 6   | Poor cable route | Inexperience, perceived cost saving | Excessive risk, potential delays and cost overruns | — Optimisation of route engineering results  
|     |                 |                  |                      | — Involvement of installation contractor(s)  |
| 7   | Insufficient corridor width | Poor planning, insufficient survey coverage | Work in unknown area, violation of permit conditions | — Assess size of required survey corridor  
|     |                 |                  |                      | — Plan with contingencies  |
| 8   | No crossing agreement | Inexperience, lack of site knowledge | Increased technical risks, (unlimited) liability, legal challenges | — Minimise cable crossings  
|     |                 |                  |                      | — Agree on cable crossing design  |
| 9   | Mismatch between cable parameters and cable route / offshore unit design | Unknown cable specifications, inexperience, negligence | Redesign, modifications, delays, cost overruns | — Understand cable specifications  
|     |                 |                  |                      | — Adequate design for installation and operation  |
| 10  | Overly conservative cable parameters | Conservatism | More costly design | — Dialogue between cable manufacturer, installer and offshore unit designer  |
| 11  | Cable manufacturing flaw (electrical cores, optical fibres) | Impurities, lack of QA, insufficient testing | Cable damage, delays, liabilities | — Selection of experienced manufacturer  
|     |                 |                  |                      | — Clear specifications  
|     |                 |                  |                      | — Quality assurance during manufacturing, audits  
|     |                 |                  |                      | — Routine and factory acceptance testing  |
| 12  | Testing to higher standard than required | Conservatism | Failed test, delays | — Clear agreement between manufacturer and buyer  |
### Table A-3 Hazard identification for subsea power cables - Projects (Continued)

<table>
<thead>
<tr>
<th>No.</th>
<th>Hazardous event</th>
<th>Possible causes</th>
<th>Possible consequences</th>
<th>Typical safeguards</th>
</tr>
</thead>
</table>
| 13  | Start-up delays, supply chain delays                 | Inexperience, lack of planning                                                  | Cost overruns, knock-on effects for other projects         | • Order parts / equipment further in advance  
• Detailed planning  
• Less reliance on ‘statistical weather’  
• Work with experienced installation contractors |
| 14  | Contractor non-performance                           | Inexperience, lack of planning                                                  | Delays, cost overruns, knock-on effects for other projects | • Contractor references and qualification assessment  
• Audits  
• Clear contractual terms & conditions |
| 15  | Wrong MWS decision                                   | Lack of knowledge / experience / training, lack of back-office work             | Damage, delays, cost overruns                              | • State level of experience required  
• Work with experienced partners  
• Offer training opportunities for junior staff |
| 16  | Limited wind farm site / cable route access          | Inadequate agreements, change of policies or regulation                        | Delays                                                     | • Clear consenting agreements, right of way contracts  
• Proactive communication with stakeholders |
| 17  | Weather unsuitable for performing operations         | -                                                                               | Delays                                                     | • Suitable vessel and equipment, long-term charter  
• Robust cable interface design at turbines  
• Good weather forecasting  
• Planning with contingencies |
| 18  | Unexpected soil conditions                           | Inadequate survey specification or results, inadequate design                  | Delays, re-engineering of cable route                      | • Extensive geophysical / geotechnical investigations  
• Planning with contingencies (schedule, equipment)  
• Pre-lay grapple run |
| 19  | Unsuitable installation or burial tool               | Lack of site information, poor design                                          | Delays, cost overruns                                      | • Extensive geophysical / geotechnical investigations  
• Selection of suitable equipment  
• Planning with contingencies |
| 20  | Equipment breakdown                                  | Overload, lack of maintenance                                                   | Delays                                                     | • Selection of suitable equipment  
• Regular maintenance |
| 21  | Unscheduled vessel maintenance                       | Lack of maintenance                                                            | Delays                                                     | • Classed vessel, performance track record  
• Preventive maintenance |
| 22  | Cable loops formed on seabed                        | Uncontrolled cable pay-out, insufficient tension                               | Early failure of cable                                     | • Controlled installation process  
• Post installation survey  
• Rectification |
| 23  | Cable damaged during installation                    | Inexperience, inadequate equipment or processes, time pressure                 | Delays, cost overruns                                      | • Fit for purpose equipment  
• Agreed handling limits, instructions  
• Procedures, training |
| 24  | Specified burial depth not reached                   | Hard soil, inappropriate tool, required stand-off distance                      | Less protection of cable, contractual disagreements        | • Selection of suitable burial method and tools  
• Definition of ‘reasonable endeavour’ |
| 25  | Excessive burial                                     | Mobile sediments                                                               | Overheating of cable                                       | • Appropriate choice of cable design and route  
• Remedial works |
| 26  | Overloading cable                                    | Wrong design assumptions, limited cooling                                       | Premature failure of cable                                 | • Design for site-specific conditions  
• Operational monitoring |
| 27  | Investigation following an incident                  | Substandard work practices                                                      | Delays                                                     | • Safety culture |
| 28  | Anchor impact (drop, drag)                           | Vessel traffic, emergency situation                                            | Cable damage                                               | • Analysis and cable routing  
• Appropriate burial / protection of cable  
• Cable awareness charts  
• Vessel movement monitoring |
### Table A-3 Hazard identification for subsea power cables - Projects (Continued)

<table>
<thead>
<tr>
<th>No.</th>
<th>Hazardous event</th>
<th>Possible causes</th>
<th>Possible consequences</th>
<th>Typical safeguards</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>Fishing (trawling) gear impact</td>
<td>Fishing in restricted area</td>
<td>Cable damage</td>
<td>— Analysis and cable routing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Burial / protection of cable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Cable awareness charts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Exclusion zones</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Vessel movement monitoring</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Fishermen liaison</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Notice to Mariners</td>
</tr>
<tr>
<td>30</td>
<td>Dredging incident</td>
<td>Dredging in proximity of cable</td>
<td>Cable damage</td>
<td>— Cable route selection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Accurate charting</td>
</tr>
<tr>
<td>31</td>
<td>Dropped object</td>
<td>Unsecured freight</td>
<td>Cable damage</td>
<td>— Analysis and cable routing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Burial / protection of cable</td>
</tr>
<tr>
<td>32</td>
<td>Work in proximity of the cable</td>
<td>Repairs, new installations</td>
<td>Cable damage</td>
<td>— Accurate charting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Proximity agreements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Stakeholder communication</td>
</tr>
<tr>
<td>33</td>
<td>Cable fault</td>
<td>Manufacturing defect, compromised cable during installation, ageing asset</td>
<td>Loss of transmission capacity, loss of income, repair cost</td>
<td>— Adequate design, manufacturing, installation and operation / maintenance</td>
</tr>
<tr>
<td>34</td>
<td>Termination fault</td>
<td>Poor workmanship</td>
<td>Loss of transmission capacity, loss of income</td>
<td>— Use of skilled workforce</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Post-installation testing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— In-service monitoring</td>
</tr>
<tr>
<td>35</td>
<td>Natural catastrophe</td>
<td>-</td>
<td>Cable exposure, cable fault</td>
<td>— Detailed analysis of site conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Reliable design</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Site monitoring</td>
</tr>
<tr>
<td>36</td>
<td>Scour at offshore unit</td>
<td>Seabed movement</td>
<td>Cable exposed, free spans</td>
<td>— Detailed analysis of site conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Appropriate interface design</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Inspections</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Remedial work</td>
</tr>
<tr>
<td>37</td>
<td>Cable free spans</td>
<td>Seabed movement</td>
<td>Cable exposure, mechanical stress, VIV, fatigue</td>
<td>— Detailed analysis of site conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Appropriate protection design</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Inspections</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Remedial work</td>
</tr>
<tr>
<td>38</td>
<td>Lack of spare cable or joints</td>
<td>Inadequate planning</td>
<td>Significant delay of repair in case of damage</td>
<td>— Appropriate planning</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Spare part storage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Contractual arrangements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Sharing of resources</td>
</tr>
<tr>
<td>39</td>
<td>Recovery of deeply buried cable</td>
<td>Requirement to repair faulty cable</td>
<td>Delays, cost</td>
<td>— Burial to required depth only</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— Consideration of sand waves</td>
</tr>
</tbody>
</table>
APPENDIX B SUBSEA POWER CABLE SPECIFICATIONS

B.1 General
This section summarises information which a purchaser may provide to a manufacturer for the selection of high voltage AC cables. It also summarises the information which the manufacturer may provide to the purchaser when offering and when supplying the cable.

Guidance note:
Some of the data may not be available at the enquiry or offer stage. A close dialogue and collaboration between the parties will help identifying the best overall solution and lead to optimised and cost effective cable system designs.

Depending on the specific project, the information provided may deviate from what is listed below. The information provided is typically limited to what is relevant for the specific application. Information related to technology may be considered as proprietary by the cable manufacturer.

In the subsections below, the following coding is used to indicate the source of information:
— P: information typically provided by purchaser
— (P): information optionally provided by purchaser
— M: information typically provided by manufacturer
— (M): information optionally provided by manufacturer.

B.2 Project information
Table B-1 lists general cable project information which should be provided by the purchaser.

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Unit</th>
<th>Condition</th>
<th>Responsibility at stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Enquiry</td>
</tr>
<tr>
<td>1</td>
<td>Project name</td>
<td>-</td>
<td></td>
<td>P</td>
</tr>
<tr>
<td>2</td>
<td>Location of project 1)</td>
<td>-</td>
<td></td>
<td>P</td>
</tr>
<tr>
<td>3</td>
<td>Water depth, for installation</td>
<td>m</td>
<td>maximum</td>
<td>P</td>
</tr>
<tr>
<td>4</td>
<td>Cable interface information 2)</td>
<td>-</td>
<td></td>
<td>P</td>
</tr>
<tr>
<td>5</td>
<td>Type of cable, e.g. 3-core AC</td>
<td>-</td>
<td></td>
<td>P</td>
</tr>
<tr>
<td>6</td>
<td>Route length, total</td>
<td>m</td>
<td></td>
<td>P</td>
</tr>
<tr>
<td>7</td>
<td>Life</td>
<td>years</td>
<td>design, service</td>
<td>(P)</td>
</tr>
<tr>
<td>8</td>
<td>Commercial terms and conditions 3)</td>
<td>-</td>
<td></td>
<td>(P)</td>
</tr>
<tr>
<td>9</td>
<td>Special conditions, if any</td>
<td>-</td>
<td></td>
<td>(P)</td>
</tr>
</tbody>
</table>

1) Preferably including coordinates. For delivery location, see also [4.4.1.8].
2) Interfaces with offshore wind turbine, offshore substation or onshore grid connection.
3) E.g. tender validity, product warranty, metal pricing.

B.3 Electrical specifications
Table B-2 lists electrical cable system specifications which should be provided by the purchaser or manufacturer and agreed or refined, where applicable.

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Unit</th>
<th>Condition</th>
<th>Responsibility at stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Enquiry</td>
</tr>
<tr>
<td>1</td>
<td>System voltage $U$</td>
<td>kV</td>
<td>rated, IEC 60183</td>
<td>P</td>
</tr>
<tr>
<td>2</td>
<td>System voltage $U_m$</td>
<td>kV</td>
<td>maximum, IEC 60183</td>
<td>P</td>
</tr>
<tr>
<td>3</td>
<td>Impulse withstand voltage $U_p$</td>
<td>kV</td>
<td>peak, IEC 60071-1</td>
<td>(P)</td>
</tr>
<tr>
<td>4</td>
<td>System frequency $f$</td>
<td>Hz</td>
<td>nominal</td>
<td>P</td>
</tr>
<tr>
<td>5</td>
<td>Current-carrying capacity (current rating) 1)</td>
<td>A</td>
<td>continuous</td>
<td>(P) 2)</td>
</tr>
<tr>
<td>6</td>
<td>Symmetrical short circuit, 3 phases, current and duration</td>
<td>kA, s</td>
<td>maximum</td>
<td>P</td>
</tr>
</tbody>
</table>
B.4 Thermal specifications

Table B-3 lists thermal cable system specifications which should be provided by the purchaser or manufacturer and agreed or refined, where applicable. The thermal conditions describe specific scenarios which the cable system is required to operate in during its service life.

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Unit</th>
<th>Condition</th>
<th>Responsibility at stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Asymmetrical short circuit, phase to earth, current and duration</td>
<td>kA, s</td>
<td>maximum</td>
<td>P</td>
</tr>
<tr>
<td>8</td>
<td>Earthing concept</td>
<td></td>
<td></td>
<td>(P) M</td>
</tr>
<tr>
<td>9</td>
<td>DC and AC resistance</td>
<td>Ω/m</td>
<td>+20°C, +90°C 3)</td>
<td>M</td>
</tr>
<tr>
<td>10</td>
<td>Positive, negative, zero sequence impedance 4)</td>
<td>Ω/m</td>
<td>+20°C</td>
<td>M</td>
</tr>
<tr>
<td>11</td>
<td>Losses, by cable element 5)</td>
<td>W/m</td>
<td>100% continuous rating</td>
<td>M</td>
</tr>
</tbody>
</table>

1) Alternatively, a power carrying capacity in MVA at a specified voltage level is sometimes used.
2) Minimum or target value(s). Alternatively, conductor cross-section(s) may be specified.
3) Temperature of +90°C applies to XLPE and EPR insulation.
4) Frequency-dependent impedances may be requested for harmonic studies.
5) E.g. conductor, sheath, armour, insulation (dielectric).

Table B-2 Electrical specifications (Continued)

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Unit</th>
<th>Condition</th>
<th>Responsibility at stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Ground temperature at cable location ϑ</td>
<td>°C</td>
<td>minimum, average, maximum</td>
<td>(P) 1) P</td>
</tr>
<tr>
<td>3.2</td>
<td>Depth of burial, cable centre</td>
<td>m</td>
<td>minimum, maximum</td>
<td>(P) 1) P</td>
</tr>
<tr>
<td>3.3</td>
<td>Thermal conductivity of soil k 2)</td>
<td>W/(K·m)</td>
<td>typical or minimum</td>
<td>(P) 1) P 3)</td>
</tr>
<tr>
<td>3.4</td>
<td>Thermal diffusivity of soil α</td>
<td>m²/s</td>
<td>typical</td>
<td>(P) (P) 3)</td>
</tr>
<tr>
<td>5.1</td>
<td>Ground temperature at cable location ϑ</td>
<td>°C</td>
<td>minimum, average, maximum</td>
<td>(P) 1) P</td>
</tr>
<tr>
<td>5.2</td>
<td>Depth of burial, cable centre</td>
<td>m</td>
<td>minimum, maximum</td>
<td>(P) 1) P</td>
</tr>
<tr>
<td>5.3</td>
<td>Thermal conductivity of (dry) soil k</td>
<td>W/(K·m)</td>
<td>typical or minimum</td>
<td>(P) 1) P 3)</td>
</tr>
<tr>
<td>5.4</td>
<td>Thermal conductivity of backfill material k</td>
<td>W/(K·m)</td>
<td>typical or minimum</td>
<td>(P) 1) P</td>
</tr>
<tr>
<td>5.5</td>
<td>Thermal conductivity of conduit material k, if applicable</td>
<td>W/(K·m)</td>
<td>typical or minimum</td>
<td>(P) 1) P</td>
</tr>
<tr>
<td>5.6</td>
<td>Dimensions of conduit, if applicable</td>
<td>m</td>
<td>typical</td>
<td>(P) 1) P</td>
</tr>
<tr>
<td>6</td>
<td>Further scenario, as applicable</td>
<td></td>
<td>yes/no</td>
<td>P</td>
</tr>
</tbody>
</table>

1) Where site data are not yet available, default values commonly used are: +15°C, 1 m, 1.43 W/(K·m).
2) Alternatively, thermal resistivity $\rho_T$ in K·m/W may be stated. A frequently used value is 0.7 K·m/W.
3) Result from cable route survey or default value.
B.5 Mechanical specifications

The type and number of handling activities (e.g. coiling) and the maximum installation water depth should be specified by the purchaser. After designing the cable, its mechanical properties can be estimated or measured. Table B-4 lists mechanical cable system specifications which are predominantly provided by the manufacturer.

For specification of mechanical dimensions of the cable cores and the completed power cables, see [B.6].

### Table B-4 Mechanical specifications

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Unit</th>
<th>Condition</th>
<th>Responsibility at stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Enquiry</td>
</tr>
<tr>
<td>1</td>
<td>Handling type and cycles 1)</td>
<td>-</td>
<td>e.g. CIGRÉ Electra 171</td>
<td>P</td>
</tr>
<tr>
<td>2</td>
<td>Weight</td>
<td>kg/m</td>
<td>in air, in water (unflooded, flooded)</td>
<td>(M)</td>
</tr>
<tr>
<td>3</td>
<td>Tensile strength</td>
<td>kN</td>
<td>maximum</td>
<td>(M)</td>
</tr>
<tr>
<td>4</td>
<td>Tension at specific bending radius 2)</td>
<td>kN</td>
<td>maximum</td>
<td>(M)</td>
</tr>
<tr>
<td>5</td>
<td>Bending radius, complete cable</td>
<td>m</td>
<td>minimum 3)</td>
<td>M</td>
</tr>
<tr>
<td>6</td>
<td>Bending radius, single core</td>
<td>m</td>
<td>minimum</td>
<td>M</td>
</tr>
<tr>
<td>7</td>
<td>Coiling diameter 4)</td>
<td>m</td>
<td>minimum</td>
<td>(M)</td>
</tr>
<tr>
<td>8</td>
<td>Axial stiffness</td>
<td>kN</td>
<td>specified 5)</td>
<td>(M)</td>
</tr>
<tr>
<td>9</td>
<td>Bending stiffness</td>
<td>kN m²</td>
<td>specified 5)</td>
<td>(M)</td>
</tr>
<tr>
<td>10</td>
<td>Torsional stiffness</td>
<td>kN m²</td>
<td>specified 5)</td>
<td>(M)</td>
</tr>
<tr>
<td>11</td>
<td>Crush load (storage)</td>
<td>kN/m</td>
<td>maximum 6)</td>
<td>(M)</td>
</tr>
<tr>
<td>12</td>
<td>Squeeze load (installation)</td>
<td>kN/m</td>
<td>specified 7)</td>
<td>(M)</td>
</tr>
<tr>
<td>13</td>
<td>Impact load</td>
<td>J, J/mm²</td>
<td>specified 8)</td>
<td>(M)</td>
</tr>
<tr>
<td>14</td>
<td>Friction and abrasion properties</td>
<td>-</td>
<td>specified 9)</td>
<td>(M)</td>
</tr>
</tbody>
</table>

1) If applicable, include number of coiling cycles (one cycle = coiling + uncoiling).
2) For specific applications, e.g. J-tube pull-in. Sidewall pressure in kN/m may also be relevant.
3) Conditions to be specified, e.g. static / dynamic, during storage / during installation / after installation.
4) Coilable cables only. Coiling direction to be specified.
5) Parameter depends on condition, e.g. temperature, and application, e.g. dry / wet, static / dynamic.
6) Static (storage) and dynamic (transport) conditions to be agreed between purchaser and manufacturer. Figure could be supplemented by maximum stacking height.
7) Depending on pad arrangement, shape and material as well as time limit. Specific conditions to be agreed between purchaser and manufacturer.
8) Impact capacity can be specified for an object (e.g. geometry, weight) and condition (e.g. velocity). Generally requires testing.
9) If relevant, e.g. pulling of cable across seabed, assumptions to be discussed between purchaser and manufacturer.

B.6 Cable component features

Table B-5 lists specifications of components which are part of a typical composite 3-core AC power cable. These specifications should typically be provided by the manufacturer at the supply stage. For integrated optical fibres, see [4.4.3].

### Table B-5 Cable component design

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Unit</th>
<th>Condition</th>
<th>Responsibility at stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Enquiry</td>
</tr>
<tr>
<td>1.1</td>
<td>Material</td>
<td>-</td>
<td>IEC 60228</td>
<td>(P)</td>
</tr>
<tr>
<td>1.2</td>
<td>Cross-section 1)</td>
<td>mm²</td>
<td>nominal</td>
<td>(P)</td>
</tr>
<tr>
<td>1.3</td>
<td>Shape, type of conductor 2)</td>
<td>-</td>
<td>-</td>
<td>(M)</td>
</tr>
<tr>
<td>1.4</td>
<td>Overall diameter</td>
<td>mm</td>
<td>typical</td>
<td>(M)</td>
</tr>
<tr>
<td>1.5</td>
<td>Water blocking method, longitudinal</td>
<td>-</td>
<td>-</td>
<td>(M)</td>
</tr>
<tr>
<td>2</td>
<td>Conductor (semi-conductive) screen</td>
<td>-</td>
<td>-</td>
<td>(M)</td>
</tr>
<tr>
<td>2.1</td>
<td>Type and material</td>
<td>-</td>
<td>-</td>
<td>(M)</td>
</tr>
<tr>
<td>2.2</td>
<td>Thickness</td>
<td>mm</td>
<td>nominal</td>
<td>(M)</td>
</tr>
<tr>
<td>3</td>
<td>Insulation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table B-5  Cable component design (Continued)

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Unit</th>
<th>Condition</th>
<th>Responsibility at stage</th>
</tr>
</thead>
<tbody>
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<td>Enquiry</td>
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<td>3.1</td>
<td>Type and material</td>
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<tr>
<td>3.2</td>
<td>Thickness</td>
<td>mm</td>
<td>nominal, minimum</td>
<td>(M)</td>
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<td>3.3</td>
<td>Maximum temperature</td>
<td>°C</td>
<td>continuous</td>
<td>(P)</td>
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<tr>
<td>3.4</td>
<td>Maximum stress at nominal voltage and impulse voltage</td>
<td>kV/mm</td>
<td>at conductor screen, at insulation screen</td>
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<tr>
<td>3.5</td>
<td>Thermal conductivity</td>
<td>W/(K·m)</td>
<td>typical</td>
<td>(M)</td>
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<td>4</td>
<td>Insulation (semi-conductive) screen</td>
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<td>4.1</td>
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<td>4.2</td>
<td>Thickness</td>
<td>mm</td>
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<td>5</td>
<td>Bedding for radial / longitudinal water blocking</td>
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<td>5.1</td>
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<td>Thickness</td>
<td>mm</td>
<td>nominal</td>
<td>(M)</td>
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<td>6</td>
<td>Metallic screen, radial water blocking</td>
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<td>6.2</td>
<td>Cross-section</td>
<td>mm²</td>
<td>nominal, minimum</td>
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<td>Protective sheath covering</td>
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<td>mm</td>
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<td>7.3</td>
<td>Cable outer diameter, single core</td>
<td>mm</td>
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<td>Thermal conductivity</td>
<td>W/(K·m)</td>
<td>typical</td>
<td>(M)</td>
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<td>Interstitial fillers</td>
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<td>typical</td>
<td>(M)</td>
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<td>Armour bedding</td>
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<td>(M)</td>
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<td>Armour layer</td>
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<td>Size / diameter</td>
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<td>10.3</td>
<td>Lay direction</td>
<td>-</td>
<td>left hand / right hand</td>
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</tr>
<tr>
<td>10.4</td>
<td>Lay length</td>
<td>mm</td>
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<td>(M)</td>
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<td>Outer sheath (serving)</td>
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<td>mm</td>
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<td>Cable outer diameter (d_{oa}), roundness</td>
<td>mm</td>
<td>nominal</td>
<td>(M)</td>
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<td>Thermal conductivity</td>
<td>W/(K·m)</td>
<td>typical</td>
<td>(M)</td>
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</table>

1) For a single conductor. For 3-core cables, stated e.g. as \(3 \times 240 \text{ mm}^2\).
2) E.g. round wire.