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Edition 3.0 2024-04

INTERNATIONAL STANDARD

colour
inside

Railway applications – Fixed installations – Electric traction overhead contact lines systems

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CONTENTS

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RAILWAY APPLICATIONS – FIXED INSTALLATIONS – ELECTRIC TRACTION OVERHEAD CONTACT LINE SYSTEMS

FOREWORD

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IEC 60913 has been prepared by IEC technical committee 9: Electrical equipment and systems for railways. It is an International Standard.

This third edition cancels and replaces the second edition published in 2013. This edition constitutes a technical revision.

The European standard EN 50119 has served as a basis for the elaboration of this document.

This edition includes the following significant technical changes with respect to the previous edition:

a) title modified;

b) requirements for urban rail systems are included;

c) requirements for rigid overhead contact line (ROCL) are included;

d) additional definitions for new terms are included (Clause 3);

e) clearances and geometry of overhead contact line are improved (Clause 5);

f) urban aspects are added, for example wall anchors (Clause 6);

g) requirements for monitoring devices, automatic earthing and short-circuiting equipment are included (Clause 7);

h) requirements for overhead contact line for electric vehicles with pantograph on electrified roads are added (Annex E)

i) improvements on the basis of EN 50119:2020 and the questionnaire 9/2619A/Q

The text of this International Standard is based on the following documents:

Draft	Report on voting
9/3031/FDIS	9/3052/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The reader's attention is drawn to the fact that Annex H lists all of the "in-some-country" clauses on differing practices of a less permanent nature relating to the subject of this document.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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RAILWAY APPLICATIONS – FIXED INSTALLATIONS – ELECTRIC TRACTION OVERHEAD CONTACT LINE SYSTEMS

1 Scope

This document specifies the requirements and tests for the design of overhead contact line systems, requirements for structures and their structural calculations and verifications as well as the requirements and tests for the design of assemblies and individual parts.

This document is applicable to electric traction overhead contact line systems in heavy railways, light railways, for trolley bus lines, electric road systems (Annex E) and industrial railways of public and private operators. This document is applicable to new installations of overhead contact line systems and for the complete renewal of existing overhead contact line systems.

This document does not apply to ground level conductor rail systems (see Figure 1).

NOTE Ground level conductor rail means conductor rails located adjacent to the running rail, e.g. the third rail or a conductor rail in the ground.

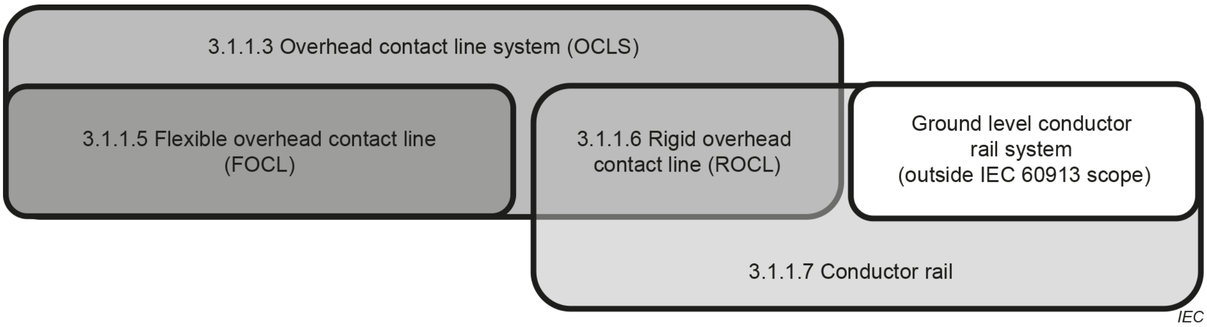

Figure 1 – Scope of contact line systems

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60099-4, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC 60168, *Tests on indoor and outdoor post insulators of ceramic material or glass for systems with nominal voltages greater than 1 000 V*

IEC 60273, *Characteristics of indoor and outdoor post insulators for systems with nominal voltages greater than 1 000 V*

IEC 60305, *Insulators for overhead lines with a nominal voltage above 1 000 V – Ceramic or glass insulator units for AC systems – Characteristics of insulator units of the cap and pin type*

IEC 60383 (all parts), *Insulators for overhead lines with nominal voltage above 1 000 V*

IEC 60433, *Insulators for overhead lines with a nominal voltage above 1 000 V – Ceramic insulators for AC systems – Characteristics of insulator units of the long rod type*

IEC 60494-1, *Railway applications – Rolling stock – Pantographs – Characteristics and tests – Part 1: Pantographs for main line vehicles*

IEC 60494-2, *Railway applications – Rolling stock – Pantographs – Characteristics and tests – Part 2: Pantographs for metros and light rail vehicles*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60660, *Insulators – Tests on indoor post insulators of organic material for systems with nominal voltages greater than 1 000 V up to but not including 300 kV*

IEC 60672-1, *Ceramic and glass insulating materials – Part 1: Definitions and classification*

IEC 60672-2, *Ceramic and glass insulating materials – Part 2: Methods of test*

IEC 60672-3, *Ceramic and glass-insulating materials – Part 3: Specifications for individual materials*

IEC 60850, *Railway applications – Supply voltages of traction systems*

IEC 60947-1, *Low-voltage switchgear and controlgear – Part 1: General rules*

IEC 61089, *Round wire concentric lay overhead electrical stranded conductors*

IEC TS 61245, *Artificial pollution tests on high-voltage ceramic and glass insulators to be used on d.c. systems*

IEC 61325, *Insulators for overhead lines with a nominal voltage above 1 000 V – Ceramic or glass insulator units for d.c. systems – Definitions, test methods and acceptance criteria*

IEC 61284:1997, *Overhead lines – Requirements and tests for fittings*

IEC 61773, *Overhead lines – Testing of foundations for structures*

IEC 61992-1, *Railway applications – Fixed installations – DC switchgear – Part 1: General*

IEC 61992-4, *Railway applications – Fixed installations – DC switchgear – Part 4: Outdoor d.c. disconnectors, switch-disconnectors and earthing switches*

IEC 62128 (all parts), *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit*

IEC 62236-2, *Railway applications – Electromagnetic compatibility – Part 2: Emission of the whole railway system to the outside world*

IEC 62313, *Railway applications – Power supply and rolling stock – Technical criteria for the coordination between power supply (substation) and rolling stock*

IEC 62486:2017, *Railway applications – Current collection systems – Technical criteria for the interaction between pantograph and overhead contact line (to achieve free access)*

IEC 62497-1:2010, *Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment*
IEC 62497-1:2010/AMD1:2013

IEC 62497-2, *Railway applications – Insulation coordination – Part 2: Overvoltages and related protection*

IEC 62498-2:2010, *Railway applications – Environmental conditions for equipment – Part 2: Fixed electrical installations*

IEC 62505-2, *Railway applications – Fixed installations – Particular requirements for AC switchgear – Part 2: Disconnectors, earthing switches and switches with nominal voltage above 1 kV*

IEC 62621, *Railway applications – Fixed installations – Electric traction – Special requirements for composite insulators used for overhead contact line systems*

IEC 62641: 2022, *Conductors for overhead lines – Aluminium and aluminium alloy wires for concentric lay stranded conductors*

IEC 62724, *Railway applications – Fixed installations – Electric traction – Insulating synthetic rope assemblies for support of overhead contact lines*

IEC 62846:2016, *Railway applications – Current collection systems – Requirements for and validation of measurements of the dynamic interaction between pantograph and overhead contact line*

IEC 62848 (all parts), *Railway applications – DC surge arresters and voltage limiting devices*

IEC 62917, *Railway applications – Fixed installations – Electric traction – Copper and copper alloy grooved contact wires*

IEC 63190, *Railway applications – Fixed installations – Electric traction – Copper and copper alloy catenary wires for overhead contact line systems*

IEC 63248: 2022, *Conductors for overhead lines – Coated or cladded metallic wire for concentric lay stranded conductors*

IEC 63438, *Railway applications – Fixed installations – Protection principles for AC and DC electric traction power supply systems*[1]

IEC 63453, *Railway applications – Current collection systems – Validation of simulation of the dynamic interaction between pantograph and overhead contact line*[2]

ISO 630 (all parts), *Structural steels*

ISO 898-1:2013, *Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1: Bolts, screws and studs with specified property classes – Coarse thread and fine pitch thread*

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[1] Under preparation. Stage at the time of publication: IEC/AFDIS 63438:2023.

[2] Under preparation. Stage at the time of publication: IEC/CCDV 63453:2023.

ISO 898-2:2012, *Mechanical properties of fasteners made of carbon steel and alloy steel – Part 2: Nuts with specified property classes – Coarse thread and fine pitch thread*

ISO 1461:2022, *Hot dip galvanized coatings on fabricated iron and steel articles – Specifications and test methods*

ISO 2394, *General principles on reliability for structures*

ISO 2859 (all parts), *Sampling procedures for inspection by attributes*

ISO 4354, *Wind actions on structures*

ISO 10721 (all parts), *Steel structures*

ISO 14713 (all parts), *Zinc coatings – Guidelines and recommendations for the protection against corrosion of iron and steel in structures*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definition

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1 Systems

3.1.1.1

contact line system

support system and contact line supplying electric energy to vehicles through current-collecting equipment

Note 1 to entry: The mechanical system can comprise

- the contact line,
- structures and foundations,
- supports and any components supporting or registering the conductors,
- head spans and cross-spans,
- along-track feeders, negative feeders, reinforcing feeders, and other lines like earth wires and return conductors, including boosters, as far as they are supported from contact line system structures,
- cross-track feeders,
- overvoltage protection devices,
- conductors connected permanently to the contact line for supply of other electrical equipment such as lights, signal operation, point control and point heating, and
- any other equipment necessary for operating the contact line.

Note 2 to entry: The electrical limits of the contact line system are the feeding point and the contact point to the current collector.

[SOURCE: IEC 60050-811:2017, 811-33-59, modified – Note 1 to entry has been modified and Note 2 to entry has been added.]

3.1.1.2
contact line
conductor system for supplying traction units with electrical energy via current-collecting equipment

Note 1 to entry: This includes all current-collecting conductors and conducting rails or bars, including the following:

- electrical connectors
- sectioning devices;
- tensioning devices;
- supports that are not insulated from the conductors;
- insulators connected to live parts;
- contact wires;
- catenary wires;
- auxiliary catenary wires;
- stitch wires;
- droppers.

Note 2 to entry: Included are all components that affect the dynamic interaction.

[SOURCE: IEC 60050-811:2017, 811-33-01, modified – "Electric energy to vehicles through" has been replaced with "traction units with electrical energy via". In the Note 1 to entry "cross-track feeders; disconnectors; section insulators; overvoltage protection devices" have been removed and "electrical connectors, sectioning devices, tensioning devices, contact wires, catenary wires" have been added. The end of the Note 1 to entry has been removed. The Note 2 to entry has been added.]

3.1.1.3
overhead contact line system
contact line system using an overhead contact line to supply current for use by traction units

3.1.1.4
overhead contact line
OCL
contact line placed above or beside the upper limit of the vehicle gauge, supplying traction units with electrical energy through roof-mounted current collection equipment

Note 1 to entry: The overhead contact line can be of a flexible or rigid configuration.

[SOURCE: IEC 60050-811:2017, 811-33-02, modified – "Catenary" has been removed as synonym and replaced with the abbeviated term OCLS. In the definition, "electric" has been replaced with "electrical". The Note 1 to entry has been added.]

3.1.1.5
flexible overhead contact line
FOCL
overhead contact line using flexible tensioned conductors

Note 1 to entry: The flexible overhead contact line can be an overhead contact line with catenary suspension (IEC 60050-811:2017, 811-33-05) or a single tramway equipment (IEC 60050-811:2017, 811-33-03).

3.1.1.6
rigid overhead contact line
ROCL
overhead contact line using almost rigid not tensioned profiles

Note 1 to entry: In this document, rigid overhead contact line is used to define conductor rail (3.1.1.7) mounted in an overhead position.

3.1.1.7
conductor rail
rigid metallic conductor mounted on insulators intended to interface with a vehicle mounted current collector

Note 1 to entry: The conductor rail can be of composite construction.

[SOURCE: IEC 60050-811:2017, 811-34-01, modified – Note 1 to entry has been removed.]

3.1.1.8
inclined overhead contact line
<system> overhead contact line in which one or more contact wires are suspended from the catenary wire by inclined droppers so the catenary wire and contact wire are not in a vertical plane in absence of a wind load

[SOURCE: IEC 60050-811:2017, 811-33-13, modified – In the term, the word "catenary" has been replaced with "overhead contact line" and the synonyms have been removed. The specific use has been added. The words "that the contact wire or wires follow a path corresponding approximately to the centre line of the track" have been replaced with "the catenary wire and contact wire are not in a vertical plane in absence of a wind load.]

3.1.1.9
supporting assembly
assembly of components attached to the main support structure that supports and registers the overhead contact line

3.1.1.10
kinematic reference profile
line specific to each gauge, representing the cross-section shape and used as a common basis to work out the sizing rules of the infrastructure and of the rolling stock

3.1.1.11
static reference profile
kinematic reference profile without the dynamic uplift of the suspension and the vertical oscillations of the vehicles during operation

Note 1 to entry: See EN 15273-1 and EN 15273-3.

3.1.1.12
vertical superelevation
margin added to the reference profile to take into consideration the interconnection of two track gradient by vertical curves of radius

Note 1 to entry: See EN 15273-3.

3.1.1.13
tensioning device
device to maintain the tension of conductors within the system design parameters

[SOURCE: IEC 60050-811:2017, 811-33-45, modified – The preferred term "tensioner" has been removed.]

3.1.1.14
urban rail system
light rail (for example tramway, subways or suburban trains) and trolleybus system, operating in urban areas, excluding heavy rail systems

3.1.1.15
sectioning device
device used to divide the contact line into different sections or circuits

Note 1 to entry: Sectioning devices includes section insulators and neutral sections.

3.1.1.16
section insulator
sectioning point formed by insulators inserted in a continuous run of a contact line, with skids or similar devices to maintain continuous electrical contact with the current collector

[SOURCE: IEC 60050-811:2017, 811-36-15]

3.1.1.17
neutral section
section of a contact line provided with a sectioning point at each end to prevent successive electrical sections differing in voltage, phase or frequency from being connected together by the passage of current collectors

[SOURCE: IEC 60050-811:2017, 811-36-16, modified – The word "from" has been added for better understanding.]

3.1.1.18
disconnector
switching device which provides, in the open position, a visible isolating distance in accordance with specified requirements

Note 1 to entry: A disconnector can be a load or non-load breaking device.

Note 2 to entry: Switch-disconnectors and earthing switches are forms of disconnectors.

[SOURCE: IEC 60050-441:1984, 441-14-05, modified – Words "a mechanical" have been removed; "visible" has been added. The note 1 to entry has been modified. The notes 2 to entry has been added.]

3.1.1.19
span length
horizontal distance between the attachment points of the conductor on two consecutive supports

[SOURCE: IEC 60050-466:1990, 466-03-02]

3.1.1.20
midpoint
point in a tension length of the overhead contact line where the conductors are fixed in position to control the along track movement

3.1.1.21
system height
vertical distance between the main catenary wire and the contact wire measured at a support point

[SOURCE: IEC 60050-811:2017, 811-33-52]

3.1.2 Conductors

3.1.2.1

along-track feeder

overhead conductor mounted on the same structure as the overhead contact line to supply successive feeding points

Note 1 to entry: Along-track feeder is a generic term for all feeders mounted to OCL structures.

[SOURCE: IEC 60050-811:2017, 811-36-24, modified – Note 1 to entry has been added.]

3.1.2.2

catenary wire

messenger wire

longitudinal conductor supporting the contact wire or wires either directly or indirectly

Note 1 to entry: The term "messenger wire" is used in some countries instead of "catenary wire".

[SOURCE: IEC 60050-811:2017, 811-33-06, modified – "Cable" has been replaced by "conductor". – The Note 1 to entry has been added.]

3.1.2.3

contact wire

electric conductor of an overhead contact line with which the current collector makes contact and is characterized by two clamping grooves

[SOURCE: IEC 60050-811:2017, 811-33-15, modified – The second term "trolley wire" has been deleted and the words "and is characterized by two clamping grooves" have been added.]

3.1.2.4

reinforcing feeder

overhead conductor mounted adjacent to the overhead contact line, and directly connected to it at frequent intervals

Note 1 to entry: The reinforcing feeder increases the effective cross-sectional area of the overhead contact line.

[SOURCE: IEC 60050-811:2017, 811-33-60]

3.1.2.5

line feeder

overhead conductor mounted parallel to, or in parallel with, the contact line either to supply successive feeding points or to increase the useful cross-sectional area

Note 1 to entry: Line feeder is not connected directly to the OCL. It can be a parallel feeding line from the substation or a bypass line to transfer energy over locations where OCL of a single-track line or of a station has to be switched off regularly to supply electric trains behind this location.

[SOURCE: IEC 60050-811:2017, 811-36-09, modified – Note 1 to entry has been added.]

3.1.2.6

negative feeder

overhead conductor mounted parallel to the contact line which has opposite (180° different) phase voltage to the contact line phase used in autotransformer system

3.1.2.7
jumper

short length of conductor(s) not under mechanical tension, making an electrical connection between two or more conductors or other electrical equipment

[SOURCE: IEC 60050-466:1990, 466-10-26, modified – "Conductor" has been replaced by "conductor(s)", "separate sections of an overhead line" has been replaced with "or more conductors or other electrical equipment".]

3.1.3 Return circuit

3.1.3.1
extended return circuit

part of the traction power supply circuit which leads the current back from the loads, such as vehicles or other equipment, to the source

Note 1 to entry: If contact is made between a live part and the return circuit, the circuit breaker should trip.

Note 2 to entry: The conductors can be

- running rails,
- return conductor rails,
- return conductors,
- return cables, or
- booster transformer return conductor.

3.1.3.2
return circuit

subset of the extended return circuit where the direct contact is permissible during both operational and fault conditions

Note 1 to entry: The earthed phase of a three-phase AC traction power supply system can be considered as a return circuit.

[SOURCE: IEC 60050-811:2017, 811-35-01, modified - Definition and Note 1 to entry have been completely changed.]

3.1.3.3
track return system

system in which the running rails of the track form a part of the return circuit for the traction current

[SOURCE: IEC 60050-811:2017, 811-35-02]

3.1.3.4
return conductor

conductor paralleling the track return system and connected to the running rails at periodic intervals

[SOURCE: IEC 60050-811:2017, 811-35-13]

3.1.3.5
return conductor rail

conductor rail used instead of the running rails for the traction return currents

[SOURCE: IEC 60050-811:2017, 811-34-10]

3.1.3.6
booster transformer return conductor
set of return conductors insulated from earth and necessary for the functionality of a booster transformer system

3.1.3.7
return cable
conductor connecting the running rails or other parts of the return circuit to the substation

[SOURCE: IEC 60050-811:2017, 811-35-04, modified – "return current rail" has been replaced with "other parts of the return circuit".]

3.1.3.8
traction return current
sum of the currents returning to the supply source, the substation or regenerative braking vehicles

Note 1 to entry: The traction return current can also include load fed from the traction systems, for example point heating, auxiliary supplies.

3.1.4 Electrical

3.1.4.1
nominal voltage
<of an electrical installation> value of the voltage by which the electrical installation or part of the electrical installation is designated and identified

Note 1 to entry: The voltage of the contact line may differ from the nominal voltage by a quantity within permitted tolerances given in IEC 60850.

[SOURCE: IEC 60050-826:2022, 826-11-01, modified – Note 1 to entry has been added.]

3.1.4.2
feeding section
electrical section of the route fed by individual track feeder circuit breakers within the area supplied by the substation

[SOURCE: IEC 60050-811:2017, 811-36-25, modified – The words "one or more substations" have been replaced with "the substation".]

3.1.4.3
functional-equipotential-bonding
equipotential bonding for operational reasons other than safety

[SOURCE: IEC 60050-195:2021, 195-01-16, modified – The word "operational" has been added, and the word "electrical" deleted.]

3.1.4.4
short-circuit
accidental or intentional conductive path between two or more conductive parts forcing the electric potential differences between these conductive parts to be equal to or close to zero

[SOURCE: IEC 60050-151:2001, 151-12-04]

3.1.4.5
rated current-carrying capacity
permanent maximum value of electric current which can be carried continuously by the overhead contact line within the system operating parameters

3.1.4.6

feeding point

point at which the feeding system is connected to the contact line

[SOURCE: IEC 60050-811:2017, 811-36-26]

3.1.4.7

electrical clearance

<of a contact line> minimum distance in air permitted between fixed structures and parts energized at contact line voltage

Note 1 to entry: The distance in air is used to provide functional insulation or basic insulation.

[SOURCE: IEC 60050-811:2017, 811-09-05, modified – In the specific use, "a contact line" has been replaced with "an electrical installation".]

3.1.4.8

electrification clearance gauge

contour which contains the various live parts of an overhead contact line, allowance being made for static electrical clearances, and from which all other fixed objects must be kept clear

[SOURCE: IEC 60050-811:2017, 811-09-04]

3.1.4.9

pantograph clearance gauge

contour beyond which must be placed any fixed structure above vehicle roof level, to allow any pantograph in use to pass safely, making allowance for lateral displacement of the pantograph and for passing electrical clearances

[SOURCE: IEC 60050-811:2017, 811-09-03]

3.1.5 Geometrical

3.1.5.1

tension length

length of overhead contact line between two terminating points

[SOURCE: IEC 60050-811:2017, 811-33-61]

3.1.5.2

gradient

<of the overhead contact line> ratio of the difference in height of the overhead contact line above top of rail (or road surface for overhead contact line system for trolleybus applications) at two successive supports to the length of the span

3.1.5.3

contact wire height

distance from the top of the rail level or road surface for trolleybus to the lower face of the contact wire

Note 1 to entry: The contact wire height is measured perpendicular to the track or road surface.

[SOURCE: IEC 60050-811:2017, 811-33-62]

3.1.5.4

minimum contact wire height

minimum possible contact wire height in the span in order to avoid flashover or contact between one or more contact wires and the vehicles in all conditions

[SOURCE: IEC 60050-811:2017, 811-33-64, modified – The definition has been completely modified in order to provide greater clarity about functional aspects.]

3.1.5.5

minimum design contact wire height

theoretical contact wire height including tolerances, designed to ensure that the minimum contact wire height is always respected

3.1.5.6

nominal contact wire height

nominal value of the contact wire height above rail (or road surface for overhead contact line system for trolleybus applications) at a support in the normal conditions

Note 1 to entry: The nominal contact wire height is used preferentially when there is no constraint on the contact wire height, and is the height to which it returns after being adjusted to accommodate a constraint (e.g. level crossing or overbridge, etc).

Note 2 to entry: For normal conditions, refer to 6.2.7.

[SOURCE: IEC 60050-811:2017, 811-33-63, modified – The words "above rail level" have been replaced with "above rail (or road surface for overhead contact line system for trolleybus applications)". Notes 1 and 2 to entry have been added.]

3.1.5.7

maximum contact wire height

maximum possible contact wire height above rail (or road surface for overhead contact line system for trolleybus applications) which the pantograph is required to reach, in all conditions

[SOURCE: IEC 60050-811:2017, 811-33-65, modified – The definition has been completely modified in order to provide greater clarity about functional aspects.]

3.1.5.8

maximum design contact wire height

theoretical contact wire height taking account of tolerances, movements, etc., designed to ensure the maximum contact wire height is not exceeded

3.1.5.9

contact wire uplift

vertical upward displacement of the contact wire due to the force produced from the pantograph

3.1.5.10

stagger

lateral displacement of the contact wire to opposite sides of the track centre at successive supports

Note 1 to entry: Stagger avoids localized wear of the pantograph contact strips.

[SOURCE: IEC 60050-811:2017, 811-33-21]

3.1.5.11
dewirement
movement of the contact wire laterally beyond the ends of the pantograph head

Note 1 to entry: There are different causes of dewirement, including vandalism and wind-blown objects on the overhead equipment. Moreover, dewirement is not the only cause of pantograph head and overhead contact line incidents. Other phenomena can lead to incidents, without exceeding dewirement limits.

Note 2 to entry: Under worst conditions, contact inside the limits of dewirement can occur without damages with catastrophic consequences. In these cases, the contact point can be located outside the working range of pantograph head with arcing and current interruption without causing dewirement.

3.1.5.12
point of incipient dewirement
point on the pantograph head where, due to uplift force and pantograph shape, a dewirement is inevitable if the contact wire reaches this point

Note 1 to entry: The point of dewirement is determined by the point where the gradient of the profile exceeds for example 40° in CEN/CENELEC countries. Until this point and with this gradient, experience indicates that the contact wire is able to return successfully into the working zone.

3.1.6 Structures

3.1.6.1
drag factor
aerodynamic drag factor
force coefficient
factor used to consider the shape of an object exposed to wind, the wind pressure being multiplied by this factor to determine the wind action

3.1.6.2
partial factor
factor to multiply characteristic loads to calculate design loads on the load side (load partial factor) of the equation for verifying adequate strength of components, or to divide the characteristic strength on the material side (material partial factor)

Note 1 to entry: The partial factors should replace the safety factors applied in design approaches used before.

Note 2 to entry: The partial factor for an action is a factor, taking into account the possibility of unfavorable deviations from the characteristic value of actions, inaccurate modeling and uncertainties in the assessment of the effects of actions.

Note 3 to entry: The partial factor for a material property is a factor covering unfavorable deviations from the characteristic value of material properties, inaccuracies in applied conversion factors and uncertainties in the geometric properties and the resistance model.

3.1.6.3
lattice structure
structure formed from a regular arrangement of connected joints and has a solidity ratio of 0,6 or less

Note 1 to entry: The solidity ratio is the ratio of total area of all individual members to envelope area.

3.1.6.4
superstructure
upward extension of an existing structure above ground level

Note 1 to entry: The term "superstructure" is applied to various kinds of physical structures, such as OCL poles, retaining walls and bridges.

3.1.6.5
midpoint anchor structure
structure at the midpoint of tension length of the overhead contact line fulfilling the function of a midpoint anchor

3.1.7 Foundations

3.1.7.1

gravity foundation

form of spread foundation formed by rectangular, square, or sometimes circular concrete "pads" that support localized single-point loads such as overhead contact line structures

Note 1 to entry: Gravity foundations are usually shallow foundations installed by excavation and backfilling.

3.1.7.2

pile foundation

long slender foundation installed without excavation

Note 1 to entry: The cross-section can be circular or non-circular and it is installed by boring, vibrating and/or hammering.

Note 2 to entry: The foundation is flexible enough to show both rotation and deformations in the pile element itself subjected to horizontal loading or overturning moments.

[SOURCE: IEC 60050-466:1990, 466-09-16, modified – Notes 1 and 2 to entry have been added.]

3.1.7.3

side bearing foundation

foundation normally consisting of a single block of concrete, into which the pole of an overhead contact line system structure or anchor bolts are embedded

Note 1 to entry: The surface area of the foundation provides the resistive force to counteract the overturn moments applied by the overhead contact line system.

3.1.8 Current collectors

3.1.8.1

current collector

equipment fitted to a vehicle and intended to collect current from a contact wire or conductor rail

[SOURCE: IEC 60050-811:2017, 811-32-01]

3.1.8.2

pantograph

apparatus for collecting current from one or more contact wires, formed of a hinged device designed to allow vertical movement of the pantograph head

[SOURCE: IEC 60050-811:2017, 811-32-02]

3.1.8.3

pantograph gauge

reference profile with its associated rules allowing verification that the pantograph head in a raised position remains within the allotted space

[SOURCE: EN 15273-1:2017, 3.23.1]

3.1.9 Current collection

3.1.9.1
static contact force
vertical force exerted upward by the collector head on the overhead contact line system at standstill

[SOURCE: IEC 62486:2017, 3.19, modified – “pantograph head” has been replaced with “collector head”. “, caused by the pantograph-raising device, whilst the pantograph is raised and the vehicle is stationary” has been replaced with “system at standstill”.]

3.1.9.2
contact loss
condition where the contact force is zero

Note 1 to entry: Contact loss surely induces arcing except in the case of coasting. However, if two or more pantographs are connected electrically each other, arc can disappear and then the condition will shift to current loss.

[SOURCE: IEC 62486:2017, 3.22, modified – In Note 1 to entry, "will immediately" was replaced by "can".]

3.1.9.3
current loss
condition where current flowing through a pantograph is zero under the condition of contact loss

Note 1 to entry: When a train is equipped with two or more pantographs electrically connected by a bus cable, necessary traction power can be supplied by other pantographs through the bus cable in case of contact loss. Therefore, current loss condition will generally not affect driving of the train.

[SOURCE: IEC 62486:2017, 3.23]

3.1.9.4
arcing
flow of current through an air gap between a contact strip and a contact wire or in case of contact force close to zero, usually indicated by the emission of intense light

[SOURCE: IEC 62486:2017, 3.1, modified – “or in case of contact force close to zero” added.]

3.1.10 Testing

3.1.10.1
sampling test
test on a sample

[SOURCE: IEC 60050-151:2001, 151-16-20]

3.1.10.2
type test
conformity test made on one or more items representative of the production

[SOURCE: IEC 60050-151:2001, 151-16-16]

3.1.10.3
routine test
conformity test made on each individual item during or after manufacture

[SOURCE: IEC 60050-151:2001, 151-16-17]

3.1.11 Miscellaneous

3.1.11.1
regulation
document providing binding legislative rules, which is adopted by an authority

[SOURCE: IEC 60050-901:2013, 901-02-10]

3.2 Symbols

A	local orography coefficient/altitude
A_ins	projected area of an insulator
A_K	characteristic value of accidental actions
A_lat	effective area of the elements of a lattice structure
A_str	projected area of a structure
a	length of conductor between specimen and centre of potential point; $a \cong 15d$
a_mp	amplitude
a_P	length of specimen
a_v	length of comparison conductor between centres of potential points; $a_\mathrm{v} \cong 30\ d + a$
b	length of potential points; $b \leq 2d$
C	compression amplitude for dropper test
C_C	drag factor of a conductor
c_f	force coefficient
C_ins	drag factor for insulators
C_lat	drag factor for lattice structures
C_str	drag factor of a structure
D	diameter of conductor
d_cant	lateral deviation of contact wire position by vertical uplift at tracks with cant
d_instl	tolerance of installation of lateral deviation of contact wire
d_instv	tolerance of installation of vertical deviation of contact
d_mess	tolerance of measurement, measuring errors refer to horizontal position of contact wire
d_pole	lateral deviation of contact wire position issued on change of pole deflection under additional load due to wind speed for serviceability in nominal contact wire height d_supp lateral deviation of contact wire position issued on movement of cantilever for change wire temperature
d_tens	lateral deviation of contact wire position issued on reduced tension force of wires considering efficiency and tolerances of tension equipment, friction in cantilevers and resetting forces (cantilever drag) due to movement of cantilever for change wire temperature
e	elasticity of the overhead contact line
E_d	total design value of actions
EC_s	static electrical clearance between live parts and earth
EC_d	dynamic electrical clearance between live parts and earth
F_Bmin	minimum breaking load of stranded conductors and ropes

F_{d}	design value of an action
F_{K}	characteristic value of an action
F_{L}	internal force for dropper test
F_{max}	maximum or failure force for test specimens
F_{nom}	nominal force
$F_{\mathrm{perm.op.}}$	permissible operating force
F_{w}	permissible tensile loading of stranded conductors and ropes
G_{C}	structural response factor for conductors
G_{ins}	structural resonance factor for insulator sets
G_{K}	characteristic value of permanent actions
G_{lat}	structural resonance factor for lattice structures
G_{q}	gust response factor
G_{str}	structural resonance factor for a structure
G_{t}	terrain factor
g_{IK}	specific characteristic ice loads
K_{clamp}	factor for termination fitting
K_{eff}	factor to the efficiency and accuracy of the tensioning device
K_{ice}	ice load factor
K_{icewind}	ice and wind load factor
K_{joint}	load factor for the effects of joints
K_{load}	factor for vertical loads acting on the catenary wire
K_{radius}	minimum bending radius factor
KRP	kinematic reference profile height
K_{wear}	allowable wear factor
K_{wind}	wind load factor
K_{x}	constant factors used to determine permissible tensile stress
l_1	minimum length between specimen and clamping piece and between specimens as per Table 20
l_2	minimum length of comparison conductor as per Table 20
L_1 / L_2	lengths of two adjacent spans
M_{dyy}, M_{dzz}	design bending moments
N	safety factor for calculating the permissible loading in wires
n_{cat}	number of catenary wires
n_{cont}	number of contact wires
T_{cat}	catenary wire tension, characteristic
T_{cont}	contact wire tension, characteristic
P_{prim}	externally applied heat
Q_{CK}	conductor tensile forces depending on the temperatures and climate related loads

Q_{IK}	characteristic ice load
Q_{K}	characteristic value of variable actions
Q_{PK}	characteristic value of construction and maintenance loads
Q_{W}	wind load
Q_{WC}	wind load on conductors
Q_{Wt}	wind load on lattice structures
Q_{Wstr}	wind load on structures
Q_{Wins}	wind load on insulators
$q_{\mathrm{p}}(z)$	peak velocity pressure
R_{dyy}, R_{dzz}	design bending resistances
R_{k}	characteristic value of the foundation ultimate resistance
$R_{\mathrm{p\ 0,2\ min}}$	0,2 % yield point
SRP	static reference profile height
u	degree of non-uniformity/variation in elasticity
U_{n}	nominal voltage
U_{Ni}	rated impulse voltage
V_{c}	wave propagation velocity of the contact wire
V_{R}	reference wind velocity
v_{w}	wind speed
X_{d}	design value of a material property
X_{K}	characteristic value of a material property
α	heat transmission coefficient
Φ	angle of incidence of the critical wind direction
γ_{A}	partial factor for accidental loads
γ_{C}	partial factor for conductor tensile forces
γ_{CG}	partial factor for permanent conductor tensile forces
γ_{CV}	partial factor for variable conductor tensile forces
γ_{E}	partial factor for actions
γ_{G}	partial factor for permanent actions
γ_{I}	partial factor for ice loads
γ_{M}	partial factor for a material property
γ_{P}	partial factor for construction and maintenance loads
γ_{W}	partial factor for wind loads
μ_{tot}	coefficient of friction for bolt connections
P	density of air
ρ_{I}	unit weight force of ice
σ_{min}	minimum failing tensile stress of the contact wire
σ_{w}	maximum permissible working tensile stress of a contact wire

Σz	sum of working tensile loads of contact wire(s)
Σm	sum of linear masses of the contact wire(s)
$\sum T_{\text{OCL}}$	total of all tolerance of the overhead contact line (IEC 62486)
Δh_{Rv}	vertical superelevation

3.3 Abbreviated terms

AC	alternating current
AACSR	aluminium alloy conductor steel reinforced
ACSR	aluminium conductor steel reinforced
ADD	automatic dropping device
DC	direct current
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ETA	European technical assessment
FOCL	flexible overhead contact line
OCL	overhead contact line
OCLS	overhead contact line system
OV	overvoltage
RAMS	reliability, availability, maintainability and safety
RMS	root mean square
ROCL	rigid overhead contact line
RTS	rated tensile strength

4 Fundamental design data

4.1 General

The function of an overhead contact line system is not only to transmit energy from fixed installations, like substations to the vehicle, but also from vehicles back to substations and auxiliary consumers using regenerative braking. In order to fulfil this function, the principal features of the contact line system shall be designed in accordance with the requirements set out in Clause 4. In particular, the integration of the overhead contact line design with the corresponding features of other interconnected systems, for example the power supply system and the traction system, shall ensure compatibility with the interconnected systems.

The requirements for overhead contact lines shall also apply to poles that are erected in connection with the overhead contact line system and used for line feeders.

The current collection system is a combination of overhead contact line and pantograph equipment, and the quality of the current collection system depends on the characteristics of both. Both sets of equipment shall be designed to appropriately fulfil their tasks. The design shall take cognisance of the compatibility between each other.

The data listed in 4.2 to 4.7 are normally specified by the purchaser.

4.2 Line characteristics

The train service characteristics and operational requirements to be considered in the design shall include:

- the speed and performance capability of the train or traction units powered from the contact line,

- the future performance capability to be anticipated and allowed for in the design, including any allowances for over speeding and increasing of mechanical and electrical load,
- the type and frequency of electrically hauled trains,
- the line speed for all tracks,
- the track gradient profile and location of the route, including turnouts and transitions,
- the type of turnouts, and
- the track gauge.

4.3 Electrical power system design

The overhead contact line system design shall be compatible with the electrical characteristics of the power supply system design, including the following:

- voltage range and frequency range and their limit values, in accordance with IEC 60850, corresponding to the nominal system voltage;
- mean useful voltage at the pantograph for the zone and train in accordance with IEC 62313;
- short-circuit current details, in accordance with IEC 62313;
- short circuit duration, in accordance with the protection design documented in accordance with IEC 63438; where the protection system employs backup protection, for example, as the method of protection reliability, the protection operating time shall be that of the backup protection;
- required current rating and the corresponding parameters (continuous, fault and short circuit condition);
- required impedance limit values (AC) or resistance limit values (DC), for reasons such as respecting voltage limitations and profile at pantographs, ensuring correct electrical protection system performance, and respecting the effective touch voltage limit values to comply with safety limits;
- proposed feeding system;
- proposed return system;
- earthing and stray current protection in accordance with IEC 62128-1 and IEC 62128-2;
- requirements to mitigate EMI and facilitate EMC in accordance with IEC 62236-2;
- when relevant, requirements for overvoltage protection, in accordance with IEC 62497-2;
- insulation coordination in accordance with the IEC 62497 series.

For urban rail systems, the short-circuit current details are not required.

4.4 Vehicle characteristics

The overhead contact line system design shall provide clearances for all vehicle types to be used on the line. In particular, the following shall be determined:

a) static and kinematic reference profile as well as any national or international requirements for structural clearances;
b) number of pantographs in service, their spacing, and whether they are electrically linked or independent.

4.5 Current collectors

The characteristics of the current collectors to be used on the line shall be determined. These characteristics include:

a) current collector head width, length and profile as defined in IEC 60494-1 and IEC 60494-2;
b) number of contact strips, the type of material and the spacing;
c) static contact force of current collector, depending on its working height;

d) details of the lateral movement of the current collector head;
e) maximum load current of the collector head when the vehicle is at standstill;
f) mean contact force at maximum line speed;
g) working width of the current collector head;
h) working range and housed height;
i) controlled height positions for current collectors with height limiting device;
j) mathematical model of dynamic characteristics;
k) inclination of current collector head;
l) number, position on the train and separation of current collectors that may be used simultaneously;
m) ADD, whether fitted, and its type (damaged carbons or overheight, or both).

For interoperable lines, the characteristics set out in IEC 62486 shall be used.

4.6 Environmental conditions

The overhead contact line system shall be designed according to the environmental characteristics selected from the conditions and classes set out in IEC 62498-2.

4.7 Design life

The purchaser may state the required design life of the system. Consumable components such as contact wire are not included in the design life of the system. Specific requirements for the design life of these components may also be specified by the purchaser.

5 System requirements

5.1 Design of electrical system

5.1.1 General

The overhead contact line system shall be designed based on the characteristics defined in 4.2 and 4.3. The design shall take into account the return circuit system, feeder connections and short-circuit.

Overhead contact lines should normally be electrically separated into sections and sub-sections by use of insulators, sectioning devices, insulated overlaps, neutral sections, etc. This provides operational flexibility for maintenance, emergency repair, planned directional operation, railway tunnel safety and neutral section.

The electrical characteristics and ratings relating to insulation coordination for the overhead contact line system, its products, assemblies, components, and its interfaces with other systems should be determined in accordance with the requirements set out in IEC 62497-1:2010, 8.4.1.3. In accordance with 5.1, 5.1.3 provides clearance dimensions for values of impulse voltages (U_{Ni}) of 95 kV and above.

Functional-equipotential-bonding shall be provided across mechanical bearings within the overhead contact line system where the efficiency of mechanical bearings would otherwise be adversely affected by the flow of load current or fault current.

5.1.2 Temperature rise in conductors

The overhead contact line system, including return circuit and feeder connections, shall be designed based on the electrical load defined by the system design under environmental operating conditions for the relevant classes defined in IEC 62498-2.

The overhead contact line shall be designed for the full temperature range taking in account the specified minimum environmental temperature and the maximum temperature rise in the conductors. For this temperature range, the proper work of tensioning devices and hinged cantilever is required. Furthermore, the minimum electrical clearances and all functional requirements have to be respected in any case.

The maximum temperature rise in the conductors, due to load or short-circuit currents, should not lead to conductor temperatures above the values given in Table 1. See also 7.3 and 7.4.

The temperature rise affects the mechanical and dimensional allowances to be made for the maximum expansion of the conductor system, and geometrical allowances for electrical clearance and contact wire height.

The design shall accommodate the maximum load current of the current collector when the vehicle is at standstill.

The temperatures above which the mechanical properties might be impaired are given in Table 1 for material compositions of tensile stressed conductors used in contact line systems.

Table 1 – Temperature limits for material mechanical properties

Material	**Temperature**		
	°C		
	Up to 1 s short-circuit current	**Up to 30 min (e.g. pantograph standstill) [a]**	**Permanent (e.g. operating condition)**
Normal and high strength copper with high conductivity	170	120	80
Silver copper alloy	200	150	100
Tin copper alloys (0,1 to 0,4)	200	150	100
Magnesium copper alloys (0,1 to 0,7)	200	150	100
Aluminium alloys	130	-	80
ACSR/AACSR	160	-	80

[a] These values are applicable for exceptional operational cases and should not happen too often in the same position.

NOTE 1 For novel products it can be necessary to reduce the limits until sufficient operational experience has been gained.

For temperatures higher than those in Table 1, the possible reduction in conductor strength according to the duration of the raised temperature should be checked and, if necessary, the dimensions of the conductor shall be increased and/or the working load shall be reduced.

NOTE 2 There have been long satisfactory experiences in Japan that the highest permanent temperature of pure copper, aluminium and ACSR wires for catenary wires and feeder wires is 100 °C.

When calculating the temperature rise in a conductor, the following contributions should be considered:

- heating caused by the current and its duration;
- heating caused by the environmental conditions, for example ambient temperature and solar radiation;
- radiant heat emitted from the conductor;
- heat lost from the conductor by convection depending on the wind speed and direction.

NOTE 3 A wind speed of 1 m/s is often used for this calculation as per IEC 62498-2:2010, category SW 2.

The values of the environmental parameters (ambient temperature, wind speed and temperature rise caused by solar gain) shall be given in the purchaser specification.

The temperature of the contact wire at the interface with the contact strips shall not exceed the appropriate value given in Table 1. Nominally, the "up to 30 min" value should be used for when assessing pantographs at standstill; however, in some cases, it may be appropriate to use the "permanent" value.

For longer than 30 min pantograph standstill and also for pantograph standstill repeatedly at the same place, the temperature limits for permanent operational conditions shall be used.

The rated current-carrying capacity of the overhead contact line based on the permanent rated current-carrying capacity of their conductors and the current distribution in these conductors should be calculated and provided by the power supply system design for the adjustment in the protection relays.

5.1.3 Clearances between live parts of contact lines and earth

The air clearances between the live parts of the overhead contact line system or pantograph head and earthed parts of the fixed installations, and those of vehicles, shall be defined to achieve acceptable availability of service and to limit damage to these assets. The safety clearances identified in IEC 62128-1 shall apply for protective provision against direct contact.

NOTE For the purpose of 5.1.3, "earth" in the context of DC includes equipment connected to the traction return system as well as parts in contact with earth.

For technical and economic reasons, typical air clearances between earth and the live parts of the overhead contact line system are stated in Table 2. These values are based on operational experience and have provided a proven acceptable level of performance and reliability.

The clearance values given in Table 2 may be reduced or increased depending on various parameters, for example highest permanent voltage, transient voltage conditions, switching and thunderstorm conditions, overvoltage protection, absolute humidity, the ambient temperature range, air pressure, pollution, relative air density, measures to avoid short circuits with birds, shape and material for both energised and earthed structures (refer to IEC 62498-2 and IEC 62497-1). Each case, however, shall be considered individually.

In areas where overvoltage can occur very often due to lightning or where reduced air clearances occur, surge arrestors, supplementary insulation or other means may be used in accordance with IEC 62497-1, if the electrical clearances to earthed structures are not sufficient.

The following provides an example of reduced clearances by the application of surge arresters:

– for overhead contact line systems with nominal voltage U_{n} = 25 kV (overvoltage category OV4, impulse voltage U_{ni} = 200 kV from IEC 62497-1:2010 and IEC 62497-1:2010/AMD1:2013, Table A.2) according to Table 2, the static clearance is given as EC_{s} = 270 mm and dynamic clearance as EC_{d} = 150 mm;

– in the same case, the prospective overvoltage at a bridge or structure can be reduced by fitment of a surge arrester with a lower impulse value than the U_{Ni} 200 kV rating for OV4. Fitment of a surge arrester with a $U_{\mathrm{10\ kA}}$ rating of ≤ 90 kV allows the effective clearance to be aligned with that applicable to 15 kV systems, namely a static clearance of 150 mm and a dynamic clearance of 100 mm (OV4 impulse voltage U_{Ni} = 125 kV).

The clearance values given in Table 2 should also be applied for clearances between adjacent live parts of contact line systems for different electrical sections of the same voltage and phase.

Table 2 – Typical electrical clearances

Nominal voltage	Typical clearances mm	
	Static (EC_s)	Dynamic (EC_d)
DC 600 V (720 V) [a]	100	50
DC 750 V (900 V)	100	50
DC 1,5 kV (1,8 kV)	100	50
DC 3,0 kV (3,6 kV)	150	50
AC 15 kV (17,25 kV)	150	100
AC 20 kV (24 kV)	250	150
AC 25 kV (27,5 kV)	270	150
AC 25 kV (30 kV)	300	150

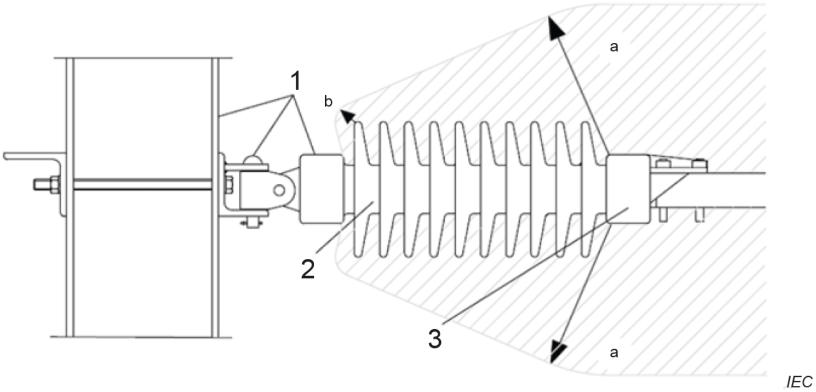
Values in brackets are the highest permanent voltages in accordance to IEC 60850.

[a] Only for existing systems.

The value for the static case is a value to be applied to the electrification clearance gauge as a minimum air clearance between the live parts of an overhead contact line to fixed objects. The value for the dynamic case is a value to be applied to a temporary case, for example the pantograph clearance gauge or the live parts of an overhead contact line during uplift by pantographs or the designed wind speed flow.

Different clearances for "static" and "dynamic" cases are justifiable by probabilistic determinations taking in account duration. For example, it is improbable that an overvoltage surge will occur at the same moment when a pantograph passes a narrow part of a tunnel. For this "dynamic" or temporary case, the use of a dynamic clearance, also called "passing" clearance, is justified. A usual train stop at a railway line, for example in a station, can be considered as a temporary case due to the limited duration. It is almost improbable that a train stops with the pantograph at the closed point to a fixed earthed structure with the dynamic clearance between and at the same moment an overvoltage surge will occur. For this temporary case, the pantograph clearance gauge with the dynamical (passing) clearances may be applied also.

Electrical clearances in air for insulators may be designed and measured according to Figure 2. The measurement approach in Figure 2 shall not be used for safety clearances. For safety clearances, the approach set out in IEC 62128-1 shall apply.



Key

1 earthed equipment

2 insulator sheds

3 live equipment

a value of static clearance (EC_s) given in Table 2

b 10 mm

Figure 2 – Static electrical clearance in air between live parts of an insulator and earthed equipment

For section insulators, it is allowed to reduce the static values of typical clearance in Table 2 for dynamic performance of the pantograph and overhead contact line system, where necessary and where the intended operation and maintenance regime is compatible. The reduced static values for section insulators shall not be less than the dynamic clearances in Table 2.

Higher minimum values for section insulators may be specified by national rules and regulations.

For urban rail systems, static values for section insulators shall not be less than

– 25 mm for 750 V, and
– 35 mm for 1,5 kV.

The primary function of section insulators is to provide operational sectioning of the overhead contact line system. To meet this functionality, the required electrical performance characteristic is to maintain integrity during switching and shall provide a minimum rated impulse voltage at least equal to the switching impulse voltage ($U_{90\text{re}}$). The electrical performance characteristics of section insulators for other functions can be subject to compliance with national rules and regulations.

5.1.4 Clearances between adjacent live AC contact lines of differing voltage phases

For an overhead contact line system, there may be a phase difference between different parts of the system, resulting in a phase-to-phase voltage higher than the nominal voltage. For 15 kV and 25 kV autotransformer systems, there is a phase difference of 180° between all live parts connected to the line feeder and all live parts connected to the overhead contact line.

For single phase AC systems, the phase difference between 90° and 180° at neutral section locations results in a similar effect.

Table 3 provides recommendations for the air clearance which should be achieved between live parts of an AC contact line system of differing phases.

Table 3 – Typical clearances between adjacent live AC contact line systems of differing voltage phase

Nominal voltage kV	Phase difference degrees	Highest permanent RMS voltage between phases kV	Recommended minimum clearance	
			Static (EC_s) mm	Dynamic (EC_d) mm
15 (17,25)	120	26	260	175
15 (17,25)	180	30	300	200
20 (24)	90	28,2	300	200
20 (24)	120	34,6	300	200
25 (27,5)	120	43,3	400	230
25 (27,5)	180	50	540	300
25 (30)	90	35,3	500	350
25 (30)	120	43,3	500	350
Values in brackets are highest permanent voltage in accordance with IEC 60850.				

When a pantograph passes the overlap of a phase separation section, a phase to phase voltage acts between both contact lines for a short period. Therefore, the clearances between both contact lines shall be selected in accordance with the dynamic clearances set out in Table 3. These clearances shall be maintained at all times.

5.2 Design of overhead contact line for current collection systems

5.2.1 General

The design of both the overhead contact line system and used pantographs shall take into account the required line speed.

The performance of the overhead contact line, when interacting with a pantograph, shall be assessed in static and dynamic conditions. For new types of OCL or new types of pantographs, dynamic behaviour shall be predicted in the design phase by computer simulations. These simulations shall later on be verified on the installed overhead contact line system with measurements. For existing OCL and pantograph designs which have already been used in operation, at least measurements shall be performed to confirm design and installation quality. For overhead contact lines with line speeds of up to 100 km/h, computer simulations and measurements at line speed need not to be performed.

The simulation programs shall be validated in accordance with IEC 63453 and the measurements shall be undertaken in accordance with IEC 62846.

The assessment of the overhead contact line shall take into account trains with multiple pantographs, and the performance of each pantograph both separately and with the pantographs used collectively shall be assessed.

Technical criteria for the interaction between pantograph and overhead contact line to achieve free access to rail infrastructure are given in IEC 62486:2017, Clause 7.

5.2.2 Elasticity and its variation

The overhead contact line should be designed in such a way that there is a small variation, u, of the elasticity, e. The elasticity e, expressed in millimetres by Newton (mm/N), is the uplift divided by the force measured at the contact wire. In every span, there is a maximum and a minimum elasticity. The elasticity values are static values. These values describe the variation u:

$$u = \frac{e_{\text{max}} - e_{\text{min}}}{e_{\text{max}} + e_{\text{min}}} \times 100 \quad [\%] \tag{1}$$

NOTE 1 The value u is also named "degree of non-uniformity".

NOTE 2 Low values of elasticity do not always give a small variation.

The elasticity and its variation depend upon the configuration of the overhead contact line. For the overhead contact system, the following main factors shall be taken into account:

- for FOCL: number, mass and tension of contact and catenary wires, system height, use of stitch wires, type, number and position of droppers;
- for ROCL: mass, profile and type of their fixation;
- for both: span length, type of support (e.g. cantilever type) and registration;

Elasticity and variation may be specified by the purchaser.

The elasticity should normally be calculated and measured with a value of force equal to either the mean contact force at maximum speed or double the static contact force. Information about reasonable values is given in the informative Annex F.

5.2.3 Vertical movement of contact point

The contact point is the point of the mechanical contact between a collector head's contact strip and a contact wire.

The overhead contact line shall be designed in such a way that the vertical height of the contact point above the track is as uniform as possible along the span length; this is essential for high-quality current collection.

The maximum permissible difference between the highest and the lowest dynamic contact point height within one span shall be in accordance with the limit set out in the purchaser specification.

This shall be verified by measurements or simulations. The verification shall include the maximum line speed allowed by the overhead contact line, considering the mean contact force.

This does not need to be verified for overlap spans or for spans over turnouts and crossings.

5.2.4 Calculated wave propagation velocity

Waves caused by pantograph forces on the tensioned contact wire(s) have a propagation velocity. The flexible overhead contact line can be designed to limit the maximum operational speed to less than 70 % of the wave propagation velocity, V_{c} of the contact wire.

$$V_\mathrm{c} = \sqrt{\frac{\sum z}{\sum m}} \quad [\mathrm{m/s}] \qquad (2)$$

where

V_c is the wave propagation velocity of the contact wire, expressed in m/s;

$\sum z$ is the sum of the working tensile loads of contact wire(s), expressed in N;

$\sum m$ is the sum of the linear mass of the contact wire(s), expressed in kg/m.

5.2.5 Quality of current collection

5.2.5.1 General

Overhead contact lines and pantographs shall be designed and installed to ensure acceptable current collection performance at all operating speeds and whilst at standstill.

The life cycle of the contact strips and contact wires essentially depends on the following:

- dynamic behaviour of the overhead contact line and the pantograph;
- current flow across the interface between contact strips and contact wire;
- contact areas and the number of contact strips;
- material of contact strips and contact elements of the overhead contact line;
- speed of the train, the number of pantographs in operation and the distances between them;
- environmental conditions;
- geometry of the contact line;
- elasticity and their uniformity;
- contact wire tensile load;
- pantograph design and contact force.

5.2.5.2 Contact forces

The overhead contact line system shall be designed to withstand the maximum permissible contact forces between the pantograph and the overhead contact line. The aerodynamic effects which occur at the maximum permissible speed of the vehicle shall be taken into account.

The overhead contact line system shall be designed to minimize contact loss between the pantograph and the overhead contact line.

NOTE 1 Contact loss can occur during testing and operation caused by the statistical behaviour of the interaction and external factors, for example track quality, vehicle suspension, etc.

In the case of using multiple pantographs connected by bus line, it is allowed to have the short-term contact loss. Assessment of conformity shall be decided between purchaser and supplier.

Contact force values vary with different combinations of pantographs and overhead contact line systems. The simulated or measured instantaneous values of contact forces are usually below the value of the mean force (F_m) plus three standard deviations (3σ). Higher values may occur at particular locations; however, they shall not exceed the maximum contact force limit value given in Table 4.

NOTE 2 $F_\mathrm{m} \pm 3\,\sigma$ represents 99,73 % of values for a normal distribution of force.

Where force values are not a normal distribution, i.e. ROCL, then at least 99,73 % of the resulting values shall be within the range defined in Table 4.

The minimum contact force values in Table 4 are limits that shall be applied in the statistical analysis of both simulations in accordance with IEC 63453 and testing in accordance with IEC 62846. The evaluation of the results shall be undertaken using a representative section of the overhead contact line, including overlap.

During simulations and testing, it may be accepted that instantaneous contact loss occurs, but this contact loss should be random. See 5.2.5.3 for details of measurement of contact loss.

Where contact forces are used to define the current collection quality, the mean value and standard deviation of contact force shall be the main assessment criteria. When assessing the dynamic behaviour and current collection quality, the limits for mean contact force (F_{m}) and maximum standard deviation (σ_{max}) that shall be applied are defined in IEC 62486.

Table 4 – Contact force limits

System	**Speed**	**Contact force limits**	
		Maximum	**Minimum (statistical)**
	km/h	N	N
AC	≤ 200	300[a]	> 0
AC	200 < V ≤ 320	350	> 0
AC	> 320	400	> 0
DC	≤ 200	300[a]	> 0
DC	> 200	400	> 0

[a] 350 N for short single rigid components, such as section insulators, or transition between FOCL and ROCL systems in overhead contact line systems up to 200 km/h.

For urban rail systems, the static contact force is recommended to be at least 60 N. If lower values are used, it should be demonstrated, that the dynamic behaviour of current collection is acceptable and the temperature limits for the contact wire according to Table 1 are followed. For trolleybus systems, the static force values are specified in 5.13.5.

Additional requirements for contact forces for interoperable lines are given in IEC 62486.

5.2.5.3 Contact loss

A high quality of current collection is achieved through continuous mechanical contact between the contact wire and contact strip. Contact loss leads to arcs that may cause many negative effects such as shortening of the lives of contact strips or contact wires by increasing wear, faults due to melting of components and inadmissible acoustic and electrical noises.

Where contact loss is used to define the current collection quality, the frequency and duration of arcing shall be the criteria for the current collection quality. Where these criteria are used, parameters and conditions of tests shall be selected in accordance with IEC 62846. This is applicable in case of using multiple pantographs connected by bus line also.

Additional requirements for interoperable lines are given in IEC 62486.

5.2.6 Fatigue of contact wire

When pantograph slides on contact wire, bending stress grows in the wire. As train speed becomes higher and more pantographs passing by, bending stress would be larger, and life of the wire by fatigue in special cases can become shorter than the life of wear. In flexible overhead contact line design, consideration can be given to the bending stress of contact wire.

NOTE Test procedures are described in IEC 62846:2016, Annex B.

5.3 Mechanical design of contact wire loads

5.3.1 Permissible tensile stress σ_w

The maximum permissible working tensile stress σ_w of a contact wire depends on the parameters defined in 5.3.2 to 5.3.8. All of these parameters shall be weighted with an individual factor. The minimum tensile failing stress σ_min of the contact wire shall be multiplied by the product of these factors and a safety factor n not greater than 0,65 to get the maximum permissible working tensile stress.

The values in Table 5 may be interpolated.

The maximum permissible working tensile stress to be applied to unworn contact wire shall be determined using Formula (3):

$$\sigma_\mathrm{w} = \sigma_\mathrm{min} \times n \times K_\mathrm{temp} \times K_\mathrm{wear} \times K_\mathrm{wind} \times K_\mathrm{ice} \times K_\mathrm{eff} \times K_\mathrm{clamp} \times K_\mathrm{joint} \ [\mathrm{N/m^2}] \qquad (3)$$

Formula (3) gives the minimum requirements which can be increased by national regulations.

5.3.2 Maximum temperature K_temp

The tensile strength and creep behaviour of contact wires depend on the maximum working temperature. The factor K_temp expresses the relationship between the permissible tensile stress and the maximum working temperature of a contact wire and shall be selected from the values given in Table 5.

Table 5 – Factor K_temp for contact wires

Contact wire material	K_temp	
	For max. temperature ≤ 80 °C	**For max. temperature ≤ 100 °C**
Cu	1,0	0,8
Cu-Ag 0,1	1,0	1,0
Cu-Sn (0,1 to 0,4)	1,0	1,0
Cu-Mg (0,1 to 0,7)	1,0	1,0

For new products, it should be considered to use lower values until sufficient operational experiences has been gained.

For maximum working temperatures above 100 °C, the reduction of conductor strength over the lifetime of the wire shall be determined by type tests. The factor K_temp shall be adjusted according to the residual strength of the wire shown in Table 5.

In addition to the requirements of the permitted tensile stress, consideration should also be given to the properties of the contact wire material with respect to resistance to creep. To achieve this resistance to creep, a lower permissible tensile stress and/or working temperature should be adopted.

5.3.3 Allowable wear K_{wear}

Provision shall be made for allowable wear by applying a factor appropriate to the permissible wear.

$$K_{\text{wear}} = 1 - x \tag{4}$$

where

x is the permissible wear expressed as a proportion of the total cross-sectional area.

5.3.4 Wind loads K_{wind}

The effect of wind load on maximum contact wire tensile strength depends on the design of overhead contact lines. The factor K_{wind} depends on the wind load and the type of the overhead contact line and provision shall made as set out in Table 6.

Table 6 – Factor K_{wind} for contact wires

Type of overhead contact line	K_{wind}
Contact and catenary wire automatically tensioned	1,00
Contact wire automatically tensioned and catenary wire fixed termination	0,95
Single contact wire automatically tensioned	0,95
Contact and catenary wire fixed termination	0,80

5.3.5 Ice loads K_{ice}

The effect of ice loads on maximum contact wire tensile strength depends on the design of overhead contact lines. The factor K_{ice} depends on the ice loads and the type of the overhead contact line and provision shall be made as set out in Table 7. In some tropical zone and temperate zone areas where ice does not appear on wires, K_{ice} may be 1,0 in any condition of Table 7.

Table 7 – Factor K_{ice} for contact wires

Type of overhead contact line	K_{ice}
Contact and catenary wire automatically tensioned	0,95
Contact wire automatically tensioned and catenary wire fixed termination	0,95
Single contact wire automatically tensioned	0,95
Contact and catenary wire fixed termination	0,88

5.3.6 Efficiency of tensioning devices K_{eff}

The efficiency and accuracy of tensioning devices is considered by the factor K_{eff}. When the tensioning device is installed in accordance with the supplier's instructions, K_{eff} shall be equal to the efficiency specified and proven by the supplier.

Where fixed terminations are used, K_{eff} shall be equal to 1,0.

5.3.7 Termination fittings K_{clamp}

The effect of termination fittings is considered by the factor K_{clamp} which shall be equal to 1,00 if the clamping force is equal to or greater than 95 % of the contact wire tensile strength. Otherwise, K_{clamp} shall be equal to the ratio of the clamping force to the tensile strength.

5.3.8 Joints K_{joint}

The effect of joints is considered by the factor K_{joint}This shall be equal to 1,00 if no joints are adopted or if the values of tensile strength and the percentage elongation after fracture at a joint area are in accordance with the specified values of the wire material. Otherwise, K_{joint} shall be equal to the ratio of the tensile strength of joints to the higher calculated rated tensile strength of contact wire. The minimum tensile strength of the joint shall be in accordance with IEC 62917.

5.4 Mechanical design of catenary wire loads

5.4.1 Permissible tensile loading F_{w}

The maximum permissible working tensile load of catenary wire depends on the parameters defined in 5.4.2 to 5.4.7. All of these parameters shall be weighted with an individual factor. The minimum breaking load F_{Bmin} of the catenary wire shall be multiplied by the product of these factors and a factor n not greater than 0,65 to get the maximum permissible working tensile load.

The maximum permissible working tensile load shall be determined using Formula (5):

$$F_{\text{w}} = F_{\text{Bmin}} \times n \times K_{\text{temp}} \times K_{\text{wind}} \times K_{\text{ice}} \times K_{\text{eff}} \times K_{\text{clamp}} \times K_{\text{load}} \ \text{[N]} \tag{5}$$

Formula (5) gives the minimum requirements which may be increased by national regulations.

5.4.2 Maximum temperature K_{temp}

The factor K_{temp} shall be selected from the values in Table 8. At higher working temperatures, the factor shall be reduced in accordance with the possible reduction in percent of the tensile strength.

Table 8 – Factor K_{temp} for stranded conductors

Examples of stranded wire material	K_{temp}	
	For max. temperature ≤ 80 °C	**For max. temperature ≤ 100 °C**
Cu [a]	1,0	0,8
Al-alloy	1,0	0,8
Cu Ag0,1 [b]	1,0	1,0
Cu-Sn (0,1 to 0,4) [b]	1,0	1,0
Cu-Mg (0,1 to 0,7) [b]	1,0	1,0
Steel	1,0	1,0
ACSR/AACSR	1,0	0,8

[a] C0 according IEC 63190.

[b] C1 to C7 according IEC 63190.

For new products, it should be considered to use lower values until sufficient operational experiences has been gained.

For maximum working temperatures above 100 °C, the reduction of conductor strength over the life of the wire shall be determined by type tests. The factor K_{temp} shall be adjusted according to the residual strength of the wire as shown in Table 8.

5.4.3 Wind loads K_{wind}

Wind load is defined by a factor K_{wind}. This factor shall be selected from Table 9 according to the corresponding wind velocity and type of termination.

Table 9 – Factor K_{wind} for stranded conductors

Type of termination	K_{wind}	
	Mean wind velocity ≤ 100 km/h (27,7 m/s)	**Mean wind velocity > 100 km/h (27,7 m/s)**
Automatically tensioned	1,00	0,95
Fixed termination	0,95	0,90

5.4.4 Ice loads K_{ice}

The effect of ice loads shall be considered when determining the maximum working load of the stranded wire. The factor K_{ice} depends on the type of termination and shall be selected from Table 10. In some tropical zone and temperate zone areas where ice does not appear on wires, K_{ice} may be 1,0 in any condition of Table 10.

Table 10 – Factor K_{ice} for stranded conductors

Type of termination	K_{ice}
Automatically tensioned	1,00
Fixed termination	0,95

5.4.5 Efficiency and accuracy of tensioning device K_{eff}

The efficiency and accuracy of the tensioning device is considered by the factor K_{eff}. When the tensioning device is installed in accordance with the supplier's instructions, K_{eff} is assumed to be equal to the efficiency specified and proven by the supplier.

Where fixed terminations are used, K_{eff} shall be equal to 1,0.

5.4.6 Termination fittings K_{clamp}

The effect of termination fittings is considered by the factor K_{clamp} which shall be equal to 1,00 if the clamping force is equal to or more than 95 % of the calculated rated tensile strength (RTS). Otherwise, K_{clamp} shall be equal to the ratio of the clamping force to RTS.

5.4.7 Additional vertical load K_{load}

The effect of vertical loads acting on catenaries is considered by the factor K_{load} equal to 0,8. For catenary wires without loads acting, the factor K_{load} shall be equal to 1,0.

Dropper loads are not included in consideration of the factor K_{load}.

5.5 Mechanical design of other stranded conductors

For stranded conductors other than catenary wires, the requirements of 5.4.1 to 5.4.7 shall only apply if the working load exceeds 40 % of the calculated breaking load of the stranded conductor.

For calculation of the working loads, the load cases according 6.3.1 should be considered.

5.6 Mechanical design of solid wires

Solid wires in overhead contact line systems other than contact wires shall not be loaded over 40 % of the minimum breaking load.

5.7 Mechanical design of ropes of non-conducting materials

5.7.1 General

Ropes formed from non-conducting materials may be used only up to their calculated working load. Particular attention shall be given to shearing loads, bending radii, termination arrangement and elongation. These requirements apply to ropes which are made from synthetic fibres and have an external synthetic sheath to protect the fibres. Refer to IEC 62724 for further details.

5.7.2 Permissible tensile loading F_{w}

The permissible tensile load of a rope shall be weighted with an individual factor (refer to 5.7.3 to 5.7.7). The minimum breaking load F_{Bmin} of the combined fibres shall be multiplied by the product of these factors and a factor n not greater than 0,45 to get the maximum permissible working tensile load.

The maximum permissible working tensile load shall be determined from Formula (6):

$$F_{\mathrm{w}} = F_{\mathrm{Bmin}} \times n \times K_{\mathrm{wind}} \times K_{\mathrm{ice}} \times K_{\mathrm{clamp}} \times K_{\mathrm{load}} \times K_{\mathrm{radius}} \ \text{[N]} \qquad (6)$$

Formula (6) gives the minimum requirements which can be increased by national regulations.

5.7.3 Wind loads K_{wind}

Wind load is defined by a factor K_{wind}. This factor shall be selected depending on the wind speed:

- K_{wind} = 1,00 for wind speed ≤ 100 km/h (27,7 m/s);
- K_{wind} = 0,90 for wind speed > 100 km/h (27,7 m/s).

5.7.4 Ice loads K_{ice}

The effects of ice loads shall be taken into consideration: K_{ice} = 0,95.

5.7.5 Termination clamps K_{clamp}

The effect of termination fittings shall be considered by the factor K_{clamp}:

- K_{clamp} = 1,00 for cone end termination fittings;
- K_{clamp} = 0,80 for other kinds.

5.7.6 Vertical loads K_{load}

The effect of vertical loading shall be considered using the factor K_{load}:

- K_{load} = 0,7 when vertical loads attached;
- K_{load} = 1,0 without loads attached.

NOTE Examples of vertical loads to be considered are direction indicators or feeding cables for traffic lights or for the overhead contact line.

5.7.7 Minimum bending radius K_{radius}

The effect of the radius on the ropes shall be considered by the factor K_{radius} according to Table 11.

Table 11 – Factor K_{radius} for ropes of non-conducting materials

Bending radius r	K_{radius}
m	
$r \geq 1$	1
$0,5 \leq r < 1$	0,9
$0,2 \leq r < 0,5$	0,8
$0,1 \leq r < 0,2$	0,7
$r < 0,1$	0,5

5.8 Suspension systems

Automatically tensioned equipment shall be suspended from supports which allow longitudinal movement. Fixed termination equipment may be supported from fixed supports. Where line speeds are greater than 120 km/h or where high operational currents demand it, an overhead contact line with a catenary suspension should be used for flexible overhead contact lines. When overhead contact rails are used, no catenary suspensions are necessary.

5.9 Tensioning device for flexible overhead contact lines

The tensions in the contact and catenary wires shall be maintained within the system design parameters. Automatic tensioning is recommended for all flexible overhead contact lines to decrease wear and tear.

Tensioning devices

- shall keep the designated tensile force of the wires included the flexible overhead contact line,
- shall absorb elongation of the wires, and
- should avoid further damage to the contact line system in case of wire breakage.

For speeds above 225 km/h, both catenary and contact wires should be automatically tensioned separately.

For automatically tensioned equipment, local tension in the overhead contact line can vary, due to the effect of along track movement of registration arms or cantilever frames. The maximum acceptable variation of tension in the overhead contact line shall be considered.

5.10 Geometry of overhead equipment

5.10.1 Lateral deviation of contact wire

Under defined environmental conditions and mechanical tolerances, the lateral deviation of the contact wire and the pantograph shall be such that it is sufficiently improbable for the contact wire to slide off the pantograph head unless specifically designed to do so at contact wire takeover points.

The definition of the permissible lateral deviation of the contact wire from track centre line should be based on checks against the working range of the pantograph head (serviceability) and against the limit of dewirement (limit of stability for lateral interaction) taking in account the point of incipient dewirement. The method of determining is described in IEC 62486 based on the interaction between pantograph and overhead contact line.

The lateral deviation of contact wire shall not exceed the permissible lateral deviation between two neighbouring support points under predefined environmental conditions. Therefore, the stagger at support points and the span lengths between two neighbouring support points of contact wire are specified in accordance with the installation design of overhead contact lines. Stagger shall be defined to minimize wear and heating of contact wire and pantograph strip. Additionally, the stagger shall achieve the required mechanical and electrical clearances.

The permissive limits of the lateral deviation of the contact wire on a line may be defined as a static value determined according to working ranges of pantographs on trains passing on the line and expected lateral deviation of the contact wires on the line.

The calculation for wind forces on conductors is described in 6.2.4.3. The requirements for determining span lengths are specified in 5.10.6.

For the definition of the permissible lateral deviation, it is necessary to determine the tolerances of all influencing variables. 5.10.5 provides the tolerances of the overhead contact line.

Mechanical and electrical clearances of conductors to other parts of the railway infrastructure, when subject to wind, shall similarly be verified through design or site measurement.

5.10.2 Uplift

The design uplift of the contact wire at the support, under normal operating conditions, shall be determined or evaluated by calculation, simulation or measurement. The space for free and unrestricted uplift of the contact wire at the support shall be a minimum of twice the design uplift. If restrictions to uplift of the contact wire are included in the design, a figure not lower than 1,5 shall be used.

The vertical upward movement of the contact wire in the span can be larger than the design uplift at the support and both the upward and downward movement of the contact wire should be calculated and checked.

5.10.3 Variation in contact wire height

If, due to local conditions, for example bridges, a variation in contact wire height is necessary, this shall be achieved with a gradient as small as possible. Design values for gradient and changes of gradient shall not exceed the values set out in Table 12 as a function of speed. For construction and operation, larger change of gradient than values shown in Table 12 is permitted. See 5.14.

Table 12 – Recommended maximum contact wire gradients for flexible contact lines

Speed up to	**Maximum gradient**		**Maximum change of gradient**	
km/h		‰		‰
10	1/17	60	1/33	30
30	1/25	40	1/50	20
50	1/40	25	1/40	25
60	1/50	20	1/100	10
100	1/167	6	1/333	3
120	1/250	4	1/500	2
160	1/300	3,3	1/600	1,7
200	1/500	2	1/1 000	1
250	1/1 000	1	1/2 000	0,5
> 250	0	0	0	0

NOTE 1 Due to reasons of the terrain characteristics, it is sometimes difficult to achieve 0 gradient, even in design phase, in order to avoid increasing cost of civil structures such as tunnels.

For construction and operation, different change of gradient than values shown in Table 12 is permitted. See 5.14.

NOTE 2 The gradient does not include the sag of the contact wire.

Where the values in Table 12 are not achievable, acceptable current collection quality can be assessed in accordance with IEC 62486. This shall be demonstrated either through testing in accordance with IEC 62846 or through simulation in accordance with IEC 63453.

For speeds that fall between the values in Table 12, the gradient and change of gradient can be calculated by linear interpolation.

The gradient and change in gradient for ROCL shall be specified by the manufacturer to meet the required current collection quality.

5.10.4 Contact wire height

5.10.4.1 General

Contact wire heights shall be determined in accordance with Figure 3 and 5.10.4.

The application of the tolerances in Figure 3 should be considered so as not to create an unrealistic case.

5.10.4.2 Minimum contact wire height

The minimum contact wire height shall always be greater than the height of the reference profile taking into consideration the electrical clearance in air and a vertical superelevation, to avoid arcing between the contact wire and the earthed parts of vehicles.

The minimum contact wire height shall also be greater than the minimum working height of the pantograph.

5.10.4.3 Minimum design contact wire height

The minimum design contact wire height shall be calculated by summation of all downwards movements of the contact wire and the minimum height. Consideration shall be given to

- vertical tolerance on the track position,
- downwards installation tolerance for the contact wire,
- downwards dynamic movements of the contact wire, and
- effects of ice load and temperature on the conductors.

The appropriate combination of tolerances shall be applied with respect to the static or dynamic cases

5.10.4.4 Nominal contact wire height

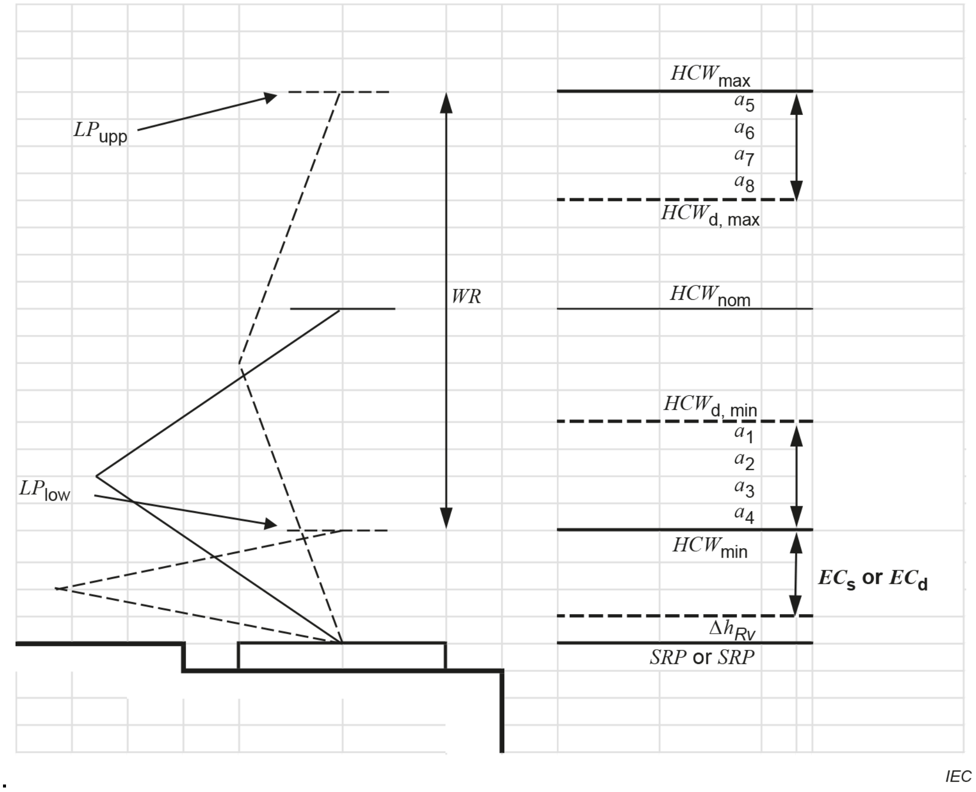
It is permissible to set the nominal height for an overhead contact line in the range between the minimum and the maximum design heights of the contact wire.

Specific requirements for contact wire heights for interoperable lines are given in IEC 62486.

5.10.4.5 Maximum design contact wire height

The maximum design contact wire height shall be obtained by deducting from the maximum working height of the pantograph the possible upwards movements of the contact wire. Consideration shall be given to the following:

- vertical tolerance of the track;
- uplift of the contact wire by the pantograph;
- upwards dynamic movement of the contact wire;
- upwards installation tolerance;
- uplift of the contact wire due to wear;
- uplift of the contact wire due to any effect of temperature changes in the conductors.



Key

LP_{upp}	upper operating position of pantograph or collector (see IEC 60494-1)
LP_{low}	lower operating position of pantograph or collector (see IEC 60494-1)
WR	working range of pantograph or collector (see IEC 60494-1)
KRP	kinematic reference profil height
SRP	static reference profile height
Δh_{Rv}	vertical superelevation
EC	electrical clearances
HCW_{min}	minimum contact wire height
HCW_{max}	maximum contact wire height
$HCW_{\text{d,min}}$	minimum design contact wire height
$HCW_{\text{d,max}}$	maximum design contact wire height
HCW_{nom}	nominal contact wire height
a_1	vertical tolerance of the track (if not included in envelope / gauge)
a_2	downwards installation tolerance for the contact wire
a_3	downwards dynamic movements of the contact wire
a_4	effects of ice load and temperature on conductors
a_5	vertical tolerance of the track
a_6	uplift of the contact wire by the pantograph and dynamic movement of the contact wire
a_7	upwards installation tolerance for the contact wire
a_8	uplift of the contact wire due to wear and any temperature changes in the conductors

Figure 3 – Relationship between contact wire heights and pantograph operating position

NOTE For example, for the calculation of the swept envelope, refer to EN 15273-1 for CEN/CENELEC countries.

5.10.5 Tolerances of lateral contact wire position

The total of all tolerances of the overhead contact line, $\sum T_{\mathrm{OCL}}$, shall be considered for determining the limit of dewirement in accordance with IEC 62486:

– d_{cant}	lateral deviation of contact wire position by vertical uplift at tracks with cant;
– d_{instl}	tolerance of static lateral position of contact wire;
– d_{instv}	tolerance of static vertical position of contact wire;
– d_{mess}	tolerance of measurement, measuring errors refer to horizontal position of contact wire;
– d_{pole}	lateral deviation of contact wire position issued on change of pole deflection under additional load due to wind speed for serviceability at nominal contact wire height;
– d_{supp}	lateral deviation of contact wire position issued on movement of cantilever for changed wire temperature;
– d_{tens}	lateral deviation of contact wire position issued on reduced tension force of wires considering efficiency and tolerances of tension devices.

National requirements and conditions can apply to values of the above listed tolerances.

5.10.6 Span length

The span length influences the interaction between pantograph and overhead contact line.

The span length between consecutive support points is determined by track curvature, permissible lateral deviation, wind loads and system parameters, for example contact line tension and maximum permissible stagger.

Assessment of the wind load on individual conductors shall be in accordance with the serviceability requirements detailed in Clause 6; national conditions can apply. At higher ice load classes, the combined action of wind and ice load shall be taken into account.

For calculation of deflection of the contact wire, wind loads shall be applied to the contact and catenary wires. When designing a fully optimized system, the wind loads of dropper wires and clamps shall be taken into account.

The interaction between contact and catenary wires shall be considered for inclined overhead contact lines, particular for the effects of wind.

When designing span lengths, consideration should be given to the maximum allowable difference in length between two successive spans. This is to avoid excessive forces on the overhead contact line system and to maintain acceptable dynamic behaviour. This is a particular issue in areas of reduced encumbrance and for turnouts and crossings.

NOTE In areas that experience issues with resonance in the overhead contact line, normally caused by wind, it is good practice to limit the number of consecutive span of the same length or install dampers.

5.11 Contact line arrangement above turnouts and crossings

Contact lines above turnouts and track crossings shall be designed such that they can be traversed in all planned directions at the planned speeds whilst still meeting the requirements of the permissible range of contact forces (Table 4).

The design of crossing points and the configuration and geometry of tangential contact lines shall ensure that no contact line equipment (e.g., contact wire, dropper clamps, steady arm, etc.) is able to slip below the pantograph contact strips.

The sway and skew of the pantograph shall be considered as well as contact wire uplift and lateral deflection due to wind. At the point where the incoming contact wire touches the pantograph head, both contact wires shall be placed on the same side of the pantograph head related to its central axis except for the case where all pantograph heads, which are used on the line, are fixed with fittings in order not to roll.

Suitable remedies, for example cross contact bars and cross droppers, shall be employed to ensure that both contact wires are lifted when being traversed by a pantograph. The temperature-related longitudinal expansions of contact wires shall be considered when adopting such remedies.

5.12 Overlap arrangements

Overlaps shall enable the pantograph to pass from one tension length to the next without speed reduction or interruption of the power supply to the traction unit. The number and lengths of spans including the differences in the length of adjacent spans and the contact wire gradients within overlaps shall be designed such that the permissible range of contact forces are met. The maximum running speeds and track radii shall be taken into account.

For overlaps in automatically tensioned equipment, the supports of both contact line equipments shall enable the unrestricted movement of the contact line due to the temperature related longitudinal expansion.

For insulated overlaps, the minimum dynamic electrical clearance specified in 5.1.3 shall be maintained between the conductors forming the overlap under the specified environmental conditions. Higher minimum values of clearance for insulated overlaps can be specified by national regulations or purchaser specification. Uninsulated overlaps should be permanently connected by a jumper. Insulated overlaps should be connected, during operational conditions, by a disconnector or via a substation.

In rigid overhead contact line systems, alternative components may be used to serve as overlaps to prevent significant dynamic uplift of the pantograph providing they comply with the permissible contact forces in 5.2.5.2.

5.13 Specific requirements for overhead contact lines for trolleybus systems

5.13.1 General

The typical characteristic of an overhead contact line system for trolleybus applications is double contact wires that are electrically separate.

The function of an overhead contact line for trolleybus applications is to transmit energy from electric substations to the trolleybus units and return it, all under the necessary protection conditions. In order to fulfil this function, the electrical system, made of cable and feeding/return wire, shall be designed in accordance with the requirements set out in 5.13.2 to 5.13.6.

5.13.2 Line characteristics

The trolleybus service characteristics and operational requirements should be taken from national standards.

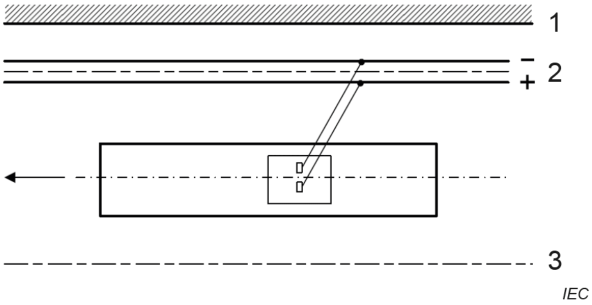
Consideration also shall be given to the environmental operating conditions and the urban area in which the overhead contact line will be installed, with particular attention being given to any national requirements for structural clearances.

The trolleybus characteristics and operational requirements include the following:

- right-of-way types: the types of road or rail alignments (e.g., street, reserved, grade-separated, etc.) commonly used for each different mode;
- average speed: the average origin-to-destination speed for each mode in revenue service. This includes time spent at station stops, in traffic and due to other delays;
- maximum speed: the top speed the vehicle is capable of reaching on a straight, level right-of-way way with no curves, gradients, stops, traffic signals or other delays;
- right-of-way dimensions: the width and height of right-of-way needed to accommodate the vehicle in dynamic mode according to modern standards of safe operation;
- minimum curves: the tightest curves that may be used for a given transit mode, measured as the radius of the curve to the centre line of the trolleybus;
- road surface gradients: the steepest gradients that may be used for a given transit mode without compromising reliability or safety of operations.

The distance between the feeding and return contact wires shall be either 0,60 m or 0,70 m, with a maximum tolerance of ±15 mm.

If one pole of the DC system is earthed or connected to the return circuit of a tram or light rail system, the contact wire of this pole shall be mounted on the outside of the right-of-way (see Figure 4).



Key

1 limit of the carriageway

2 overhead contact line: (−) return wire; (+) feeding wire

3 axis of right-of-way

Figure 4 – Position of return wire in relation to right-of-way

The assemblies of an overhead contact line (wires, suspension, switches and crossing) shall be so positioned as to allow:

- a regular vehicle circulation along the route,
- a correct approach to platform stops, and
- overtaking of another vehicle of the maximum admissible dimensions for road vehicles.

5.13.3 Vehicle characteristics

The following characteristics shall be determined and incorporated into the system design:

- nominal voltage of the overhead contact line;
- type of trolleybus and road characteristics;
- maximum and minimum road gradient of the route;
- maximum and permanent current of the vehicle;
- type of traction (by resistance, chopper, inverter, etc.);
- type of braking (by resistance, energy saving, etc.);
- environmental characteristics of the vehicle;
- trolleybus horizontal displacement from overhead contact line.

5.13.4 Current collector system

In particular, the following information shall be considered for the current collector:

- current collector dimension and type;
- construction characteristics of the current collector and all equipment that comprises the overhead contact line, such as switching and crossing points;
- static contact force between the current collector and contact wire;
- range of the contact forces related to the dynamic movement of the vehicle and variation of the height of the overhead contact line;
- type of contact line.

NOTE EN 50502 for CEN/CENELEC countries provides information regarding safety requirements and connection systems for electric equipment in trolley buses in Europe.

5.13.5 Static contact forces

The range of static contact force applied to feeding and return wires shall be between 70 N and 120 N for each wire.

5.13.6 Trolleybus in the vicinity of tramways

It is typical, especially for an urban area, that trolleybus and trams run under the same supporting system. In this case, the overhead contact lines for both systems are supported by the same suspension.

The distance between the contact wires for trolleybus and tramways shall not be less than the distance between the feeding and return wires.

In any case, the following shall be determined and incorporated into the system design:

- static and kinematic load gauge of the trolleybus and tram;
- if the distance between the return wire and the tramways overhead contact line is at least the distance between the feeder and return contact wires of the trolleybus overhead contact line.

Overhead contact lines for trolleybuses and tramways are generally supplied by separate feeding sections to facilitate maintenance activities.

5.14 Tolerances and limits

Parameters which are capable of being influenced by construction shall be limited by tolerances and limits. Tolerances and limits depend on the type of contact line and shall be defined in accordance with the requirements on safety, quality of current collection, compatibility to interfaces and aesthetic aspects. The interdependencies between the individual values shall be considered as well as the relationship between the tolerances and limits and external effects like climate, pantograph design and power supply.

For parameters which are capable of changing during operation, and so influence the system performance, for example due to the shift of track position, operational limits shall be additionally defined. The relationship between the tolerances and limits for construction and the limits for operation shall consider the possible changes of parameters over time between inspection and maintenance periods.

NOTE 1 The parameters are documented for the purpose addressed in 9.5 and handed over to maintenance entity (e.g. infrastructure manager).

NOTE 2 Limits for interoperable lines are defined in the Energy Technical Specifications for Interoperability (TSI) for countries of the European Union. These limits can be used as a guideline for non-interoperable lines, as defined by the purchaser and the system designer.

The tolerances and limits shall be implemented in the design and kept during construction and operation.

Table 13 shows examples of the parameters for which tolerances and limits should be defined. The types of parameters are divided in four main groups in the order of their importance to the system. In each main group, examples of parameters for tolerances and limits are given in relation to construction and/or operation. The specific values shall be defined by the system designer. Table 13 shows for which parameters tolerances or limits should be defined for construction and/or operation.

Normal behaviour and change of OCL parameters during defined maintenance periods and components lifetime shall be taken in account to ensure sufficient degree of freedom.

It is recommended to define different values for construction and operation to be used for maintenance period through its life cycle

Table 13 – Important parameters to assist in the definition of tolerances and limits

Type of parameter	Tolerances	Limits	To be defined for:	
			construction	operation
Type A, safety related				
Dimension of foundations	X		X	
Position of foundations perpendicular to track, rotation angle of masts	X	X	X	
Safety clearance, electrical clearances, maximum deviation of contact wire due to wind		X	X	X
Contact wire height (minimum/maximum), contact wire stagger	X	X	X	X
Maximum contact wire wear		X		X

Type of parameter	Tolerances	Limits	To be defined for:	
			construction	**operation**
Type B, related to quality of current collection				
System height, distance between droppers	X		X	
Position of foundations along the track	X	X	X	
Inclination of droppers along the track, maximum/minimum contact forces, variation of elasticity (u)		X	X	X
Inclination of droppers perpendicular to track		X	X	
Contact wire and conductor rail gradient, change of gradients		X	X	X
Type C, compatibility related				
Geometrical tolerances of component interfaces	X		X	
Type D, aesthetics related				
Pole height to align their tops	X		X	
Inclination of poles, inclination of horizontal cantilever tubes		X	X	
NOTE "X" denotes parameters that do apply.				

Refer to Annex H for special national conditions requirements.

6 Structures and foundations

6.1 Basis of design

6.1.1 General

The aim of Clause 6 is the proof of structural safety, which can be subject to local laws or conditions. For this reason, structures for overhead contact lines may be designed in accordance with the general principles contained in 6.1.2 to 6.1.8 or refer to the international standards, national standards or national regulations or as described in EN 1990:2002 for CEN/CENELEC countries.

NOTE References made to EN-Standards are normative for CEN/CENELEC countries. For all other countries, these references are informative. See also Annex H.

6.1.2 Basic requirements

Structures for overhead contact line shall be designed and constructed in such a way that, during their intended life,

- they will perform their purpose under a defined set of conditions with acceptable levels of reliability and in an economic manner (this refers to aspects of reliability requirements),
- they will not be liable to progressive collapse if a failure is triggered in a defined component (this refers to aspects of security requirements), and
- they will not be liable to cause human injuries or loss of life during construction, operation, and maintenance (this refers to aspects of safety requirements).

An overhead contact line shall also be designed, constructed and maintained in such a way that due regard is given to safety of the public, durability, robustness, maintainability and environmental considerations.

The above requirements shall be met by the choice of suitable materials, by appropriate design and detailing, and by specifying control procedures for design, production, construction and use relevant to the particular project.

6.1.3 Design with regard to structural limits

Generally, a distinction is made between ultimate limit state and serviceability limit.

Ultimate limit states are those associated with collapse or with other similar types of structural failure due to excessive deformation, loss of stability, overturning, rupture, buckling, etc. Ultimate limit states concern the reliability and security of supports, foundations, conductors and equipment as well as the safety of people.

Serviceability limit states correspond to certain defined conditions beyond which specified service requirements for an overhead contact line are no longer met. Serviceability requirements concern the mechanical functioning of supports, foundations, conductors and equipment and the unrestricted transmission of electric energy to the vehicles.

Therefore, serviceability limits require consideration of deformations and displacements which affect the use of the overhead contact line and any damage which is likely to affect the durability or function of the supports and equipment adversely.

Serviceability limits may be given in the purchaser specification.

Design with reference to ultimate limit state and serviceability limit states shall be carried out by:

- setting up structural and load models for relevant ultimate and serviceability limits to be considered in the various design conditions and load cases,
- considering design values which are generally obtained by using characteristic values as defined in this document in conjunction with partial factors as defined
    - in this document,
    - in ISO 10721 (all parts),
    - in EN 1990, EN 1992 (all parts), EN 1993 (all parts), EN 1995 (all parts), EN 1997 (all parts), EN 1998 (all parts) and EN 1999 (all parts) for CEN/CENELEC countries, and
    - in national standards or purchaser specifications,
- verifying that the limits are not exceeded when design values for actions, material properties and geometrical data are used in the model, and
- referring to Eurocodes in CEN/CENELEC countries, alternative standards or experimental data for materials not covered by this document.

6.1.4 Classification of actions

Actions can be classified by their variation in time or by their nature and/or structural response.

NOTE For the definition of an "action", reference can be made to EN 1990:2002, 1.5.3.1, in CEN/CENELEC countries.

- Permanent actions (G) are self-weight of supports including foundations, fittings and fixed equipment, self-weight of conductors and the effects of conductor tensile loads at the reference temperature without ice and/or wind action. The characteristic value of permanent actions can normally be determined as one value G_K since the variability of G is small.

- Variable actions (Q) comprise wind loads, ice loads, or other imposed loads. Wind and ice loads as well as applicable temperatures are climatic conditions which can be assessed by probabilistic methods or on a deterministic basis or from applicable standards such as IEC 62498-2. Conductor tensile load effects due to wind and ice and temperature deviations are variable actions as well. For variable actions, the characteristic value Q_{K} corresponds to a nominal value used for deterministic based actions or an upper value of an intended probability not to be exceeded or a lower value with an intended probability not to be lower during a reference period.
- Accidental actions (A) are loads related to failure containment, etc. The representative value is generally a characteristic value A_{K} corresponding to a specified value. The dynamic actions after the operation of the fall arresting device of an automatic tensioning device or the failure of a contact or catenary wire may be considered by the use of an equivalent static action in accordance with 6.3.2.7.
- Construction and maintenance loads (Q_{PK}) take into account working procedures, temporary guying, lifting arrangements, etc. The characteristic values Q_{PK} for construction and maintenance loads are deterministic values stipulated to guarantee the safety of structures and people.

6.1.5 Reliability levels

In principle, overhead contact lines can be designed using certain reliability levels with respect to variable loads which are described by probabilistic laws. The reliability level can be based on the return period T of a climatic action, for example wind load, ice load, combination of wind loads, ice loads and loads caused by temperature change.

Structures for OCL shall be classified as consequence class 2 structures according to ISO 2394. This leads to a classification for OCL support structures to importance class II (EN 1998-1 for CEN/CENELEC countries) and risk category II (ASCE 7 for US). Different classification can be given in national standards or in purchaser specification.

NOTE Damage or loss of class 2 structures according to ISO 2394 does not lead to big societal impact or high number of fatalities (examples: smaller buildings, minor bridges and minor tunnels).

6.1.6 Models for structural analysis and resistance

Calculations shall be performed using appropriate design models involving relevant variables. The models shall predict the structural behaviour and the serviceability and ultimate limit states. They should be based on an established engineering theory and practice, verified experimentally if necessary.

Concerning the interaction between foundation and soil, special attention should be paid to the loads derived from the supports, loads resulting from active soil pressure and permanent weight of foundation and soil and buoyancy effects of groundwater on soil and foundation. Together with the reaction forces of the soil strata, these effects shall be taken into account when calculating the foundations. In addition, the criteria for acceptable settlements of the foundations, imposed deformations on supports and the contact lines and inclinations of the supports should be defined and taken into consideration.

6.1.7 Design values and verification methods

In this document, reliability is achieved by the application of partial factors and appropriate return periods for climatic actions based on statistical approach and partial factors for deterministic actions and for material properties. The partial factor method verifies that the effects of design actions do not exceed the design resistance at the failure limit and that design complies with the performance requirements concerning the serviceability limit.

The design value F_d of an action is expressed in general terms as:

$$F_\text{d} = \gamma_\text{F} \times F_\text{K} \tag{7}$$

where

γ_F is the partial factor for actions;

F_K is the characteristic value of an action.

In general, the partial factor for actions γ_F takes account of the possibility of unfavourable deviations of the actions, inaccurate modelling and uncertainties in the assessment of the effects of actions. For deterministic calculations including accidental loads, the partial factor may be applied to the effect of the characteristic values of action, i.e. on the conductor tensile load including the effects of wind, temperature and ice.

The design value X_d of a material property is generally defined as:

$$X_\text{d} = \frac{X_\text{K}}{\gamma_\text{M}} \tag{8}$$

The partial factor γ_M for material property covers unfavourable deviations from the characteristic value X_K of the material property, inaccuracies in applied conversion factors, and uncertainties in the geometric properties and the resistance model.

In the design of any component or their connection, it shall be verified that:

$$E_\text{d} \leq R_\text{d} \tag{9}$$

where

E_d is the total design value of effects of action such as internal forces or moments or their combination;

E_d is a function of the actions in a certain design situation:

$$E_\text{d} = f\left(\gamma_G G_K ; \gamma_W Q_{WK} ; \gamma_I Q_{IK} ; \gamma_P Q_{PK} ; \gamma_C Q_{CK} ; \gamma_A A_K\right) \tag{10}$$

where

G_K is the characteristic self-weight of supports, conductors fittings and conductor tensile forces depending on self-weight considering reference temperature;

Q_WK is the characteristic wind load;

Q_IK is the characteristic ice load;

Q_PK is the characteristic construction and maintenance load;

Q_CK is the characteristic conductor tensile forces depending on the temperatures and climate related loads;

A_K are the characteristic actions induced by accidental loads and special actions;

γ_G, γ_W, γ_I, γ_P, γ_C, γ_A are associated partial factors.

R_d is the corresponding structural design resistance associating all structural properties with the respective design value X_{nd} according to:

$$R_d = f\left\{X_{1d}; X_{2d} \ldots\right\} \tag{11}$$

For more details, refer to EN 50341-1 in CEN/CENELEC countries.

6.1.8 Wall anchors

When designing a wall anchor on a new superstructure, it shall be confirmed that the impacts caused by the overhead contact line system do not impair the serviceability and ultimate limit states of the superstructure.

When designing a wall anchor on an existing superstructure, a condition assessment shall be carried out. The results of the condition assessment indicate if remedial work to ensure that the superstructure is not compromised is required. If it is not possible to determine the substrate or the material is not covered by the European Technical Assessments (ETA) for CEN/CENELEC countries or other regional or national regulations, the wall anchor shall be tested when it has been installed to verify that the forces generated by the overhead contact line system can be transferred to the superstructure.

Verification and testing shall be in accordance with either the manufacturer’s specification, ETA for CEN/CENELEC countries, national regulations or the purchaser specification.

It is not necessary to carry out a full verification of the overall superstructure if it can be determined that the loads imposed by the overhead contact line system are within the capacity of the superstructure.

Based on experience from calculations and test results, it is recommended to limit the test load of wall anchors to the twice the value of the characteristic load effects. This recommendation is for the design of new wall anchors on existing superstructures and the reuse of existing wall anchors.

6.2 Actions on overhead contact lines

6.2.1 General

Characteristic values for actions on lines concerning climatic data can be derived from probabilistic or deterministic approaches based on long periods of successful experience. The climatic data may be taken from relevant standards such as IEC 62498-2 or ISO 4354 or national standards or EN 1991-1-4 in CEN/CENELEC countries and may be given in the purchaser specification. The total of actions constitutes a complete design system especially taking the established load cases into consideration.

Actions on overhead contact lines shall be considered as quasi-static actions, which do not require the verification of fatigue strength. The exceptions to this are detailed in 6.2.10.

6.2.2 Permanent loads

Self-weight of supports and their equipment such as cantilevers, tensioning equipment, insulators and span wires act as permanent loads. Conductor tensile forces and stagger loads of automatically tensioned wires and stagger loads may be considered as permanent loads. The characteristic value is G_{K}.

6.2.3 Variable loads

The variation in tension of fixed termination equipment shall be determined according to each individual load case such as:

- conductor under the action of ice load,
- conductor at both the design temperature and the minimum temperature,
- conductor under the action of maximum wind load, and
- conductor under the combined action of wind and ice load.

The characteristic values are Q_{CK}, Q_{WK}, Q_{IK} and Q_{PK}.

6.2.4 Wind loads

6.2.4.1 General

Design of wind load on overhead contact lines shall be undertaken in accordance with standard methods, for example in national standards or in EN 1991-1-4 in CEN/CENELEC countries or alternatively in accordance with methods described in 6.2.4.2 to 6.2.4.7. For the structural design of the supports, the wind velocity having a return period of 50 years shall be used whilst for the verification of the serviceability the return period for wind velocity shall be given in the purchaser specification.

For serviceability, it is recommended to use a wind return period of 3 to 5 years or use national standards.

If the site concerned is located on high viaducts or bridges, the wind velocities to be used shall consider the relevant height above ground.

6.2.4.2 Peak velocity pressure

Peak velocity pressure (q_{p}(z)) may be calculated according to:

$$q_p\left(z\right)=\frac{1}{2}\times\rho\times v_b^2\times c_e\left(z\right)\ [\mathrm{N/m^2}] \qquad (12)$$

where

ρ is the air density, expressed in kg/m^3;

v_{b} is the basic wind velocity, expressed in m/s;

c_{e}(z) is the exposure factor.

From a physical point of view, each factor depends on some parameters (as shown in Table 14), which can be calculated according to national/local rules.

Further additional parameters may be added in order to consider some specific local physical phenomenon (e.g. typhoons).

Table 14 – Parameters for wind load calculation

Factor	Related parameters
Air density ρ	Altitude above sea level
	Air temperature
	Barometric pressure during windstorm
Basic wind velocity v_b	Wind direction
	Return period
	Height above ground level
	Terrain characteristics
Exposure factor c_e(z)	Height above ground level
	Ground roughness of the terrain
	Terrain orography
	Wind turbulence

Further information can be found in Annex B.

6.2.4.3 Wind forces on conductors

Wind pressure on conductors causes forces transverse to the direction of the line. From two adjacent spans, the wind force on a support shall be determined by:

$$Q_\text{WC} = q_\text{p}\left(z\right) \times G_\text{C} \times d \times C_\text{C} \times \frac{L_1 + L_2}{2} \times \cos^2\Phi \ \ [\text{N}] \tag{13}$$

where

q_p(z) is the peak velocity pressure, expressed in Nm^{-2};

G_C is the structural response factor for conductors taking into account the response of moveable conductors to wind load. The factor G_C should be determined according to national experience. A widely accepted value would be G_C = 0,75;

d is the diameter of the conductor for FOCL and the section depth for ROCL, expressed in m;

C_C is the drag factor of the conductor. A value of 1,0 is recommended; other values may be given in the purchaser specification;

L_1, L_2 are the lengths of the two adjacent spans, expressed in m;

Φ is the angle of incidence of the critical wind direction in respect to the perpendicular to the conductor. In general, Φ is assumed to be zero, expressed in degrees.

Where twin conductors are run in parallel, a reduction in the wind load may be taken on the leeward conductor, as 80 % of the windward conductor, if the spacing between the axes is less than five times the diameter.

In the case where ROCL is used in open air, specific values of G_C and C_C shall be calculated or defined by the purchaser specifications.

6.2.4.4 Wind forces on insulators and other line fittings

The wind force on an insulator acts at the attachment point to the support in wind direction and shall be determined by:

$$Q_{\text{Wins}} = q_{\text{p}}(z) \times G_{\text{ins}} \times C_{\text{ins}} \times A_{\text{ins}} \quad [\text{N}] \tag{14}$$

where

$q_{\text{p}}(z)$	is the peak velocity pressure, expressed in Nm^{-2};
G_{ins}	is the structural resonance factor for insulator sets. A value of 1,05 is recommended; other values may be given in the purchaser specification;
C_{ins}	is the drag factor for insulators. A value of 1,2 is recommended; other values may be given in the purchaser specification;
A_{ins}	is the area of the insulator projected horizontally on a vertical plane perpendicular to the axis of wind action, expressed in m^2.

The wind force on other components shall be calculated using the equation and appropriate drag factors. In many cases, wind loads on insulators or line fittings will be very low in proportion to that from other sources.

The consideration of wind force on insulators with a surface area less than $1,1 \times 10^{-2}\ \text{m}^2$ is not necessary up to a height of 25 m above ground in urban areas.

6.2.4.5 Wind forces on cross-spans and cantilevers

The wind forces acting on cross beams, head spans and cross-spans as well as cantilevers shall be determined by summing the wind actions on the individual elements. The wind actions on the individual elements can be determined by the formulae specified in 6.2.4.3 for conductors, 6.2.4.4 for insulators and 6.2.4.7 for other structural components.

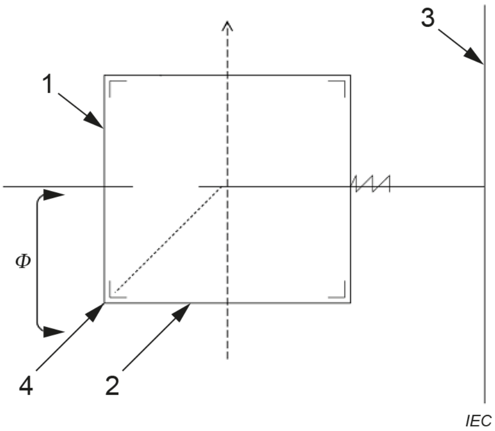
6.2.4.6 Wind forces on lattice structures

For lattice structures of rectangular cross sections, the wind forces shall be calculated from Formula (15):

$$Q_{\text{Wt}} = q_{\text{p}}(z) \times G_{\text{lat}} \left(1 + 0{,}2\sin^2 2\Phi\right)\left(C_{\text{lat1}} \times A_{\text{lat1}}\cos^2\Phi + C_{\text{lat2}} \times A_{\text{lat2}}\sin^2\Phi\right) \quad [\text{N}] \tag{15}$$

where

$q_{\text{p}}(z)$	is the peak velocity pressure, expressed in Nm^{-2};
G_{lat}	is the structural resonance factor; for lattice structures, this should be taken as 1,05;
C_{lat1}	is the drag factor for the lattice structure face 1 in a wind perpendicular to this face;
C_{lat2}	is the drag factor for the lattice structure face 2 in a wind perpendicular to this face;
A_{lat1}	is the effective area of the elements of the lattice structure face 1, expressed in m^2;
A_{lat2}	is the effective area of the elements of the lattice structure face 2, expressed in m^2;
Φ	is the angle between wind direction and the perpendicular to structure face 1 (see Figure 5), expressed in degrees.



Key

1 face 1

2 face 2

3 overhead contact line

4 wind direction

Figure 5 – Wind action on lattice steel structures

Alternatively, the wind force may be calculated in accordance with EN 1991-1-4, EN 1993-3-1 in CEN/CENELEC countries or national standards or purchaser specifications.

The drag factors C_{lat} depend on the solidity ratio as described in ISO 4354 and EN 1991-1-4:2005, 7.11, for CEN/CENELEC countries. An appropriate value is C_{lat} = 2,8 for lattice structures with square or rectangular cross-section made of angle sections.

6.2.4.7 Wind forces on poles

Wind force on poles shall be calculated from:

$$Q_{\text{Wstr}} = q_{\text{p}}(z) \times G_{\text{str}} \times C_{\text{str}} \times A_{\text{str}} \quad [\text{N}] \tag{16}$$

where

$q_{\text{p}}(z)$ is the peak velocity pressure, expressed in Nm^{-2};

G_{str} is the structural resonance factor for a structure. For self-supporting steel and concrete structures typically used for overhead contact lines, G_{str} shall be 1,0. Other values may be used if determined from relevant standards or methods published by an international, European or national standard body;

C_{str} is the drag factor depending on the shape and surface roughness of the structure. This value should be calculated in CEN/CENELEC countries in accordance with EN 1991-1-4 referenced as force coefficient (c_{f}) or national standards; other values may be given in the purchaser specification; in the absence of further information, the values in Figure 6 can be applied for double channel poles;

A_{str} is the projected area of the structure, expressed in m^2.

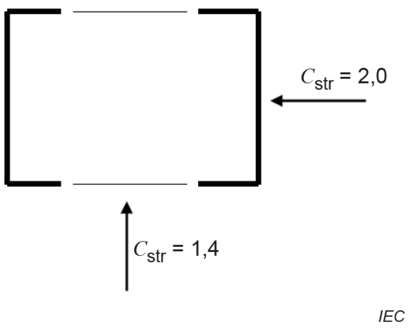


Figure 6 – Definition of drag factors for double channel pole

6.2.5 Ice loads

Ice loads are created by accretion due to hoar frost, precipitation icing or wet snow at the conductors of overhead contact lines. The characteristic ice loads g_{IK} depend on the climate and the local conditions, for example the height above ground, the proximity to lakes and the exposure to wind. Definitions for ice loads are given in IEC 62498-2. The ice loads should be given in the purchaser specification.

If specified in the purchaser specification, ice on structures shall be considered.

6.2.6 Combined wind and ice loads

Where the combined actions of wind and ice load are considered for the design of overhead contact line installations and structures, 50 % of the wind load according to 6.2.4 may be assumed as acting on structures and equipment without ice and on conductors with ice accretion. The ice loads shall be used according to 6.2.5 taking consideration of DI as following. An alternative value may be given in the purchaser specification. This is a simplified method of the common cases of considering independent variable actions by additional combination factors. The unit weight force ρ_{I} of the ice may be taken from appropriate standards and the aerodynamic drag factor as 1,0.

An increase in the diameter of the ice accretion should be considered if given in the purchaser specification. The equivalent diameter D_{I} in metres of the ice accretion shall be calculated from:

$$D_{\mathrm{I}} = \sqrt{d^2 + \frac{4 \times g_{\mathrm{IK}}}{\pi \times \rho_{\mathrm{I}}}} \quad [\mathrm{m}] \tag{17}$$

where

d is the conductor diameter without ice measured, expressed in m;

g_{IK} is the characteristic ice load measured, expressed in Nm^{-1};

ρ_{I} is the unit weight force of the ice, expressed in Nm^{-3}.

6.2.7 Temperature effects

The temperature effects shall be taken in account along with the other existing climatic actions. The following parameters should be defined by the purchaser specification, based on IEC 62498-2:

- the minimum temperature to be considered with no other climatic action;
- the ambient reference temperature for the extreme wind load condition;
- the temperature to be assumed with ice loads and combined wind and ice load, where relevant;
- the reference temperature for the calculation of tensile forces as a permanent action.

NOTE The following temperatures are used in many European countries: minimum temperature –20 °C; ambient reference temperature +5 °C; temperature with ice loads (and combined wind and ice load where relevant) –5 °C; reference temperature for calculation of tensile force as a constant action is +15 °C. The temperatures can be used when considering the tensile load of the conductors.

Temperature effects are considered as variable loads, but for structural calculations the partial factors for permanent loads may be applied for the permanent and variable part of the tensile force as design is based on a deterministic value.

6.2.8 Construction and maintenance loads

Loads due to construction and maintenance activities shall be considered, taking into account working procedures, temporary guying, lifting arrangements, etc. Recommended values of at least 1,0 kN shall be assumed for the horizontal cross-beams of portal structures and at least 2,0 kN for other types of structures, acting vertically. These forces shall act at the individually most unfavourable nodes of the cross-beams or at the attachment points of supports or conductors to the structures.

Structural elements need not be designed for such loads where appropriate working practices are adopted. Details should be given in the purchaser specification.

The configuration of the overhead contact system during the construction stage may result in higher loads than the final configuration. The climatic conditions during the intermediate phase shall be considered as part of the design.

6.2.9 Accidental loads

Accidental loads are specified to take care of failure containment and emergency situations. In general, at any conductor attachment point to a structure, the relevant residual static load resulting from the release of the tension of a contact wire, catenary wire or line feeder shall be applied. It is sufficient to consider accidental loads for structures at the end of tensioning sections or for anchor structures of mid-span anchors in accordance with 6.3.2.7. Details should be given in the purchaser specification together with a definition of associated load cases, including, but not limited to, the combination and/or coincidence of failures of different conductors and components at the same time and location.

6.2.10 Special actions

Depending on the local situation, different special actions may be considered.

- Forces imposed on the overhead contact line system after very high short-circuit currents. This does not apply to urban rail systems.
- Forces on installations due to earthquakes and/or seismic tremors, when overhead contact line systems are to be constructed in seismically active regions. Information is given in the EN 1998 series for CEN/CENELEC countries. See also informative Annex G.
- During construction, the loads due to the wheels running on the tracks should be considered where required, for example for foundation excavation. EN 1991-2 gives the general requirements for CEN/CENELEC countries.

Further requirements on special actions can be given by national regulations.

Dynamic actions due to pantograph/contact line interaction caused by running trains are small and need not be considered.

Aerodynamic actions by running trains are small and need not be considered. The exception to this is in a railway tunnel according to IEC 62498-2.

To avoid damages due to dangerous wind actions (e.g., against galopping OCL), different span lengths can be used in areas known in advance as relevant for this kind of impact. Furthermore, dampers in the catenary are useful.

Detailed requirements should be given in purchaser specification.

6.3 Types of structures and related load cases

6.3.1 Load cases and load combinations

6.3.1.1 General requirements

For the design of conductors, equipment and supports including foundations, ultimate limit state shall be determined by consideration of the load case giving the maximum load effect in each individual element.

Conductor tensile forces shall be determined according to the loads acting on the conductors in the load case under consideration. The force components of the conductor tensile forces at the attachment points of the support including the effect of vertical and horizontal angles shall be taken into account properly. The loads on the supports shall be selected taking into account the defined function of the support in the overhead contact line system. Where a support carries out several functions, for example a tensioning structure also carrying cantilevers, the most unfavourable combination of the loads that can occur simultaneously shall apply.

The purchaser specification may give additional requirements, if necessary. Short-term load conditions occurring during installation and re-construction activities shall be separately considered.

The standard load cases are defined in 6.3.1.2 to 6.3.1.7. The applications of these load cases are shown in Table 15 and 6.3.2.

The temperature conditions described in 6.2.7 shall be considered for respective load cases.

There are relations between environmental conditions like temperature and wind velocity.

6.3.1.2 Load case A: Loads at minimum temperature

Permanent loads, conductor tensile forces at the minimum temperature shall be considered.

6.3.1.3 Load case B: Maximum wind loads

Permanent loads, conductor tensile forces increased by the action of wind and wind loads on each element according to 6.2.4, acting in the most unfavourable direction shall be considered.

6.3.1.4 Load case C: Ice loads

Permanent loads, conductor forces increased by the ice loads according to 6.2.5 and ice loads on structures shall be considered, if applicable.

6.3.1.5 Load case D: Combined action of wind and ice loads

Permanent loads, conductor tensile forces increased by the combined effect of ice loads and wind loads, according to 6.2.6, and wind and ice loads acting on structures shall be considered. The wind load acts in the most unfavourable direction.

6.3.1.6 Load case E: Construction and maintenance loads

Permanent loads, increased by construction and maintenance loads according to 6.2.8 together with a reduced wind load and reduced ice load where specified shall be considered.

6.3.1.7 Load case F: Accidental loads

Permanent loads together with the unintentional reduction of one or several conductor forces shall be considered.

6.3.2 Type of structures and application of load cases

6.3.2.1 General

The load cases that shall be considered are summarized in Table 14.

Desription of individual structure types, along with supplementary details where applicable, are provided in 6.3.2.2 to 6.3.2.15.

6.3.2.2 Cantilevers

Cantilevers carry the overhead contact line of one or more tracks. They may be fixed to the supports by hinges allowing the cantilevers to rotate around a vertical axis, providing no resistance to longitudinal loads from the overhead contact line. Alternatively, cantilevers fixed rigidly to the structures offer resistance against longitudinal forces created by the overhead contact lines.

6.3.2.3 Head spans

Head spans carry overhead contact lines by means of rope elements and insulators under tensile load only.

6.3.2.4 Rigid cross-span structures (cross-beams, portals)

Rigid cross-span structures consist of moment resistant structures which can either be fixed at all joints or be built as a two-hinged frame.

6.3.2.5 Suspension structures

A suspension structure carries one or several cantilevers to support the overhead contact line.

6.3.2.6 Curve pull-off structures

Curve pull-off structures carry radial forces from one or several overhead contact lines, and sometimes vertical loads (e.g., when cants and/or slopes exist).

6.3.2.7 Midpoint anchor structures

A midpoint anchor structure is designed to resist the termination forces of the midpoint anchor in addition to other functions such as carrying cantilevers. The termination forces depend mostly on the requirements caused by temporary works on the overhead contact line system in the form of conductor installation; the governing load combination should be determined by the designer with the installation contractor.

Midpoints are not required to prevent consequential damage to the overhead contact line system in the event of conductor breakage, unless stated in the purchaser specification.

If the midpoint anchor and the midpoint anchor structure are required to withstand the consequences of wire breakage (FOCL), the following load combinations are recommended:

a) $n_{\text{cat}} \times T_{\text{cat}} \times \gamma_{\text{A}} \times k$;

b) $n_{\text{cont}} \times T_{\text{cont}} \times \gamma_{\text{A}} \times k$

where

n_{cat}	is the number of catenary wires;
n_{cont}	is the number of contact wires;
T_{cat}	is the catenary wire tension, characteristic;
T_{cont}	is the contact wire tension, characteristic;
K	is 1,5 (in accordance with EN 1993-1-11:2006, 2.3.6);
γ_{A}	is the partial factor for accidental loads (Table 15).

For the verification of z-wires, connecting clamps, catenary wire (between z-wires), midpoint anchor and midpoint anchor structures against wire breakage, the above given loads shall be used as accidental loads, not as operating loads.

6.3.2.8 Midpoint structures

A midpoint structure is designed to resist the radial forces from the midpoint anchors in addition to the other functions such as carrying the cantilevers.

6.3.2.9 Poles for head span or rigid cross-span structures

A pole or structure for head span or rigid cross-span structures is designed to resist the forces resulting from any kind of cross-supporting structures such as head spans, cross-beams and cross-spans.

6.3.2.10 Structures for horizontal catenary wire arrangements

At structures for horizontal catenary wire arrangements forces act in several directions and at different heights simultaneously.

NOTE A horizontal catenary wire is an arrangement where the contact wires are supported from wires that are mainly in a horizontal position. This arrangement is mainly used within urban areas. The masts or buildings where the horizontal wires are fixed can be relatively far from the tracks.

6.3.2.11 Tensioning structures

A tensioning structure carries the termination of overhead contact line equipment and other conductors being automatically tensioned or rigidly fixed and may also have other functions such as carrying cantilevers or head span elements.

Load case F is applicable if contact lines are terminated in two opposing directions in order to allow for the unintentional reduction of tensile loads.

Loads from falling weights when using fall arresting automatic tensioning devices need not be taken into account in load case F for the calculation of the ultimate limit state of the pole and foundation.

6.3.2.12 Structures with additional conductors

These structures additionally carry the loads from conductors, not part of the overhead contact line, but part of the overhead contact line system, and perform other functions within the overhead contact line installation.

Intermediate anchor structures for additional conductors which are not part of the overhead contact line shall be calculated in accordance with EN 50341-1 in CEN/CENELEC countries. In addition to the loads from the overhead contact line, the unilateral full horizontal tensile force of one of the additional conductors and two-thirds of the unilateral horizontal tensile force of the remaining additional conductors shall be taken into account.

6.3.2.13 Overhead contact line structures carrying additional overhead power lines

Structures with additional overhead power lines carry the loads from overhead lines and take care of other functions within the overhead contact line installation.

6.3.2.14 Anchor supports

Anchor supports are structural elements to resist the tensile forces terminating wires of overhead contact line system.

6.3.2.15 Structure foundations

Foundations shall be considered in accordance with 6.5.

Table 15 – Load cases to be considered for each type of structures

Type of structure		Load case to be considered					
		A	B	C	D	E	F
		Minimum temperature[f]	Wind[g]	Ice[e, h]	Wind and ice [e, h]	Construction and maintenance [e, h]	Accidental [e, g]
1[a]	Cantilevers hinged	X	X	X	X	X	-
1[b]	Cantilevers rigid	X	X	X	X	X	X
2	Head spans	X	X	X	X	X	X [a]
3	Portals/ Cross-beams	X	X	X	X	X	X [a]
4	Suspension structures	X	X	X	X	X	-
5	Pull-off structures	X	X	X	X	X	-
6	Midpoint anchor	X	X	X	X	X	X
7	Midpoint structures	X	X	X	X	X	-
8	Structures for flexible and rigid cross-supports	X	X	X	X	X	X [a]
9	Structures for horizontal catenary wire arrangements	X	X	X	X	-	X
10	Tensioning structures	X	X	X	X	X	X [c]
11	Structures with additional conductors	X	X	X	X	X	X
12	OCLS structures carrying additional power lines [b]	X	X	X	X	X	X
13	Anchor supports	X [d]	X [d]	X [d]	X [d]	X [d]	X [d]
14	Structure foundations	X	X	X	X	X	X
The above is provided as a guide. For some structures, additional load combinations will be necessary.							

Type of structure		Load case to be considered					
		A	B	C	D	E	F
		Minimum temperature[f]	Wind[g]	Ice[e, h]	Wind and ice [e, h]	Construction and maintenance [e, h]	Accidental [e, g]

[a] If midpoint.

[b] The lead cases according to EN 50341-1 in CEN/CENELEC countries should be considered with respect to the function of the support within the overhead contact line system.

[c] If contact lines are terminated in two opposite directions or auto tensioned devices with weight blocks are used.

[d] Depending on the type of anchor.

[e] If necessary (as specified in the purchaser's specification).

[f] Minimum temperature to be considered with no other climatic action. See 6.2.7.

[g] The normal ambient reference temperature to be assumed for the extreme wind load condition. See 6.2.7.

[h] Temperature to be assumed with ice loads and combined wind and ice load, where relevant. See 6.2.7.

6.3.3 Partial factors for actions

6.3.3.1 General

The use of factors is standard practice according to ISO 10721 (all parts) or national standards and in CEN/CENELEC countries EN 1993 (all parts) for steel structures, EN 1999 (all parts) for aluminium structures and to EN 1992 (all parts) in for concrete structures. The partial factors are separated into partial factors for actions and partial factors for materials. The relevant partial factors for actions and for materials are specified in this document. For conditions not covered in this document, partial factors may be taken from ISO 2394 or national standards and EN 1990 in CEN/CENELEC countries for structural design or may be taken from the purchaser specification. The applicable partial factors are summarized in Table 16 or can be defined in national regulations.

6.3.3.2 Permanent actions

The partial factor for permanent actions of self-weight is γ_{G} and for permanent actions of conductor tensile forces is γ_{CG}. A value of 1,3 is recommended; alternative values may be given in the purchaser specification. Where the self-weight of any element acts favourably, i.e. reducing the loading, the partial factor γ_{G} shall be assumed to be 1,0.

6.3.3.3 Variable actions, wind and ice loads

For the partial factors γ_{W} for wind loads, γ_{I} for ice loads and γ_{CV} for conductor tensile forces under the action of wind or ice loads, a value of 1,3 is recommended. Alternative values may be given in the purchaser specification.

6.3.3.4 Accidental loads

In case of accidental load cases, the partial factors γ_{G} for permanent loads, γ_{C} for conductor tensile forces and γ_{A} for accidental loads may be assumed as 1,0.

The dynamic actions after the operation of the fall arresting device of an automatic tensioning device or the failure of a contact or catenary wire may be considered by the use of an equivalent static action in accordance with 6.3.2.7.

6.3.3.5 Construction and maintenance loads

The partial factor for construction and maintenance loads γ_{P} shall be 1,5. This shall be combined with the value for partial factors γ_{G} and γ_{CG} for permanent actions as set out in 6.3.3.2.

Table 16 – Partial factors for actions to be considered

Type of load	Load case					
	A	B	C	D	E	F
Permanent γ_G γ_{CG}	1,3 [b]	1,3 [b]	1,3 [b]	1,3 [b]	1,3 [b]	1,0 [b]
Relieving γ_G, γ_{CG}	1,0 / 0 [a]	1,0 / 0 [a]	1,0 / 0 [a]	1,0 / 0 [a]	1,0 / 0 [a]	1,0 / 0 [a]
Wind γ_w, γ_{CV}	-	1,3 [b]	-	1,3 [b]	-	1,0 [b]
Ice γ_I, γ_{CV}	-	-	1,3 [b]	1,3 [b]	-	-
Accidental γ_A	-	-	-	-	-	1,0
Construction and maintenance γ_P	-	-	-	-	1,5	-

[a] Equipment removed.

[b] Recommended value.

6.4 Design of cross-span supports and structures

6.4.1 Analysis of internal forces and moments

The internal forces and moments within structures and cross-span supports as described in 6.3.2 shall be determined using the static principles for rigid and flexible structures whether being statically determinate or statically indeterminate structures or flexible rope systems. Additional requirements can be found in:

- ISO 10721 (all parts) or national standards and EN 1993 (all parts), EN 1090-1 and EN 1090-2 in CEN/CENELEC countries for steel structures,
- EN 14229 (in CEN/CENELEC countries) or national standards for timber structures,
- EN 12843 (in CEN/CENELEC countries) or national standards for concrete poles,
- EN 1992 (all parts) (in CEN/CENELEC countries) or national standards for concrete structures,
- national standards and EN 1999 (all parts) for aluminium structures (in CEN/CENELEC countries),
- EN 50341-1 (in CEN/CENELEC countries), and
- the recognized publications of structural analysis or national regulations.

6.4.2 Analysis of resistance

The elements of cross-span supports of contact line installations are loaded in compression, tension, bending or torsion. The calculation of the resistance of elements shall consider the type of load as well as buckling, stability if required and the analysis of connections.

Concerning the analysis of resistance of structures, reference shall be made to EN 50341-1 (in CEN/CENELEC countries) or national standards and to:

- ISO 10721 (all parts), ISO 630 (all parts), national standards and EN 1993-1-1 (in CEN/CENELEC countries) for steel structures,
- EN 14229 (in CEN/CENELEC countries) or national standards for timber structures,
- in CEN/CENELEC countries, to EN 1992-1-1 and EN 12843 or national standards for reinforced concrete structures.

The resistance of solid wires, stranded conductors of metallic material loaded by tensile forces follow from the relevant standards, for example EN 50149 or EN 50182 in CEN/CENELEC countries. The design resistance shall be obtained by dividing the failing load by a material partial factor.

6.4.3 Material partial factors

The partial factors γ_M should be taken in CEN/CENELEC countries:

- for concrete from EN 1992-1-1;
- for steel from EN 1993-1-1;
- for timber from EN 1995-1-1;
- for aluminium from EN 1999-1-1.

Alternative values can be found in national regulations or in Annex C.

6.4.4 Verification of resistance

The verification of resistance shall demonstrate that the resistance, taking into account the relevant material and structure behaviour partial factors, is higher than the effects of action with their relevant partial factors applied.

6.4.5 Verification of serviceability

The deformation of supports and all other structural components shall be kept in permissible limits to guarantee the serviceability of the overhead contact line. Detailed requirements should be given in the purchaser specification.

The deformation can be calculated using the methods of static analysis as described in 6.4.1. Types of tolerances and limits are given in Table 13.

6.4.6 Material for structures

Concerning suitable materials, reference shall be made to national standards or to the following standards.

- Steel materials shall comply with the requirements of ISO 10721 (all parts), ISO 630 (all parts) and EN 1993-1-1 and EN 1993-1-10 in CEN/CENELEC countries as well as EN 10025 (all parts), EN 10210 (all parts), EN 10219 (all parts), EN 10149 (all parts) and EN 10164 in CEN/CENELEC countries or national standards. Structural steel grades S235J0/J2, S275J0/J2, S355J0/J2 and S355J0/J2 according to EN 10025 (all parts) in CEN/CENELEC countries or equivalent grades are preferred. Where different steel grades are proposed, the performance at low temperatures should be considered, for example through the use of impact testing or by long-term experience.
- Welding consumables shall comply with the requirements of EN 1993-1-8 in CEN/CENELEC countries or national standards.
- Use of higher strength steel grades that are outside those specified on the above standards are acceptable. The suitability of these steel grades shall be assessed considering all performance criteria and agreed separately with the purchaser.
- When weathering steel is utilized, material properties should be in accordance with EN 10025-5 and tolerances applied from EN 10025 (all parts), EN 10210 (all parts) and EN 10219 (all parts) in CEN/CENELEC countries or national standards.
- Structural parts made of aluminium or aluminium alloys shall comply with EN 1999 (all parts) in CEN/CENELEC countries and national standards. EN 755 (all parts) for extruded tubes and profiles made of aluminium and EN 485 (all parts) for sheets, strips and plates made of aluminium shall also be considered in CEN/CENELEC countries or national standards.
- EN 50182 for stranded conductors made of aluminium, aluminium alloy and composite conductors in CEN/CENELEC countries or national standards.
- IEC 62724 for synthetic ropes or national standards.
- Concrete structures for new foundation should comply in CEN/CENELEC countries with EN 1992-1 or national standards.

NOTE Steel qualities S235JR/355JR are currently used in some CEN/CENELEC countries.

Timber structures should be specified in conformity with the requirements of EN 14229 in CEN/CENELEC countries or national standards.

Hollow sections shall comply with EN 10210 (all parts) or EN 10219 (all parts) in CEN/CENELEC countries or national standards.

Additionally, guidance may be given in a purchaser specification. Guidance on the design of structural details can also be found in Annex A and in EN 1090 (all parts) for steel and aluminium for CEN/CENELEC countries or national standards.

6.4.7 Corrosion protection and finishes

Structures and cross-span supports shall be designed to fulfil their intended working life. To ensure their longevity, steel components shall be protected against corrosion. Copper, copper alloy and aluminium components do not always require protection, due to their material properties. Plastic components do not corrode, but their longevity in service will need to be assured.

Galvanizing of steel parts is standard practice as described in ISO 1461. In addition, a paint coating over galvanizing applied in plant (Duplex system) can be recommended, subject to earthing and bonding requirements. The coating material should be lead-free and in accordance to national labour safety regulations. The galvanization specification shall be in accordance with ISO 14713 (all parts). The execution of steel and aluminium structures should comply to EN 1090 (all parts) for CEN/CENELEC countries or national standards.

Moreover, the guidelines established by operators should be applied accordingly.

Generally, it is presupposed that the execution of work is carried out with the necessary skill and adequate equipment.

6.5 Foundations

6.5.1 General

Subclauses 6.5.2 to 6.5.12 contain details on the geotechnical and civil engineering design of foundations for overhead contact lines, which are important and sufficient for the design of structures.

NOTE Subclauses 6.5.2 to 6.5.12 are essentially based on EN 1997-1:2004 and EN 1997-2:2007 for CEN/CENELEC countries and refer to these two standards where appropriate.

Alternatively, foundations may be designed by referring directly to EN 1997-1:2004 and EN 1997-2:2007 in CEN/CENELEC countries or national standards. Where these standards are used, they should be supplemented with additional requirements taken from 6.5.2 to 6.5.12 as required. Empirical methods are also allowable to the purchaser specification.

Annex D gives information on geotechnical soil investigation and soil characteristics.

6.5.2 Design of foundations

The foundations of supports shall be capable of transferring the structural loads resulting from the actions on the support into the subsoil.

The following items should be taken into consideration when designing foundations:

– design loads and design formulae;
– configuration of the foundation;

- limiting values of displacements;
- geotechnical design parameters taking into account groundwater levels;
- design parameters for structural materials;
- support/foundation interconnections;
- foundation construction and installation;
- special loads;
- electrical resistance of the foundation to earth.

6.5.3 Calculation of actions

The loads resulting from the pole and structural design as well as the dead load of the foundation itself and the dead load of the soil shall be considered with their design values as specified in 6.3, 6.4 and 6.5.2.

6.5.4 Geotechnical design

6.5.4.1 Basis of design

Subclause 6.5.4.1 gives the general principles, which apply when designing foundations.

The geotechnical category of the foundation shall be defined in accordance with EN 1997 (all parts) in CEN/CENELEC countries or national standards within the project specification. For single pole arrangements, the geotechnical category 1 may be applicable. The procedures of geotechnical category 1 should only be used if negligible risk exists with regard to overall stability.

NOTE Geotechnical category 1 can be assumed for relatively simple structures

- for which it is possible to ensure that the fundamental requirements will be satisfied on the basis of experience and qualitative geotechnical investigations, and
- with negligible risk.

The following factors shall be considered when determining the geotechnical design requirements:

- site conditions with respect to overall stability and ground movements;
- nature and size of the structure and its elements, including any special requirements such as the design life;
- conditions with regard to its surroundings;
- ground conditions;
- groundwater conditions;
- regional seismicity;
- influence of environment;
- stabilizing forces of soil.

For each geotechnical design situation, it shall be verified that no relevant limit state, as defined in EN 1997-1:2004 for CEN/CENELEC countries or national standards, is exceeded.

Limit states can occur either in the ground or in the structure or by combined failure in the structure and ground.

Limit states should be verified by one combination of the following:

- use of calculations as described in 6.5.4.2;
- experimental models and load tests, as described in 6.5.4.3;
- adoption of prescriptive measures, as described in 6.5.4.4.

The following limit states should be considered for foundations for overhead contact lines:

- loss of overall stability;
- bearing resistance failure, punching failure, squeezing;
- failure by sliding;
- combined failure in the ground and in the structure;
- structural failure due to foundation movement;
- excessive settlements;
- excessive heave due to swelling, frost and other causes.

If anchored poles are used to stabilise the structure, limit states for anchors in EN 1997-1:2004, 8.2, in CEN/CENELEC countries or national standards, shall also be considered. If pile foundations are used, the limit states for piles in EN 1997-1:2004, 7.2, in CEN/CENELEC countries or national standards, shall also be considered.

For design and construction, the following should be considered:

- to avoid effects of frost, the provisions in EN 1997-1:2004, 6.4, in CEN/CENELEC countries or national standards, should be considered;
- the type of foundation and method of installation for pole foundations along railways should be chosen with respect to the special geometrical conditions of the ground surface and the layered ground conditions normally accounted for;
- limiting values for displacements of the top of the foundation (due to angular rotation) in different directions shall be assessed on both ultimate and serviceability limit states taking account of the stiffness of the pole itself;
- when calculating settlements of the foundation, also the settlement of the embankment itself should be considered.

The results of geotechnical design of the foundation should be summarised in a geotechnical design report, including the type and dimensions of foundations and special requirements for installation and supervision, if any. For more information, refer to EN 1997-1:2004, 2.8, in CEN/CENELEC countries.

For specifications on geotechnical design methods and formulae, refer to the respective purchaser specification.

6.5.4.2 Geotechnical design by calculation

Prior to the design, a soil investigation shall be performed to establish the geotechnical design parameters. Annex D gives guidelines for soil investigation and selection of geotechnical parameters.

The calculation model shall describe the behaviour of the ground for the limit state in consideration.

Wherever possible, the calculation model should be correlated with field observations of previous designs, model tests or more reliable analyses.

The formulae to be used to determine the foundation resistance are those given in the appropriate code of practice, as given in EN 1997-1 in CEN/CENELEC countries, or in the respective national annex, or in national standards, or in the relevant literature, or those which have been used with satisfactory practical experience.

The general design formula has the format of Formula (18):

$$E_\mathrm{d} \leq \frac{R_\mathrm{k}}{\gamma_\mathrm{M}} \qquad (18)$$

where

E_d is the design value of the structural load;

R_k is the characteristic value of the foundation ultimate resistance;

γ_M is the partial factor for the resistance.

NOTE Additional requirements for the selection of characteristic values for geotechnical parameters are given in EN 1997-1:2004, 2.4.5.2, in CEN/CENELEC countries.

If the soil investigations do not yield other values, the soil characteristics may be assumed according to Annex B (where applicable), an appropriate code of practice, in the relevant literature, or the respective purchaser specification when designing the foundations.

In case of groundwater, the reduction of load carrying capacity of the foundation due to buoyancy shall be considered when analysing the foundation taking into account the most unfavourable groundwater table.

The design resistance of foundations depends on the type of foundation (e.g. pile foundation, sidebearing foundations and gravity foundations), the type of load as well as on the soil characteristics and installation conditions. The stability of a foundation under overturning moments or axial forces as well as the pressure between the foundation body and the surrounding soil shall be verified. Alternatively, the verification of the foundation may be carried out based on characteristic values with the application of proven calculation models where they have been proven by long-term experience.

6.5.4.3 Load tests and tests on experimental models

Load tests or tests on experimental models form a valuable method for justifying the design of foundations or to test the strength of individual foundations whether test or production foundations. Details concerning the preparation of tests, the testing arrangement, the testing procedure and evaluation are given in IEC 61773.

General rules for design by load tests are given in EN 1997-1:2004, 2.6, for CEN/CENELEC countries or in national standards. In this case, a special program for the load test should be made considering the site conditions, type of foundation installation procedure and actual load situations. Deformations at variable loads should be considered.

The results of the load test shall be reported and evaluated. For evaluation, refer to IEC 61773 and the literature or national standards. For load testing of piles, refer to EN 1997-1:2004, Clause 7, in CEN/CENELEC countries.

Design rules evaluated for a specific foundation type and foundation method by load tests or tests on experimental models can also be given in the purchaser specification.

6.5.4.4 Geotechnical design by prescriptive measures

In situations where calculation models are not available or unnecessary, the design may be done by the use of prescriptive measures confirmed by experience. These involve conventional and generally conservative details in design, and attention to specification and control of materials, workmanship, and maintenance procedures.

Prescriptive methods may be used where comparable experience exists and the load situations and ground conditions are equal or more favourable than those from experiences. For more information, refer to EN 1997-1:2004, 2.5, in CEN/CENELEC countries.

Reference to such conventional and generally conservative rules may be given in the respective purchaser specification.

6.5.4.5 Structural design

The structural design of the foundation body should be based on design loads. The design may also make allowance for additional capacity, depending on the structure design.

The rating and calculation of forces and bending moments and the installation of concrete side bearing foundations shall be carried out according to EN 1992-1 (all parts) in CEN/CENELEC countries or national standards.

For special structural requirements on spread foundations refer to EN 1997-1:2004, 6.8 in CEN/CENELEC countries or national standards.

The rating of the steel reinforcement shall be carried out in accordance with and EN 1992-1-1 in CEN/CENELEC countries or national standards. Where applicable, the rules for design of non-reinforced concrete shown in EN 1992-1-1 in CEN/CENELEC countries or in national standards should also be applied.

The structural design of piles depends essentially on the type of pile. Piles are loaded by axial and shear forces and by bending. The maximum combined loads shall be determined and the cross-sections shall be verified by adoption of relevant standards such as EN 1992-1-1 in CEN/CENELEC countries for concrete piles and ISO 10721 (all parts) and EN 1993-1-1 in CEN/CENELEC countries for steel piles or national standards respectively. The internal forces and moments can be calculated using appropriate methods presented in the literature and/or proved by long-term application.

NOTE Additional information about structural design of piles is given in EN 1997-1:2004, 7.8, for CEN/CENELEC countries.

If applicable, the limitation of the deformation shall be considered in accordance with 6.5.7.

6.5.5 Partial factors for foundations

The partial factors for the geotechnical design depend on the type of foundation and the type of loading.

Values of the partial factors shall be selected from EN 1997-1 for CEN/CENELEC countries or national standards, taking into consideration the appropriate geotechnical parameters and design model.

Partial factors may be given in the purchaser specification depending on the type of foundation, the approach used for their verification and national conditions.

6.5.6 Verification of stability

In general, the proof of stability shall verify that the resistance with the partial factors included is higher than the design loads with the partial factors included. The methods for verification of stability are those given in the appropriate codes of practice, for example as given in EN 1997-1:2004 for CEN/CENELEC countries, in the respective national annex, in the relevant literature, or which have been used with satisfactory practical experience.

The design of pole foundations shall be checked at the ultimate limit states indicated in 6.5.4.1 using design actions or action effects and design resistance.

In case of embankment slope, the overall stability shall be analysed according to provisions in EN 1997-1:2004, Clause 11, in CEN/CENELEC countries or in national standards.

In cases where a foundation is surrounded by soft soil, the resistance shall be calculated as the foundation is installed directly in the natural soil, also when it is installed by excavation and back-filling.

For pile foundations, it shall be checked that the design bending moment capacity of the pile is not exceeded at the connection between the pole and the pile.

For axisymmetric foundations, the analysis can be performed in the direction of the resulting actions and overturning moments. For other foundations, the verification should be made in two directions considering the overlapping resistance zones in the ground.

Where applicable, for example for rectangular foundations loaded by moments in different directions, stability may be verified using Formula (19).

$$\frac{M_{\mathrm{dyy}}}{R_{\mathrm{dyy}}} + \frac{M_{\mathrm{dzz}}}{R_{\mathrm{dzz}}} \leq 1{,}0 \qquad (19)$$

where

M_{dyy}, M_{dzz} are design moments, expressed in kNm;

R_{dyy}, R_{dzz} are design moment resistances, expressed in kNm.

6.5.7 Calculation of displacements

In order to guarantee the serviceability of the contact line, the displacements shall be limited according to the requirements of the operator as given in the purchaser specification. Limits on overall displacement of support structures shall be in accordance with 6.4.5. Deformation of the foundation shall be considered as a contribution to the overall structure deflection.

A significant contribution to the displacements may be carried out by using adequate methods as described in the literature, for example based on the subgrade moduli of the soil strata encountered.

The methods for calculation of displacements are those given in the appropriate codes of practice, for example as given in EN 1997-1:2004, 2.4, for CEN/CENELEC countries, or in the respective national annex, or in the relevant literature, or those which have been used with satisfactory practical experience.

The design of pole foundations shall be checked at the serviceability limit state using the appropriate limit states in 6.5.4.1.

NOTE The serviceability limit state is often the crucial limit state for single pole foundations.

6.5.8 Materials for foundations

The main materials used for foundations are concrete, reinforcement steel and steel section or tubes.

Concrete for foundations shall conform to EN 206 in CEN/CENELEC countries or national standards and the quality shall be at least C25/30 (to cater for sufficient frost proofing), and when frost proofing is not required C16/20 shall be used as a minimum or as defined in national standards. Higher grades may be required in the purchaser specification.

Concrete structures shall comply with EN 1992-1-1 in CEN/CENELEC countries or national standards.

Steel piles produced from structural steel shall be manufactured from materials in accordance with EN 10025 (all parts), EN 10210 (all parts) or EN 10219 (all parts) in CEN/CENELEC countries or national standards; preferably the steel qualities mentioned under 6.4.6 should be used.

Materials for driven piles shall meet the requirements according to EN 12699 in CEN/CENELEC countries or national standards.

6.5.9 Structural details

Special attention shall be paid to the interaction between support and foundation, especially where fatigue has an influence. It is standard practice either to arrange anchor bolts in the foundation and fix the support to these anchor bolts. For design of anchor bolts, reference shall be made to EN 50341-1:2012, Table K.2 (Design of holding-down bolts), in CEN/CENELEC countries or national standards.

Supports may be inserted into the foundation body. The dimensions of the holes in the foundation body shall be large enough to enable adjustment of the support. A space of 0,1 m between the hole and the support is advisable. This space may be filled up with sand, fine gravel or concrete. A layer of concrete shall be placed over the hole to prevent water ingress; a thickness of at least 0,2 m is advisable. The requirements of EN 1992-1-1 in CEN/CENELEC countries or national standards concerning the concrete covering should be applied.

To protect the supports against humidity and the aggressiveness of the soil, the top of the foundation should be arranged above the soil surface; a height of at least 0,3 m is preferable. The top of the foundation should be shaped to avoid standing water.

In urban areas that are publicly accessible, a protection should be put around the base of the pole.

6.5.10 Protection against corrosion and weathering

The protection of foundations against weathering and corrosion shall be achieved by selection of appropriate concrete quality and a sufficient compaction. If steel reinforcement is used, the requirements given in EN 1992-1-1 in CEN/CENELEC countries or national standards concerning the concrete covering should be considered. In addition, to limit any cracks a structural reinforcement may be applied in the caps of concrete foundations according to the requirements of the purchaser specifications.

The supports and foundations of structures for DC railway installation need to be protected against stray current corrosion. For details refer to IEC 62128-2.

Anchor bolts shall be protected against corrosion. In case of galvanization, an additional protection should be applied if specified by the purchaser.

Steel piles shall be adequately protected against corrosion. This can be achieved either by providing a concrete sleeve or by applying a coating made of a thick layer of protective material. Alternatively to the mentioned protective provisions, the expected corrosion of steel can be allowed for by providing additional steel thickness.

For steel piles, the cross-section should, for the structural design, be reduced with a measure corresponding to the expected average corrosion in the ground over the lifetime; see ISO 10721 (all parts) and EN 1993-5 in CEN/CENELEC countries or national standards or the purchaser specification. Hot dip galvanizing protects the steel from corrosion in drained and lime-rich soils but will only slow the corrosion rate in saturated soils. Coatings such of epoxy or polythene can be used where the foundation is installed by excavation and back-filling. Additionally, the durability of the coating itself should be considered.

6.5.11 Electrical design

Foundations may be used as earth electrodes, especially in AC systems. The earth electrode is formed by providing a conductive path enabling current to flow through the foundation and into the surrounding ground. Earth electrodes shall be connected with the metallic poles with concrete foundations. The following items should be considered to ensure the resistance to earth is decreased:

- no insulation included between reinforcement and soil (not including the resistivity of the concrete);
- the earth resistance will reduce with the increased length and diameter of the foundation, where the length is more significant.

6.5.12 Installation of foundations

Although general requirements for installation of overhead contact lines are not included in this document, requirements for installation for the foundations are necessary as the foundation detail cannot readily be inspected at a later stage to ensure compliance with the design.

Foundations made of concrete shall be constructed and installed in accordance with EN 1992-1-1 in CEN/CENELEC countries or national standards. Refer also to EN 1997-1:2004 in CEN/CENELEC countries.

The method of installation described in the geotechnical design report shall be transformed into an installation program, with consideration given to the actual site conditions and required design ground parameters.

NOTE For the general requirements for checking, supervision and monitoring of installations, refer to EN 1997-1:2004, Clauses 4, 5 and 7, in CEN/CENELEC countries.

When excavating for a foundation, the ground beneath the foundation shall not be disturbed and shall be protected against disturbing effects, for example frost or groundwater seepage. Refer to EN 1997-1:2004, 6.9, in CEN/CENELEC countries.

The installation methodology should include a plan of supervision so that, if ground conditions vary from those envisaged, an alternative foundation may be used or amendments to existing foundation dimensions made. During excavation, attention shall be paid to the agreement between the assumptions made for design and the encountered soil profile. Adequate supervision should always be ensured during foundation construction.

Any backfill shall be compacted to achieve soil characteristics as close as possible to those of the undisturbed soil.

Pile driving shall be recorded and record of pile driving checked against the specified requirements to achieve the required stability.

For foundations driven into the ground with or without pre-boring, criteria for assessing the capacity of foundations shall be assessed in the installation program. General requirements for supervision of construction are shown in EN 1997-1:2004, 7.9, in CEN/CENELEC countries or in national standards.

Requirements for execution of bored piles are given in EN 1536, for displacement piles in EN 12699 and for ground anchors in EN 1537 in CEN/CENELEC countries, or in national standards respectively.

The results of supervision, monitoring and maintenance activities should be compiled in a report as an addendum to the Geotechnical Design Report, confirming that the construction and installation has been made in accordance with given requirements. If there are divergences that might affect the behaviour of the foundations, they should be reported and the possible effects analysed in the addendum.

7 Assembly and Component requirements

7.1 General

7.1.1 Design life

Under normal operating conditions, the components of the overhead contact line system shall have a design life at least equal to the design life of the system, unless stated otherwise by the supplier or by the purchaser (e.g., contact wire).

EXAMPLE Contact wires are typical components whose lifetime does not follow the lifetime of the system and depends on the interaction with the pantographs.

The OCLS components should be free of maintenance before and between the scheduled cycle as specified.

It is recommended to design the components in a way that they require as less as possible maintenance and especially periodic treatment, such as lubrication of wires, electrical contacts, bearings and gears, for keeping equipment working properly, for example using dry bearings both in tensioning devices and in disconnectors drives and self-lubricating contact surfaces for disconnectors without need of greasing.

7.1.2 Component identification

If there are no other requirements in the relevant product standards and the size and shape of the component is large enough, all components shall be marked with a supplier’s identification and component identification. The form of marking shall be agreed with the purchaser.

7.1.3 Corrosion and erosion

Surface protection shall be provided on components of ferrous material. The local environmental conditions shall be considered when determining the type and thickness of surface protection. For components made of corrosion resistant materials, a surface protection is not necessary.

Where galvanization is used to protect from the corrosion, it shall be designed in accordance with ISO 1461:2022, ISO 14713 (all parts).

Additional protection shall be considered for internal strands of ferrous multi-stranded wires (e.g., greasing).

Clamps, splices and other fittings shall not cause any bimetallic corrosion with the conductors with which they are in contact. Consideration shall be given to the risk of water retention so as to reduce the potential for damage during freezing conditions.

Components shall be designed in such a way that the danger of stress corrosion cracking does not occur.

7.2 Supporting assemblies

Supporting assemblies shall be compatible with the kinematic and static reference profile of the vehicle and the pantograph clearance gauge by a margin specified by system design.

Registration assemblies shall be designed such that:

- the stagger of the contact wire and catenary wire or conductor rail are maintained at the registration point within the defined tolerance in relation to the track centre line (refer to 5.14),
- the longitudinal movement of the contact wire and catenary wire caused by temperature variation is accommodated,
- the worst case uplift of the contact wire, as per 5.10.2, can be accommodated without causing mechanical fouling of the pantograph and any other part of the registration assembly after allowing for maximum wear and tolerance variation of the pantograph, and
- the mass of the moving parts of the registration assembly, including the connections to the contact wire and registration arm or supporting assembly, shall be kept to a minimum to achieve the specified current collection quality.

7.3 Contact wire

The contact wire shall conform to the requirements of IEC 62917. Contact wires should be installed without microwaves.

7.4 Other conductors and ropes

Stranded conductors shall conform to the requirements of EN 50182 in CEN/CENELEC countries for AL1/STyz and AL3/STyz (ACSR and AACSR) or to other relevant standards, depending on the types of conductors. Synthetic ropes shall conform to IEC 62724. For all other types of wires or in non-CEN/CENELEC countries, the relevant international or national standards should be applied.

The copper and copper alloy catenary wires shall conform to the requirements of IEC 63190.

Other wires such as zinc-coated steel wires, aluminum wires or ACSR may be used in accordance with the purchaser specification.

Where grease is used for the strands of the conductors, this shall be chosen so as not to have a melting point under the maximum temperature rise of the conductor (as described in Table 1).

Design loads shall be in accordance with the requirements of Clause 5.

7.5 Tensioning devices

The tensioning device shall maintain the mechanical tension in the overhead contact line conductor(s) as defined in the purchaser specification. The device shall be designed to achieve an efficiency defined in the purchaser specification over the specified design temperature range of the equipment.

Particular attention shall be given to the corrosion protection of any bearing arrangements in tensioning devices and suitable maintenance instructions made available to maintain the design efficiency of the tensioning arrangement. Dry bearings or self-lubricating bearings are recommended to reduce maintenance.

Where weights are used in the tensioning devices, these shall be located away from publicly accessible areas. Where this cannot be achieved, suitable precautions shall be taken to ensure public safety is maintained. The safety of public shall be ensured by using a specific device, such as a protection barrier or a fall arresting device.

The fall arresting device shall function correctly without permanent deformation at a load of 1,33 times the maximum permissible operational load.

To ensure that the tensioning device does not fail in the case of an incident, the breaking load of the tensioning device shall be higher than the breaking load of the tensioned conductor.

7.6 Mechanical midpoints

7.6.1 General

Fixed anchor points or other devices shall be used in a tension length of overhead contact line that is tensioned automatically at both ends, to ensure the conductors do not migrate towards one end of the tension length with changes in the loading conditions. Fixed points shall also be used with rigid overhead contact lines to prevent migration of the conductor rail. Mechanical midpoints should be provided by the installation of an anchoring arrangement at approximately the midpoint of the tension length or at such a location which balances the along track forces at the midpoint.

Fixed points are not required to prevent consequential damage to the overhead contact line system in the event of conductor breakage, unless stated in the purchaser specification.

7.6.2 Catenary wire fixed points

The design of the catenary wire fixed point shall take into account the different tension loads of either the catenary wire or the contact wire. The highest value shall be applied.

For cantilevers, the fixed point shall be designed to prevent movement of the cantilever. For head spans, measures shall be taken to ensure the upper cross-span wires can withstand the required longitudinal load.

For example, several adjacent head spans may act as the fixed point.

7.6.3 Contact wire fixed points

If a contact wire fixed point is required, this can be achieved in several ways. For example, the contact wire is connected to the catenary wire by a conductor installed close to the catenary wire fixed point. Thus, the contact wire is fixed in its position along the track.

The design of the contact wire fixed point shall take into account the difference of the operating tensioning forces of the contact wire on both sides of the fixed points.

7.7 Droppers

7.7.1 Mechanical requirements

Droppers can be rigid, flexible or sliding. The different types shall withstand the loads, as defined in the purchaser specification, without an adverse effect on the performance of the dropper over the life-cycle of the system.

The factor of safety for the complete dropper shall be a minimum of 2,5 for vertical and 1,5 for horizontal working loads.

The following service loads shall be considered in the design of droppers:

- vertical loads resulting from contact wire weight, ice loads, wind loads and loads coming from the contact wire profile;
- horizontal loads in the axis of the contact wire coming from a dropper inclination of up to 30° (for reduced encumbrance overhead contact lines, it may be appropriate to reduce the angle of inclination);
- dynamic loads coming from vibration, dropper buckling, etc.

In addition to the service loads, the following additional loads shall be considered:

- loads during construction;
- temporary loads coming from failures (e.g. the failure of an adjacent dropper).

Where these additional loads are greater than 2,5 times the service loads, they shall be used for the design of the dropper, in place of the service loads. Additional loads less than 2,5 times the service load may be ignored.

Loads imposed by staff standing on or attaching to the contact wire may be omitted when considering the loading of droppers, unless stated otherwise by the purchaser.

7.7.2 Electrical requirements

Droppers may be defined as current carrying, non-current carrying or insulating.

Current carrying droppers shall be designed to allow for current to flow between the contact and catenary wires without deterioration of the electrical and mechanical properties. Electrical design shall take into account the current distribution between the droppers in at least one span. A short-circuit close to one single dropper could cause a very high short-circuit current in the dropper. Under these circumstances, the dropper is not required to be rated for a full short circuit current.

Non-current carrying droppers are not designed to carry current. However, in the event of a potential difference being present across the dropper, current can flow. Where current flow is restricted by design, insulating droppers are required. The electrical requirements for insulating droppers are contained in IEC 62724.

7.8 Clamps and line fittings

7.8.1 Mechanical requirements

Anchoring clamps should be capable of securing ropes with a minimum of 2,5 times the working load or with 85 % of the rated tensile strength (RTS) of the conductors. The lower value shall be attained in any case. The anchoring clamps used shall not incur permanent deformations which impair operation at 1,33 times the working load.

Anchoring clamps should be capable of securing cables and wires with a minimum of 2,5 times the working load or with 85 % of RTS of the conductors

Other clamps and line fittings shall have a factor of safety of 2,5 times the working load. Clamps and line fittings subject to vibration shall be designed to prevent loosening over time. In addition, the mass of in-line fittings should be kept to a minimum, within the functional requirement of the component.

These values give the minimum requirements which can be increased by national regulations.

Clamps or fittings that carry conductors shall be designed in order to avoid any damage during the repetitive horizontal and vertical movements as a result of wind or temperature variation. The maximum horizontal and vertical angles for the conductors at the interface of the clamp or fitting should be specified by the purchaser or system designer. It may be necessary to design the clamp or fitting with chamfered or rounded edges to avoid damage to the conductor.

7.8.2 Electrical requirements

Clamps and line fittings shall provide a path for the specified normal and short-circuit current flow without causing failure.

7.9 Electrical connectors

Electrical connectors (not including current carrying droppers) shall have the following characteristics:

- to be able to sustain thermal load cycling with no reduction in mechanical and electrical integrity;
- the temperature rise with the specified short-circuit current shall not cause fusion or deformation or exceed the maximum allowable temperature of the wire in Table 1 (not including current carrying droppers);
- the temperature at normal operation of the electrical connector shall not exceed the maximum allowable temperature of the conductor.

7.10 Insulators

7.10.1 General requirements

The following standards shall apply. They specify requirements for the design of insulators used most in overhead contact line systems.

For ceramic or glass insulator units:

- IEC 62497-1;
- IEC 60305;
- IEC 60672-1;
- IEC 60672-3;
- IEC 60433.

For composite insulators:

- IEC 62621.

For post insulators:

- IEC 60273.

Where other designs are required, their functional requirements shall be contained in the purchaser specification.

The minimum creepage distances for insulators shall conform with IEC 62497-1, for the rated insulation voltage of the overhead contact line system (as defined in IEC 62497-1) and for the applicable pollution degree.

NOTE The use of composite insulators can avoid insulator replacement after lightening strokes.

7.10.2 Mechanical requirements

The mechanical requirements for composite insulators shall be in accordance with IEC 62621.

For other insulators, the minimum tensile strength of the insulator shall be at least 95 % of the calculated tensile strength of the conductor. The maximum working tensile load on the insulator shall not exceed 40 % of the minimum tensile strength of the insulator. In either case, the highest value should be used. The minimum tensile strength of the insulator which is installed on the conductor having calculated tensile strength of more than 100 kN may be determined by agreement between purchaser and supplier.

The maximum working, bending or torsion load shall not exceed 40 % of the minimum, bending or torsion strength of the insulator. Simultaneous tensile and bending and/or torsion load shall be taken into account if necessary. The maximum working bending load may additionally be limited by any deflection criteria defined in the purchaser specification.

The end fittings shall be suitably protected from corrosion and electrochemically compatible with interface connections. Particular attention shall be given to the protection of the end fittings against moisture entry, chemical activity or fixing degradation.

7.10.3 Insulator surface

In addition to the electrical and mechanical performance requirements, the design should address the suitability of the insulator surface in catering for

– cleaning by natural or manual methods,

– localized atmospheric pollution,

– low voltage erosion,

– electro-chemical activity or water absorption, and

– anti-vandalism;

7.11 Sectioning devices

7.11.1 Definition

The term "sectioning device" refers to section insulators and neutral section insulators.

7.11.2 Mechanical requirements

The sectioning device shall be designed such that no permanent or temporary deformation with detriment to function shall appear up to 1,33 times the working tensile load. When traversed by one or more pantographs, the contact forces shall comply with 5.2.5.2. In addition, the sectioning device shall not damage the pantograph collector strip.

The non-continuous pantograph head profile, as specified in IEC 62486, shall be considered if they are operating on the line and the purchaser shall provide all required pantograph details as outlined in 4.5.

For requirements for tension clamps in sectioning devices, refer to 7.8.1.

7.11.3 Electrical requirements

The insulators in the sectioning device shall comply with the electrical requirements set out in 7.10. If the pantograph runs on the insulating components, the possible carbon or metal deposition from the pantograph shall be taken into account.

A section insulator shall be designed to withstand,

a) in normal operation, the arcing caused by the passing of pantographs drawing a current corresponding to a single pantograph, and

b) in abnormal conditions, the arcing (due to load and any consequential short-circuit current) caused by the passing of pantographs drawing a current corresponding to a single pantograph, where one side of the sectioning device is energized and the other side is de-energized or earthed.

Any damage to the sectioning device due to arcing shall not reduce its mechanical integrity in a way which endangers continued operational use.

7.12 Disconnectors and drives

Disconnectors together with their drives and linkages shall comply with the requirements of

- IEC 61992-4 for DC disconnectors, switch-disconnectors and earthing switches, and
- IEC 62505-2 for AC disconnectors earthing switches and switches.

They shall be designed for the rated current and rated voltage of the system.

Disconnectors shall be suited to interrupt rated operational currents for a number of switching cycles if determined in the purchaser specification.

The interruption of current can cause arcs. Disconnectors shall be arranged in such a way that arcing does not damage other parts of the installation.

When specified as switch-disconnector, respectively switch, interruption of operational currents is required. The purchaser shall specify the required load-breaking and load-making capacity and the mechanical and electrical endurance. Guidance is provided by IEC 61992-4 and IEC 62505-2.

Electrical or remote control is recommended for disconnectors.

7.13 Protection devices

7.13.1 Covers and obstacles

Covers may be required, sufficient to provide mechanical protection against damage or electrical insulation suitable for application in the overhead contact lines. Insulated covers shall be in accordance with IEC 62497-1 and, for safety protection against direct contact by obstacles, shall be in accordance with IEC 62128-1.

7.13.2 Surge protection and voltage limiting devices

Protection devices, such as surge arrestors and spark gaps, shall be designed for the voltage, overvoltage conditions and discharge current of the specific traction power system.

The requirements of the IEC 62128 series shall be followed, for example voltage limits as set out in IEC 62128-1. The IEC 62497 series provides guidance on insulation coordination and related protection of overvoltages. Where specified as load breaking disconnectors, they shall be capable of interrupt breaking the rated current. See requirement of 7.12.

7.14 Specific components for trolleybus systems

7.14.1 General

The performance parameters for the design of components for trolleybus systems shall be defined in the system design, in terms of its mechanical and electrical requirements.

In particular, the following shall be taken into account:

- the mass of moving parts, including the connections to the contact wire, shall be kept to a minimum to achieve a good current collection quality, without interrupting the current flow to the trolleybus;
- the mechanical characteristics, including their weight, of assemblies and components shall enable them to be suspended using insulating or steel rope to supporting structures;
- the electrical parameters shall consider the possible activation of these components by current impulse or "wireless" systems, such as radio-frequency or infrared.

7.14.2 Turnouts and crossings

7.14.2.1 Mechanical requirements

Components for turnouts and crossings shall be designed so that no permanent or temporary deformation appears at 1,5 times the maximum working tensile load.

No damage shall occur to the current collector head during the passage of the trolleybus under the turnout or crossing at the maximum speed defined between the supplier and the purchaser.

7.14.2.2 Electrical requirements

The level of insulation of trolleybus turnouts shall be as defined in IEC 62497-1.

When the command system of the turnout has a different supply voltage (e.g., AC/DC low voltage), the level of insulation required shall be as defined in IEC 60947-1.

7.15 Automatic earthing and short-circuiting equipment

Automated earthing and short-circuiting equipment may be used for overhead contact line to facilitate fast earthing in emergency situation if necessary, for example tunnels, and to establish safe conditions in work areas where it is necessary to routinely earth the overhead contact line, for example in depots, train washing facilities, test tracks and border control points.

If the earthing or short-circuit equipment is used, once applied, the resultant touch potential of the overhead contact system shall comply with the IEC 62128 series.

Automated earthing and short-circuiting equipment shall verify absence of operating voltage, carry out earthing and short-circuiting and provide protection against adjacent live parts according to EN 50110-1:2013 and EN 50488 (for CEN/CENELEC countries) or national standards. This can be achieved by a combination of stationary voltage detectors, switching devices, access limiting demarcation or signals, which are managed by control and monitoring.

The switching devices used for earthing and short-circuiting shall fulfil the requirements of IEC 61992-4 or IEC 62505-2. In addition, the switching device position indication used to permit access to the overhead contact line system shall be generated directly on the switching device and not only in the drive connected by long linkage to the switching device. This avoids false information due to linkage problems. A reliable provision and transmission of the signals, commands and measurements for voltage detection shall be ensured.

7.16 Monitoring devices

Overhead contact line monitoring devices collect and transfer data with respect to overhead contact line and pantograph state and behaviour, which may be used for condition-based maintenance interventions or system and component validation.

When required, the application and functional parameters of overhead contact line monitoring devices shall be determined by the purchaser and supplier depending on the RAMS requirements, as per EN 50562 for CEN/CENELEC countries or national standards, and their effect on life cycle costs. They may include monitoring of tensile force, temperature, uplift, lateral and vertical position of the overhead contact line, wear of conductors as well as insulation state, system oscillation, arcing and contact strip condition. Additional information about the climatic conditions may be required in combination. The design of overhead contact line monitoring devices shall consider the condition and failure mode of the monitored assets and provide data to enable system or component analysis and decision. Normal operational conditions and emergency cases shall be clearly differentiated.

Monitoring devices should not impart excessively negative influence on the function and operational behaviour of the overhead contact line. Electronic equipment shall meet the EMC requirements according to IEC 62236-2.

8 Testing

8.1 Testing of components and assemblies – General

Testing comprises three different types; type tests, random sampling tests and routine tests.

Type tests are intended to validate design characteristics. They are normally only made once and repeated only when the design or the material of the component is changed. The results of type tests are recorded as evidence of compliance with design requirements. If there is a group of similar components, it shall be sufficient for the type test to be performed on one kind of component of the group. In this case, the selected component shall be selected so that its results are also valid for all components within the group.

Sampling tests serve for monitoring production. If statistical quality tests are performed for monitoring production, it is permissible for their results to be used as a substitute for acceptance. The sampling procedures shall be in accordance with ISO 2859 (all parts), if not otherwise specified in the purchaser specification.

Routine tests shall be carried out on components which have increased probability of failure to specific requirements and are made on every item. The intent of the tests is to prove conformity and to eliminate defective items. These tests shall not damage the item. After a positive test, the tested specimen may be used in an installation. A routine test should be used to detect latent defects which could influence the operating reliability of the component. Routine tests can typically include load tests, magnetic crack tests, ultrasonic tests, X-rays, resistance and insulation tests or other non-destructive test methods.

8.2 Support assemblies

8.2.1 Type test

8.2.1.1 Coverage

At least four test specimens shall be subjected to each type test.

All components or clamps forming part of a support assembly which are subjected to type testing shall not be used for other tests or in-service application.

The following tests shall be undertaken:

- material test;
- dimension and visual test;
- functional test;
- test of mechanical load capacity;
- heat cycling test (where continuous traction current carrying is expected).

All test conditions, test arrangements and test results shall be recorded in a test report.

8.2.1.2 Material verification

Type tests shall include verification of materials to ensure that they are in accordance with the purchaser specification. This verification may be carried out by inspecting documentation relating to material purchasing specifications, certificates of conformity or other quality documentation.

8.2.1.3 Verification of dimension and visual examination

Functional dimensions given in the drawing shall be measured on the samples. A visual examination shall include a check for the general condition and the surface of the sample for cracks, sink marks, inadmissible burrs or flashes, sharp edges, etc.

The chamfered and rounded edges of clamps shall be checked in relation to all possible position of conductors in the clamp, as specified in 7.8.1.

8.2.1.4 Functional test

Samples shall be assembled according to the supplier's instructions, using all necessary connecting parts. Bolts shall be tightened to 1,1 times the tightening torque stated in Table 17. The relevant functional dimensions shall be checked. No permanent deformation shall be permitted unless it is intended to do so by design.

The tightening torque to be applied corresponds to the lower limit of friction variability of a certain bolt.

A lower coefficient of friction of μ_{tot} = 0,1 or 0,12 may be assumed for example for the bolt connections listed in Table 18.

For coefficients of friction other than μ_{tot} = 0,12, the tightening torques stated in Table 17 shall be converted according to the factors given in Table 20 by multiplying the values.

Pairings according to Table 19 are recommended when bolts with hexagonal nuts are used.

Table 17, Table 18, Table 19 and Table 20 are applicable to clamps and fittings for the overhead contact line system.

Table 17 – Tightening torques M_t for regularly used bolts

Torques in Newton metres

Thread dimensions	Material of the bolts					
	Unalloyed and alloyed steels according to ISO 898-1 hot dip galvanized (tZn)			Rust and acid resistant steels steel groups A2 and A4		Copper-nickel alloy CU5
	Strength class			Strength class		
	4.6	5.6	8.8	70	80	
	$R_{\text{p 0,2 min}}$ =			$R_{\text{p 0,2 min}}$ =		$R_{\text{p 0,2 min}}$ =
	240 N/mm^2	300 N/mm^2	640 N/mm^2 [a]	450 N/mm^2	600 N/mm^2	540 N/mm^2
M8	-	-	23	16	22	20
M10	-	-	46	32	43	39
M12	25	38	80	56	75	68
M16	60	90	195	135	180	165
M20	120	180	390	280	370	330

NOTE The values in this table were established using the following assumptions:

- the bolt can be stressed up to its guaranteed minimum yield point;
- the tightening torques are based on a coefficient of friction for threads and head support of μ_{tot} = 0,12;
- a deviation of 10 % when applying the tightening torque is already taken into account in the table values: M_t Table = 0,9 $M_{\text{t max}}$, where $M_{\text{t max}}$ is the tightening torque for stressing up to the guaranteed minimum yield point;
- the tightening torques for bolts made of rust and acid resistant steels of the strength classes 70 and 80 are based on the 0,2 % yield point.

[a] Above M16: 660 N/mm^2.

Table 18 – Examples of bolt connections

Bolt	**Nut**	**Head support**	**Lubricant**	**Coefficient of friction**
				μ_{tot}
Steel annealing black or zinc-phosphate	Steel bright	Steel machined	Oil	0,12
A2/A4	A2/A4	A2/A4	S	0,12
A2/A4	Al alloy	A2/A4	S	0,12
Steel hot dip galvanized	Al alloy	A2/A4	K	0,12
Steel hot dip galvanized	A2/A4	A2/A4	K	0,12
Steel hot dip galvanized	Steel hot dip galvanized	A2/A4	K	0,10
CU5	CU5 or copper	A2/A4	K, S	0,12

A2/A4: rust and acid resistant steel steel groups A2 and A4.

CU5: copper-nickel alloy.

S: special lubricant.

K: corrosion protection grease.

Table 19 – Assignment of the strength of bolt and nut

Strength class of the bolt	**Strength class of the nut**
4.6 [a]	5 [b]
5.6 [a]	5 [b]
8.8 [a]	8 [b]
A2/A4, strength class 70	A2/A4 – 70
A2/A4, strength class 80	A2/A4 – 80
CU5	CU5
(CuNi 1,5 Si F 59)	(CuNi 1,5 Si F 59)

[a] According to ISO 898-1.

[b] According to ISO 898-2.

Table 20 – Conversion factor for tightening torques

Coefficient of friction	Conversion factor
μ_{tot}	MA
0,08	0,77
0,10	0,89
0,12	1,00
0,14	1,10
0,16	1,18
0,20	1,33
0,25	1,47
0,30	1,57

8.2.1.5 Mechanical load capacity test

8.2.1.5.1 Components

Accessories which are used to connect the tensile testing machine to the support assembly shall ensure the loading is as close as possible to that which occurs in operational use. These tensioning parts shall not influence the test result. In the case of components with several load points, it shall be ensured that the forces are distributed accurately in every condition to represent the real load conditions.

The test specimens shall be loaded progressively up to the maximum force F_{max}. The rate of change shall be within the range 5 N/mm^2 per second to 10 N/mm^2 per second, related to the conductor cross-section. A force-elongation or force-time diagram shall be made at the same time. This diagram can be derived either by the test machine itself or by measuring by means of suitable instruments at different load stages. From the force- elongation diagram, it shall be possible to determine the force in the transition from the elastic into the plastic range.

For components, the following characteristics shall be determined:

- ability of test specimen to withstand 1,33 times the operational force without a permanent deformation occurring;
- failure load F_{max} of the test specimen;
- nature and location of failure on the test specimen.

All values shall be recorded in test reports together with the characteristic data for the test specimens, such as material, material condition, type of processing, surface condition, etc. The test data shall be used for determining the nominal force F_{nom} or permissible operating force $F_{\text{perm.op}}$. The maximum force F_{max} of the test specimen shall be equal to or greater than the required nominal force F_{nom} or the force specified in the appropriate standards or drawings.

8.2.1.5.2 Clamps

Accessory parts for conductors, anchor cables and wires are assembled with the intended conductors corresponding to the assembly instructions and inserted in the testing machine using suitable clamping parts. For bolted clamps, the bolts are tightened with a tightening torque corresponding to Table 17 or the data provided by the supplier.

The tensile force shall be increased to 1,33 times the permissible operating force $F_{\text{perm. op}}$ and held for the duration of 1 min. Marks shall be applied at the exit of the conductor from the test specimen for observing possible slippage. The force shall be increased constantly with a load change of 5 N/mm^2 per second to 10 N/mm^2 per second, related to the conductor cross-section up to the maximum force F_{max} or up to destruction of the component. For suspension clamps, the maximum force F_{max} in the direction of the force effective in operation (mass of the conductor and additional loads) shall be determined.

For accessory parts to conductors, the following results shall be determined:

- force when the conductor starts to slip in the clamp;
- maximum force F_{max} of slipping through or breaking of the conductor in the area of influence of the clamp;
- functional defects of the clamp.

For stranded conductors, the first wire break shall be considered as a breakage of the conductor.

For suspension clamps, the maximum force F_{max} in the direction of the force effective in operation (weight of the conductor and additional loads) shall be determined.

8.2.1.6 Heat cycling tests (electrical tests)

8.2.1.6.1 Object of the test

Heat cycling tests are used to determine the long-term electrical behaviour of current-conducting connections.

8.2.1.6 does not apply to:

- terminals which are inherent parts of an equipment,
- fittings which are used in enclosed units (e.g., motor-operated mechanism),
- installation material and earthing terminals, and
- clamps which are mainly used for mechanical purposes (e.g. ,dropper clamps).

8.2.1.6.2 Connections

8.2.1.6.2.1 General

The current carrying connections can be divided into two main groups for tensile strength:

- connections designed to withstand tensile stress;
- connections which are not designed to withstand tensile stress.

8.2.1.6.2.2 Temperature rise in conductors

The maximum permissible temperature limits during the heat cycling test shall be defined by:

- temperature with continuous current (refer to Table 1), and
- temperature at short-circuit current in accordance with IEC 61284.

If, in exceptional cases, a connection is designed for higher temperatures than those defined above, the test temperatures shall be suitably modified.

8.2.1.6.2.3 Subdivision for test purposes

Since all possible applications of connections cannot be clearly identified, two classes of connections are defined for test purposes.

- Class A: the connections are subjected only to electrical heat cycling tests. Connections which can withstand tensile stress are typically class A connections.

- Class B: the connections are subjected to electrical heat cycling tests and short-circuit peak withstand current test. Connections which cannot withstand tensile stress are typical class B connections.

NOTE In the case of class A connections, the short-circuit peak withstand current test is not required since the mechanical design is sufficiently robust so that this test is not necessary.

8.2.1.6.3 Test specimens

Four specimens of each type of connection shall be subjected to the tests. The specimens supplied for testing shall be identical to the commercially available products.

8.2.1.6.4 Variable diameter connectors

For clamps that are designed for a range of conductor cross sections, the clamp shall be tested with the largest conductor cross-section as a minimum. If further tests are carried out, then it is advised that the smallest conductor cross section is tested. If bolts of different materials are used, the test specimens shall be fitted with bolts having the lowest conductivity.

8.2.1.6.5 Preparation of specimens

The contact surfaces of the fitting and the conductor shall be prepared according to the supplier's instructions. The fittings shall be fitted on the specified type and size of conductor according to the supplier's instructions with which they are to be used without any further preparation.

It is not permitted to subsequently tighten or press the fitting during the test.

The following technical details of the test specimens and the conductors shall be recorded before carrying out a test.

- Clamps and fittings:
  - supplier, catalogue or reference number;
  - class of connection: A or B;
  - installation procedures: preparation of contact surfaces, contact grease (if specified), details of fitting procedures and tools to be used.
- Conductor:
  - specification;
  - material;
  - size and stranding.

8.2.1.6.6 Test rules

8.2.1.6.6.1 General

Heat cycling tests should be carried out in accordance with IEC 61284.

8.2.1.6.6.2 Test conditions

The test shall be carried out in suitable draught-free conditions at an ambient temperature between 5 °C and 35 °C.

The test set-up shall ensure there is a sufficient distance between the test connections and other connections in order to ensure that the mutual thermal influence is negligible. The test arrangement shall be supported in such a manner that there is free air circulation and cooling by natural convection.

If forced cooling is used, it shall be used after switching off the current, and it shall have a uniform effect on the complete set-up.

The test set-up shall be such that the specimens are not subjected to any noticeable mechanical stress (bending, tension, pressure, etc.) during the electrical test. For this reason, it is recommended that the position of the specimens is not changed during the tests.

New conductors shall be used for the tests and for arrangements with tension on the connection. The tensile force should not exceed 20 % of the nominal tensile strength of the main conductor.

8.2.1.6.6.3 Arrangement of test specimens and the test loop

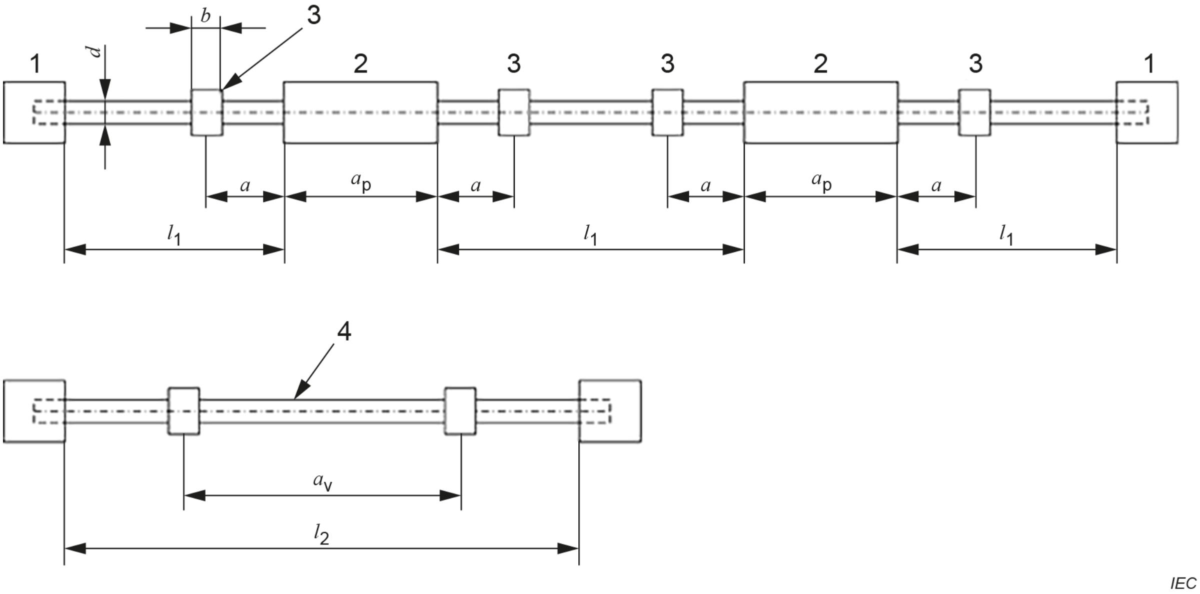
The arrangement of the test specimens during the electrical tests is not mandated. However, it is recommended that the tests are carried out in the horizontal position.

Typical arrangements of the test loop are shown in Figure 7. Alternative arrangements can be found in IEC 61284:1997, Annexes B and C.

In the case of T-connections, both the current paths shall be tested separately. Different samples shall be used for the tests.

8.2.1.6.6.4 Free conductor length

The free conductor length l_1 (refer to Figure 7) between the clamping pieces and the test specimens, as well as between the specimens themselves and the length l_2 of the comparison conductor should not be less than the values given in Table 21.



Key

1 clamping piece

2 test specimen

3 potential points

4 comparison conductor

a length of conductor between specimen and centre of potential point; $a \cong 15d$

a_p length of specimen

a_v length of comparison conductor between centres of potential points; $a_v \cong 30d + a$

b length of potential points; $b \leq 2d$

d diameter of conductor

l_1 minimum length between specimen and clamping piece and between specimens as per Table 21

l_2 minimum length of comparison conductor as per Table 21

Figure 7 – Description of dimensions and minimum conductor lengths

Table 21 – Minimum conductor lengths

Conductor diameter d mm	**l_1** m	**l_2** m
$d \leq 10$	0,5	2,0
$10 < d \leq 15$	0,8	2,0
$15 < d \leq 25$	1,2	2,0
$25 < d \leq 43$	1,5	2,0
$43 < d \leq 63$	2,0	2,5
$63 < d$	2,0	3,0
NOTE The conductor diameter for a shaped conductor is the diameter of the circle which surrounds the conductor.		

In the case of stranded conductors, the current shall be uniformly distributed throughout the complete cross-section.

8.2.1.6.6.5 Comparison conductor

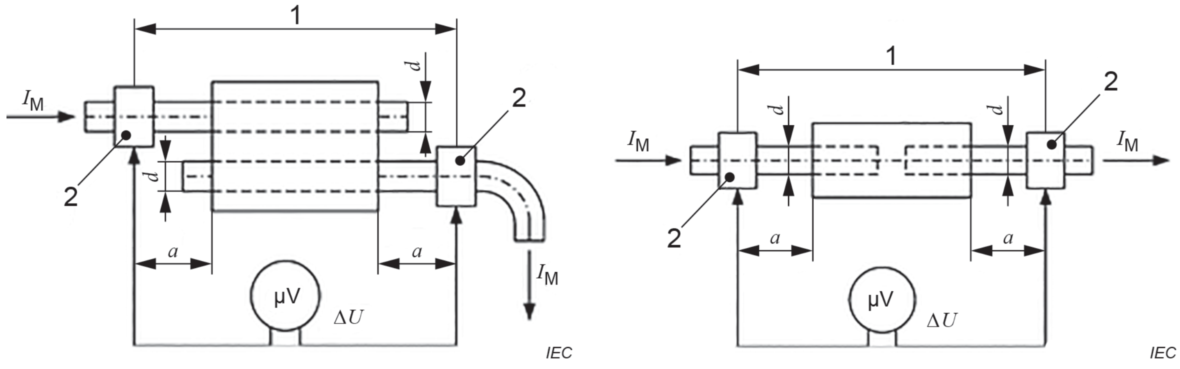
For the comparison of temperature and resistance values during the temperature and resistance measurements, the test set-up shall include one uncut conductor. If a clamp is used to connect two conductors of different sizes, the smaller of the two shall be used as the comparison conductor.

8.2.1.6.6.6 Potential measuring points

In the case of stranded conductors, the points for measuring the voltage ΔU shall be at the potential points (Figure 7, Figure 8a, Figure 8b and Figure 9). In the case of solid conductors, the measuring points should be as close as possible to the test specimen without making contact with the specimen. The voltage is picked up using either measuring probes or fixed connections. The point of voltage pickup shall be clearly marked.

For an example of a method of making a practical voltage pickup, refer to IEC 61284:1997, Annex G.

Other commonly used methods may also be used.



a) At a connecting clamp **b) At a butt joining clamp**

Key

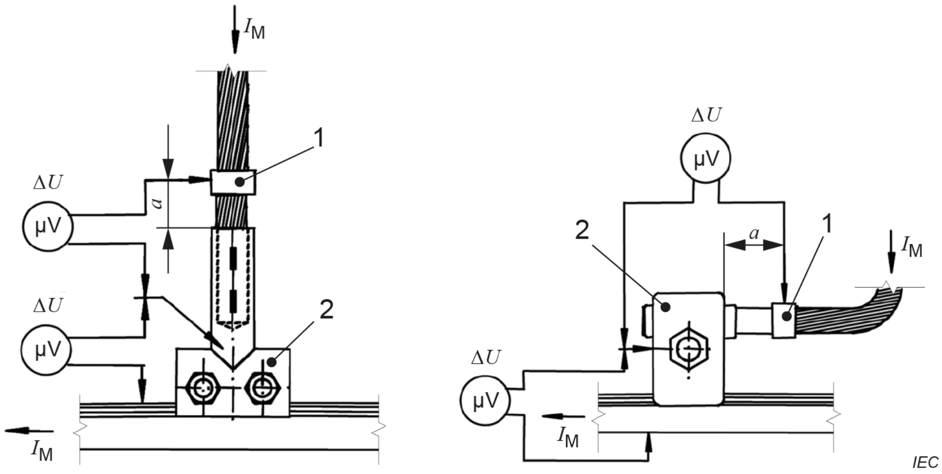
1 measurement distance

2 potential points

a length of conductor between specimen and centre of potential point; $a \cong 15d$

d diameter of conductor

Figure 8 – Potential measuring points



Key

1 potential points

2 test specimen

Figure 9 – Potential measuring points at a T-type infeed terminal

Heat cycling tests shall be carried out in accordance with IEC 61284.

8.2.2 Sampling test

8.2.2.1 Number of test specimens

Sampling tests shall be performed only if a sufficient quantity of components is made, typically more than 100 of the same components. The number of the test specimens for the sampling test, p, shall be in accordance with the following formulae.

$$p = 3 \qquad \text{for} \qquad 100 < n \leq 500$$

$$p = 4 + \frac{n}{1000} \qquad \text{for} \qquad 500 < n \leq 20\,000$$

$$p = 15 + \frac{0{,}5n}{1000} \qquad \text{for} \qquad n > 20\,000$$

where

n is the batch size.

Alternatively, methods defined in ISO 2859 (all parts), including skip-lot sampling methods, may be used to adjust the inspection severity depending on test results and manufacturer behaviour.

8.2.2.2 Selecting the test specimens and repeat tests

The test specimens are selected arbitrarily from the batch. If the specimens pass the sampling test, then the batch shall be accepted. If one test specimen does not pass the sampling test, the test shall be repeated but with twice the number of samples selected from the same batch. If all the new test specimens pass the tests, then the batch shall be accepted. If any test specimen fails the sampling test, then the batch shall be rejected. Test specimens subjected to the sampling test shall not be used for further testing or in service.

8.2.2.3 Material verification

Sampling tests shall include verification of materials to ensure that they are in accordance with contract documents. This verification shall normally be carried out by inspecting the documentation relative to material purchasing specifications, certificates of conformity or other quality documentation.

8.2.2.4 Verification of dimensions and visual test

To take account of the influence of variations in dimension and strength on the mechanical characteristics of the components, the dimensions influencing the characteristics according to 8.2.1.3 shall be determined on all inspected specimens. All values shall be recorded in the test report.

The critical dimensions important for correct function shall agree with the values determined in the appropriate standards and supplier's drawings.

Sampling tests shall include visual examination to ascertain conformity of the components, in all essential respects, with the design drawings.

8.2.2.5 Functional test

The functional test may be performed in accordance with 8.2.1.4. The components or clamps shall be assembled according to the supplier's assembly instructions. Existing bolts shall be tightened to 1,1 times the tightening torques stated in Table 17. The critical dimensions for correct function shall be checked.

No defects impairing the function of the components or clamps are acceptable. Deformation intended in the design is acceptable if it does not impair the function.

8.2.2.6 Tensile test

The testing shall comply with the requirements set out in 8.2.1.5, but subject to the differences set out in the paragraph directly below.

The test specimens are initially loaded with a load increment of 5 N/mm^2 per second to 10 N/mm^2 per second, related to the conductor cross-section, constantly and smoothly up to a force amounting to the permissible operating force $F_{\text{perm.op}}$ multiplied by the determined rating factor, and the remaining shape change shall be determined. This shall be done either on a force-distance diagram or by checking the connection dimensions after relaxation and removal of the test specimens. The test specimen shall be then reloaded with the same load increment up to the maximum force F_{max} or up to failure of the component.

8.2.2.7 Evaluation of the test for components

All test values shall be recorded in the test report and statistically evaluated.

In the case of accessory parts for insulators and support assemblies, the following characteristics shall be determined:

- the component shall not have a permanent deformation which affects its functionality after applying a load of 1,33 times the operating load;
- the maximum force F_{max};
- the nature and place of failure of the test specimen, for example rupture, shape change, etc.

The force at which a deformation impairs the function shall be greater than the permissible operating force $F_{\text{perm.op}}$ required for the component. The maximum force F_{max} of the test specimen shall be equal to or greater than the required nominal force F_{nom} or that specified in the appropriate standards or drawings.

8.2.2.8 Evaluation of the test for clamps

The evaluation shall be undertaken according to the requirements set out in 8.2.1.5.2, and the requirements set out in the paragraph directly below.

The force at which a permanent deformation occurs, which affects the correct function of the test specimen, shall be greater than 1,33 times the permissible operating force $F_{\text{perm.op}}$ required for the corresponding component. The maximum force F_{max} of the test specimen shall be equal to or greater than the required nominal force F_{nom} or that determined in the appropriate standards or drawings.

8.2.3 Routine test

Routine tests shall be carried out on components which have an increased probability of failure to specific requirements and shall be made on every item. The intent of the tests is to prove conformity and to eliminate defective items.

Routine tests may include a specified level of material verification (including tests) where required by the contract quality plan.

Load tests shall be carried out with forces and conditions representative of normal operation. Initial cracks or fractures shall not occur on the test specimens once the routine test force is reached.

8.3 Contact wires

Contact wires shall be tested in accordance with the requirements set out in IEC 62917.

8.4 Other conductors

Wires or conductors shall be tested in accordance with the requirements of the relevant International Standards or, if they are not available, with European Standards in CEN/CENELEC countries or national standards in non-European countries. The following documents are usually applied in Europe and in other countries:

- EN 50182;
- EN 50183;
- EN 50189;
- EN 50326;
- IEC 62724;
- IEC 62641;
- IEC 61089;
- IEC 63248;
- IEC 63190.

In China, the following document is also applied:

- GB/T 1179-2017.

8.5 Tensioning devices

8.5.1 Tests required

Only type tests are required for tensioning devices.

8.5.2 Type tests for tensioning devices with balance weights

8.5.2.1 Tensile test

The tension device shall be tested in accordance with the requirements given in 7.5.

8.5.2.2 Dynamic test

Where applicable, the test of the fall arresting device consists of a simulated breaking of the conductor with the specified tension under laboratory conditions as specified by purchaser. The laboratory conditions should cover typical conditions of the purchaser’s system to ensure a reliable operation (e.g., load relieving due to rupture and displacement of pole and tensioning device).

8.5.2.3 Efficiency test

In accordance with the test shown in Figure 10, the mechanical efficiency of the tensioning device shall be determined. The test shall be undertaken with the following considerations:

- wind and ice load shall not be taken into account;
- at least four tests shall be performed on four wheel working positions evenly distributed at least over one rotation of one of the wheels or a quarter of the complete range of movement, firstly in one direction of rotation, then in the opposite direction.

The deviation of the tension of the conductor(s) shall be recorded and comply with the values given by the supplier.

The efficiency can be determined by Formula (20):

$$E = \frac{T}{W \times r} \tag{20}$$

where

T is the mechanical tension of the conductor (N) (see Figure 10);

W is the load of the balance weight (N) (see Figure 10);

r is the reducing ratio of the tensioning device.

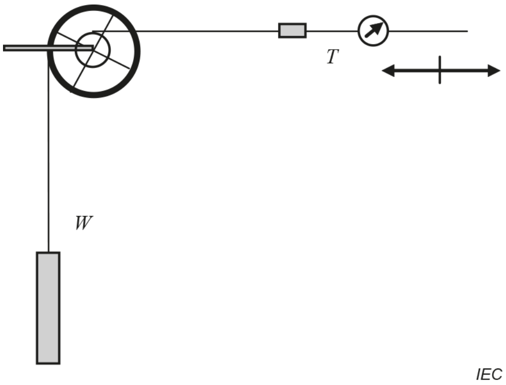


Figure 10 – Example of a tensioning device measurement test

If a field test is performed in cooperation with the purchaser on a comparable overhead contact line, the field test results may replace the efficiency test above. The field test shall run continuously, with a minimum duration of one year. To determine the behaviour within the overhead contact line system during the field test, it is necessary to install additional equipment like tensile force or elongation measurement instruments to measure and record the efficiency under different conditions and therefore over a wide working range of the tensioning device.

8.5.3 Type tests for tensioning device without balance weight

8.5.3.1 Tensile tests

Refer to 8.5.2.1 for tensile tests and 8.5.2.2 for dynamic tests.

8.5.3.2 Efficiency tests

The mechanical efficiency of the tensioning device shall be determined. In order to perform this test, the following assumptions shall apply.

- Wind and ice load need not be taken into account. If the tensioning device is intended to be used under ice conditions the efficiency test shall be performed under such conditions.
- The efficiency shall be measured on four locations evenly distributed over the complete range of movement, one direction first, and then the other direction.

The deviation of the tension of the conductor or wire(s) shall remain within the range specified by the supplier throughout the required range of temperature.

If a field test is performed in cooperation with the purchaser on a comparable overhead contact line, the field test results may replace the efficiency test above. The field test shall run continuously, with a minimum duration of one year. To determine the behaviour within the overhead contact line system during the field test, it is necessary to install additional equipment like force or elongation measurement instruments to measure and record the efficiency under different conditions and therefore over a wide working range of the tensioning device.

8.6 Mechanical midpoints

The testing procedures for any clamps, wires, termination fittings and insulators that constitute the mechanical midpoint assembly shall comply with the appropriate and specific requirements related to the component in Clause 8.

8.7 Droppers

8.7.1 Tests required

Only type tests are required for droppers.

8.7.2 Mechanical fatigue test

This test consists of an alternate load and compression cycle, as shown in Figure 11 a) or Figure 11 b). The droppers shall be tested with their specific clamping devices. The test parameters shall be defined within the range given below taking into account the operational conditions and the different types of contact line design.

The dropper lengths of the samples shall be specified between 0,15 m and 2,00 m.

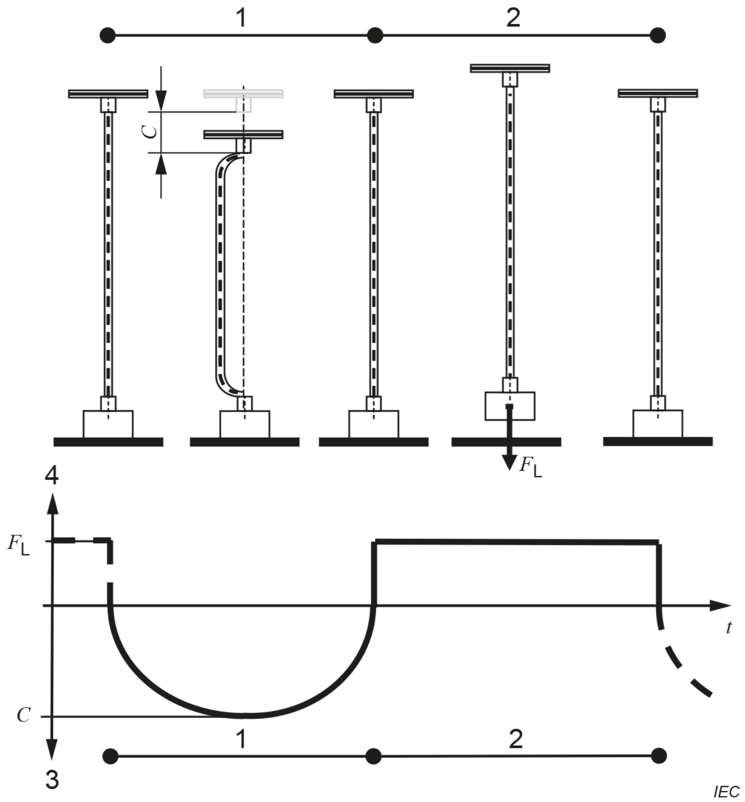
The compression distance C shall be specified, between 20 mm and 200 mm, and the force F_L in the dropper shall be specified, between 100 N to 400 N.

The frequency of the cycles shall be between 0,5 Hz and 10 Hz. The dropper shall not break before the specified number of cycles is exceeded. The purchaser should specify the minimum cycles, frequency, loading methods, loading curves according to Figure 11 and the criteria for breakage.

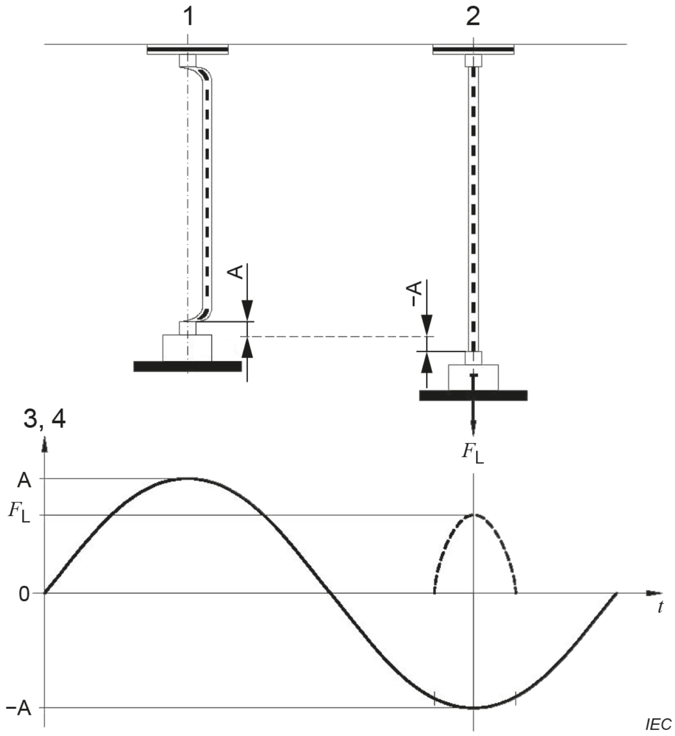
NOTE 1 A typical value of minimum number of cycles is 2 000 000.

NOTE 2 Frequencies are selected from within the frequency range depending on the intended application, based on simulations or measurement.

For special applications, such as low encumbrance and high uplift locations, the total length and the dimension for compression shall be reconsidered.



a) **Example 1**



b) **Example 2**

Key

1	half-cycle – dropper in compression	C	compression amplitude
2	half-cycle – dropper subject to force F_L	F_L	force
3	compression	t	time
4	force		

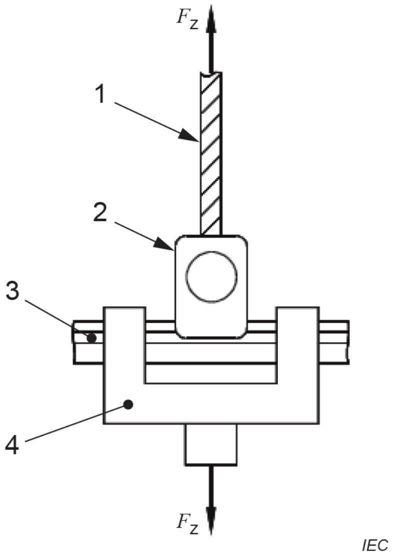
Figure 11 – Examples of a dropper test cycle

8.7.3 Mechanical tests

The dropper clip shall be installed on the corresponding wire according to the supplier's installation instructions.

For contact and catenary wire clips, separate tests shall be performed for each type of contact wire groove and catenary wire diameter. If the clamp is designed for both types of contact wire grooves or catenary wire diameters, only the smallest and the largest sizes are required to be tested.

An example of a dropper tension test assembly is given in Figure 12.



Key

1 dropper wire

2 dropper clamp

3 contact wire or other substitute with the same contact wire profile

4 contact wire adaptor

Figure 12 – Example of a dropper tension test assembly

The clamp shall not be pulled off until a force of at least 3 kN is reached.

8.8 Clamps, splices and other fittings

Clamps, splices and other fittings shall be tested in accordance with the relevant requirements set out in 8.2.

8.9 Electrical connectors

8.9.1 General

The electrical connection includes conductors and clamps. Only type tests are required for electrical connections.

The clamps shall be tested mechanically in accordance with the applicable subclauses in 8.2.1.5. The electrical test of the connection shall comply with 8.2.1.6.

In addition, the tests in 8.9.2 shall be performed.

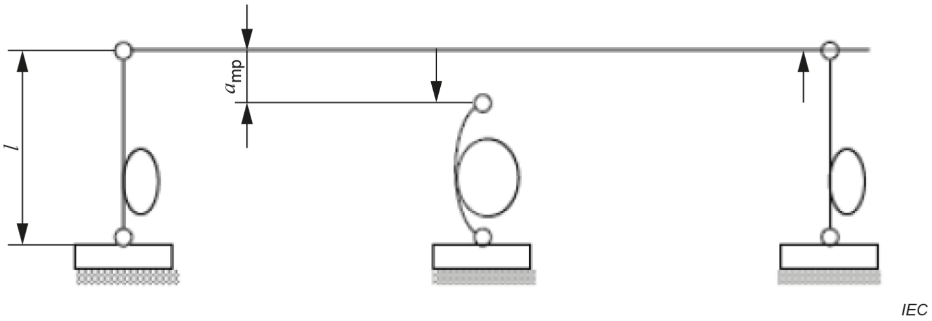
8.9.2 Mechanical fatigue tests

This test is only necessary for electrical connections used on lines with a speed of 160 km/h and higher if they are used at the contact wire. At least three complete electrical connections shall be tested. The test parameters shall be defined within the range given below taking into account the operational conditions and the different type of contact line design.

The following parameters shall be applied:

- the minimum specified length (l) of the connection;
- the amplitude (a) of the movement shall be up to 100 mm;
- frequency shall be 0,5 Hz to 10 Hz;
- minimum number of cycles shall be 2 000 000.

An example of a test cycle is given in Figure 13. The electrical connection shall not break before the specified number of cycles is exceeded.



Key

l minimum specified length

a_{mp} amplitude

Figure 13 – Example of a test cycle for an electrical connection

8.10 Insulators

Tests shall be carried out in accordance with the following standards.

Ceramic or glass insulator units or strings:

- IEC 60383 (all parts);
- IEC 60672-2;
- IEC TS 61245 (DC);
- IEC 61325 (DC).

Composite insulators:

- IEC 62621

Post insulators:

- IEC 60168;
- IEC 60660.

Specialised tests can be agreed between the purchaser and supplier as appropriate.

8.11 Sectioning devices

8.11.1 Type test

8.11.1.1 General

Type test certification shall be provided for the design of the sectioning devices verifying the electrical and mechanical parameters; the standards used shall be stated. Testing requirements and type tests shall verify the suitability of the components. Specifications shall be quoted for speed, weight, dimension, clearances and creepage distance, nominal voltage, short-circuit current, permissible working load and breaking load. The specification shall also state the environmental characteristics for which it is suitable (e.g., temperature, pressure, pollution degree, etc).

The insulating body of the sectioning device shall be tested separately in accordance with 8.10. Clamps and fittings of the sectioning device shall be tested according to 8.2.

The following tests shall be made on the whole sectioning device assembly.

8.11.1.2 Mechanical tests

Mechanical tests shall be carried out when assembled to a contact wire length through which the load will be applied.

The sectioning device shall be fixed in a tensile testing machine and loaded to the specified operational tensile load of the contact wire; the device shall be adjusted so that the runners are in their operational condition. The load shall be increased at a rate of approximately 1 kN/s up to 1,33 times the operational tensile load of the contact wire and held for 1 min. The load shall then be reduced to the operational tensile load of the contact wire. No permanent deformation with negative influence on function may occur.

The tension load shall then be increased at a rate of change of approximately 1 kN/s until a break occurs. The break shall occur at the contact wire.

8.11.1.3 Electrical tests

If required by the purchaser, electrical tests shall be carried out for the sectioning device and the suspension arrangement, in laboratory or under operational conditions. The device need not be loaded with the full mechanical tension.

To establish the insulating capability of the sectioning device, a lightning impulse test and power frequency test in wet and dry conditions according to IEC 62497-1 shall be undertaken. This test may also be used to confirm that the point of flashover for the sectioning device occurs where the designer intended.

In addition, an arcing test shall be performed to ensure that the sectioning device is capable of withstanding the expected levels of arcing without sustaining damage. The sectioning device shall be bridged by a wire at the same position where arcs are likely to be formed.

If the longitudinal length of a section insulator is more than 7 m, the test results of a shorter section insulator with the same material and the cross section may apply. The current shall be, as a minimum, be in accordance with the requirements set out in 7.11.3 limited to the maximum operational current of the sectioning device, as defined by the supplier. A voltage shall be applied to the sectioning device. The flashover shall occur on the intended parts and be extinguished by the device. The flashover shall not affect the mechanical integrity of the sectioning device.

A short-circuit test shall also be performed to ensure that the sectioning device can withstand the flow of short-circuit current without damage. A short-circuit current, of duration and magnitude as defined by the supplier, shall be applied. The effects of the short-circuit current shall not affect the mechanical integrity of the sectioning device.

8.11.2 Field test

The electrical test can be replaced by field tests. These tests shall be carried out as agreed between the purchaser and the supplier.

Other tests when specified by the purchaser shall be performed, such as a field test in operation. Should a field test be undertaken, the duration for the test should be one year and the sectioning device should be inspected at regular intervals as defined by the purchaser.

8.11.3 Sampling tests

At least 2 % of specimens, or alternatively a number defined in accordance with ISO 2859 (all parts), from each batch shall be tested with the following procedures:

- visual inspection to verify identification marks;
- verification of dimensions and weight, as given by the supplier's drawing.

8.11.4 Routine tests

All sectioning devices shall be subjected to a routine visual inspection.

8.12 Disconnectors and drives

Testing of disconnectors and drives shall be performed according to the requirements of the applicable standard:

- IEC 61992-4 for DC disconnectors, switch-disconnectors and earthing switches;
- IEC 62505-2 for AC disconnectors, earthing switches and switches.

For routine testing, the overhead contact line disconnector, earthing switches and switches shall be tested together with their drives and linkages on site. The routine testing on-site includes mechanical operations test and checking of clearances according to installation guides for verification of dielectric requirements.

Additional tests may be agreed between purchaser and supplier as appropriate.

NOTE It can be difficult to perform some tests on site, for example dielectric test if other than checking of clearances and determining operation speed of disconnector.

8.13 Surge protection and voltage limiting devices

Surge protection devices and voltage limiting devices shall be tested in accordance with IEC 62848 (all parts) and IEC 60099-4.

8.14 Specific components for trolleybus systems

Routine tests shall be performed in a laboratory under normal operating conditions. Alternatively, tests may be performed in service based on agreements between supplier and purchaser.

All turnouts shall be checked by routine tests, in accordance with IEC 61992-1.

Electrical tests, such as dry or wet power voltage frequency tests, shall be performed in accordance with IEC 61992-1 and IEC 60529.

Type tests for turnouts, such as lightning impulse voltage, shall be undertaken in accordance with IEC 61992-1.

8.15 System test

8.15.1 Demonstration of conformity

For the purposes of providing a demonstration of conformity, an overhead contact line "as built" and its design shall be considered to conform with the requirements of this document if the following are fulfilled.

- The current collection system is designed in accordance with the design requirements of 5.2. Verification shall be via simulation and/or full scale line testing.
- Full-scale line tests form the most adequate means of demonstrating that a newly installed overhead contact line satisfies the quality requirement of this document for a given running speed. Full-scale line tests shall be carried out on installed equipment using instrumented vehicles/pantographs. The instrumentation shall have a minimal effect on pantograph performance and shall be in accordance with IEC 62846.
- Computer simulations are suitable for demonstration of the anticipated current collection performance, especially in comparison with existing lines or with other designs. The computer simulation programme shall be validated against measurements, in accordance with IEC 63453. When the current collection system has already been proven by practical operation on at least one existing line, it shall be deemed as a conformable system. The demonstration of conformity to the requirements given in 5.3 to 5.12 is performed by verification of design deliverables.
- The system components are designed in accordance with the requirements of Clause 7 and tested (routine and type test) as prescribed by the relevant subclauses of Clause 8.
- The structures are designed and calculated in accordance with the requirements of Clause 6.

  NOTE For information about methods of testing supports, see IEC 60652.
- The electrical and mechanical line parameters fulfil the electrical requirements given in 5.1 and both the static (dimensional validation test) and the dynamic (dynamic validation tests) design requirements given in 5.2 within the design tolerances.

In addition to the above aspects which are specifically linked to the demonstration of conformity, an overhead contact line "as built" and its design is also required to comply with all other requirements within this document, if conformity with this document is to be claimed.

The conformity assessment of an overhead contact line need only be performed once. The design of the overhead contact line system assessed in the processes above in a certain condition (e. g., line characteristics, climates, designated train speed, and pantographs) shall be considered to be demonstrated to conform to the requirements in the document and may be applied to lines in the same condition. The purchaser may consider this to be an acceptable demonstration of conformity.

8.15.2 Acceptance tests

Acceptance of the overhead contact line shall provide assurance that the requirements of the overhead contact line system in the design are reflected in the final installation. Such requirements shall include the following:

- verification that the overhead contact line system was built within the given construction tolerances;
- visual and physical inspection, from the ground and inspection car, for example foundation and poles, earthing, corrosion protection, insulation, cantilever position in relation to temperature and contact wire stagger and height and other component position in relation to the pantograph and pantograph gauge, clamps, droppers and electrical disconnectors;

- verification by measurement that the mechanical and electrical clearances conform to the specified design;
- verification by functional random sample tests that the installed components work properly, for example bolted connections, clamps, steady arms, flexible supports, disconnectors (manual and remote), tensioning and sectioning devices.

8.15.3 Commissioning tests

The electrical and mechanical integrity of the overhead contact line system shall be established once all previous requirements have been satisfied. The commissioning tests shall ensure all configurations with regard to electrical sectioning are in accordance with the design requirements and shall include the following:

- check that the system conforms to IEC 62128 (all parts);
- the nominal voltage is applied to the overhead contact line in accordance with national regulations;
- electrical section proving test in accordance with national regulations.

Dynamic tests shall be specified by the purchaser depending on the type and scale of the project. Dynamic validation shall be undertaken to ensure compliance with the performance criteria as defined in 5.2.

The interaction between the pantograph and overhead contact line shall be checked according to IEC 62486:2017 and IEC 62846:2016. A measurement vehicle may be used to measure and check the dynamic behavior of the current collection system.

NOTE Some countries also use ground based measurement systems for checking the dynamic behaviour of the current collection system.

9 Minimum documentation

9.1 General

Documentation should be provided as described in the following 9.2 to 9.5. Additional documentation may be required by the purchaser specification.

9.2 System specification

The system specification contains the fundamental design and system design data, as described in Clause 4 and Clause 5 respectively. It shall be produced in accordance with the purchaser’s specification or, if such specification is not available, as a separate system study.

9.3 Basic design

The basic design is based on the system specification and comprises all the relevant system, arrangement, assembly and component drawings.

9.4 Installation design

Installation design is the application of the basic design arrangements to the particular characteristics of the railway line. The result is a set of plans/documents, (e.g., layout plans, cross-sections, bill of quantities, etc.) which describe and illustrate how the system is assembled.

9.5 Installation and maintenance

General installation and maintenance document which outlines routine maintenance checks, instruction, processes and associated periods, should be provided by the contractor if required by the purchaser.

When specific installation or maintenance is required, all necessary documentation shall be provided to the purchaser.

Annex A
(informative)

Structural details

The thickness of supporting components made of steel should not be less than 4 mm. In case of hollow sections and tubes made of steel (excluding steady arms), the thickness can be reduced to 3 mm if effective protection against corrosion is ensured. These minimum dimensions apply also to elements made of aluminium or aluminium alloy. Lower thicknesses may be used for steady arms. The eccentricity of connections of members at nodes should be kept as small as possible.

In Table A.1, the dimensions of connections and edge distances of jointing components are recommended. The minimum distances between centres of boreholes should be not less than 2,5 times the diameter of the holes, and the edge distances rectangular to the direction of forces should be not less than 1,2 times of the diameter of the boreholes.

Table A.1 – Recommended dimensions of connections and edge distances of jointing components

Dimensions in millimetres

Dimension of bolt		**M12**	**M16**	**M20**	**M24**	**M27**	**M30**
Maximum diameter of borehole	Hexagon bolts and pins:	13	18	22	26	30	33
Minimum width of angle leg		35	50	60	70	75	80
Minimum edge distance in direction of the force	1) all types of members	20	25	30	40	45	50
	2) members under tension	25	35	40	50	55	65

For the design of solid-wall steel structures, the requirements are specified in ISO 10721 (all parts) and EN 1993-1-1 for CEN/CENELEC countries. Slip joint connections need not be verified by calculation if the requirements specified in EN 50341-1:2012, 7.4.8.3, in CEN/CENELEC countries are met.

Due consideration should be given to defining the limiting material thickness for drilling or punching of holes for rivets and bolts. The effect of the material ductility should be duly considered. In accordance with EN 1090-2 in CEN/CENELEC countries, punching is permitted provided that the nominal thickness of the component is not greater than 12 mm or 1,4 times the nominal diameter of the hole. Further limitations regarding the process of punching should be followed according to EN 1090-2:2018, 6.6.3, in CEN/CENELEC countries. Permanent supervision should ensure that sharp punches and suiting dies are used for manufacturing. Structural members which are permanently loaded in tension should not be punched.

Structures for overhead contact lines do not need special walkways for climbing and access to working positions. If required by a project specification or the operator, an adequate walkway may be specified. The elements of the walkways should be designed to meet the requirements according to 6.2.8.

Where anti-climbing provisions are required, refer to IEC 62128-1.

It is standard practice to provide concrete structures with inserts and other elements for the connection of cantilevers and tensioning equipment. The reinforcement or special bars are needed to provide earthing. Reinforcement can be carried out with or without pre-stressing. For closed tubular structures made of steel or concrete, ventilation is necessary to avoid corrosion caused by condensation of water inside the structure.

Annex B
(informative)

Information on wind load calculation

B.1 Peak velocity pressure calculation

For the peak velocity pressure calculation according 6.2.4.2, different parameters should be considered. For standard situations, the following recommendations may be used:

- basic wind velocity v_b is the reference wind velocity in m/s at a height of 10 m above ground averaged over 10 min having a return period in accordance with 6.2.4.1;
- air density ρ:

$$\rho = 1{,}225 \times \left(\frac{288}{T}\right) \times e^{-1{,}2\times10^{-4}} \times H$$

where

T is the absolute temperature in K;

H is the altitude in m;

- exposure factor $c_\mathrm{e}(z)$:

$$c_\mathrm{e}\left(z\right) = G_\mathrm{q} \cdot G_\mathrm{t}$$

where

G_q is the gust response factor. For overhead contact lines with heights of approximately 10 m, G_q should be 2,05; see Table B.1 for other heights;

G_t is the terrain factor taking into account the protection of lines, for example in cuts, cities or forests. In open terrain, G_t shall be 1,0; see Table B.2 for other terrain categories.

Table B.1 – Recommended values for gust response factor G_q

Terrain category	Gust response factor as function of height above ground										
	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m	55 m	60 m
I	1,77	1,72	1,69	1,67	1,65	1,64	1,63	1,62	1,61	1,60	1,59
II	2,05	1,96	1,91	1,87	1,84	1,82	1,80	1,78	1,77	1,76	1,75
III	2,72	2,51	2,38	2,30	2,24	2,19	2,15	2,12	2,09	2,07	2,05
IV	3,96	3,39	3,10	2,92	2,79	2,69	2,62	2,56	2,51	2,46	2,42

Table B.2 – Recommended values for terrain factor G_t

Terrain category	Terrain factor as function of height above ground										
	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m	55 m	60 m
I	1,37	1,54	1,66	1,77	1,85	1,93	1,99	2,04	2,10	2,13	2,19
II	1,00	1,17	1,30	1,39	1,49	1,54	1,61	1,66	1,72	1,77	1,82
III	0,59	0,74	0,85	0,94	1,02	1,10	1,17	1,21	1,28	1,32	1,37
IV	0,30	0,42	0,52	0,59	0,67	0,72	0,79	0,83	0,88	0,92	0,96

B.2 Drag factors C_{str}

Drag factors depend on the shape and surface roughness of the structure. In case no values are given in relevant national standards or purchaser specifications, the recommendations in Table B.3 may be used.

Table B.3 – Recommended values for factor C_{str} for different pole types

Mast type	C_{str}
Tubular steel and concrete structures with circular cross section	0,7
Tubular steel structures with dodecanal cross section	0,85
Tubular steel and concrete structures with hexagonal or octagonal cross section	1,0
Tubular steel and concrete structures with square or rectangular cross section	1,4
H profiles	1,4

Annex C
(informative)

Recommendations for ultimate limit state (ULS) design

C.1 General

The partial factors γ_M for materials to be considered for ULS design are used in accordance with the relevant national design standards to guarantee a coherent design approach. In case no values are given in national standards or purchaser specification, the recommendations in Clause C.2 and Clause C.4 may be used.

C.2 Material partial factors for structural calculations

The partial factors for timber structures may be taken as γ_M = 1,50, for the resistance of cross sections and elements. Partial factors for steel and concrete structures may be used according to Table C.1 and Table C.2.

Table C.1 – Recommended values for partial factors γ_M for steel structures

Structure type	γ_M
Resistance of cross-sections under tensile forces and bending	1,10
Resistance of members to buckling	1,10
Resistance of connections under shearing and bearing	1,25
Resistance of net cross-sections based on ultimate tensile stress under tensile load	1,25
Resistance of welded connections	1,25
Resistance of bolts in tension	1,25
Metallic ropes under tensile force	1,50

Table C.2 – Recommended values for partial factors γ_M for concrete structures

Structure type	γ_M
Pre-stressing force [a]	0,90 or 1,20
Concrete	1,50
Reinforcing steel (ordinary or pre-stressed)	1,15

[a] Depending upon whether the action is relieving or not for the calculated effect.

C.3 Design limits for pre-stresses concrete poles

Tensile stresses in the concrete of pre-stressed concrete poles are not permitted under the following conditions:

– 66 % of the sum of permanent and variable loads;

– sum of permanent and 40 % of variable loads.

C.4 Partial factors for foundations

The partial factors for the geotechnical design depend on the type of foundation and the type of loading. Recommended values are given in Table C.3.

Table C.3 – Recommended values for partial factors γ_M for foundations

Structure type	γ_M
Spread foundation	
Bearing resistance	1,4
Earth resistance and bearing resistance	1,4
Sliding resistance	1,1
Pile foundation	
Resistance for piles in compression	1,4
Shaft resistance for piles in tension	1,5

Annex D
(informative)

Geotechnical soil investigation and soil characteristics

Prior to determination of the type of foundation, its design and dimensions, the structure of soil down to a depth of at least the effective foundation width below the bottom face or deeper than the pile tip should be known in sufficient detail. Also, the geotechnical parameters should be known. Therefore, soil investigations should be carried out which form the basis to establish the geotechnical soil parameters. Other approved parameters and procedures may be used as well.

The basic information required for geotechnical design of pole foundations follows the provisions in EN 1997-1:2004, Clauses 2 and 3, in CEN/CENELEC countries. The planning of site investigations should also follow the provisions in EN 1997-1 in CEN/CENELEC countries considering the type of foundation planned.

Special considerations should be taken during the site investigations to find the following:

- geometrical data of the surface with respect to embankment slope and position of the track;
- levels of interfaces between fill layers and natural layers to a depth of at least twice the foundation width beneath the expected foundation level – in the case of compressible soft ground creating embankment settlements, the investigation depth can be increased;
- level of the groundwater table and its variation;
- types of soil and their strength and deformation properties;
- changes of the ground conditions along the railway;
- special condition with respect to installation of the foundation (very soft soils, rock surface, boulders, etc.).

The geotechnical properties for design should be evaluated according to the guidelines in EN 1997-2 in CEN/CENELEC countries. Special considerations should be taken when the deformation properties of the upper embankment fill layers should be assessed as well as when excavated and back-filled material should be investigated, compacted or not.

Cone penetration tests or dynamic probing are proposed for finding the layering and basic estimates of parameters. Cone penetration tests are proposed in fine-grained soils and dynamic probing in coarse-grained soils. Sampling and following laboratory investigations are proposed in a number of selected representative points for identification of soils and determination of characteristics of existing fill material. In situ-measurements with a pressure meter in deep fills and cohesionless soils and field vane in cohesive soils are recommended.

Geotechnical investigation and laboratory testing should be executed according to ISO 22475-1, ISO 22476-2, ISO 22476-3 and ISO 17892 (all parts).

The site investigation should also consider the environmental conditions on the site as a basis for assessing the durability of the foundations. See EN 1997-1:2004, 2.3, in CEN/CENELEC countries.

For foundations installed by excavation and back-filling, representative samples of the filling material should be taken and investigated considering the provisions in EN 1997-1:2004, Clause 5, in CEN/CENELEC countries.

In case of concrete back-filling, the provisions in EN 1992-1-1 in CEN/CENELEC countries should be followed.

The results of the geotechnical investigations should be compiled in a Ground Investigation Report according to the provisions in EN 1997-1:2004, 3.4, in Europe. Identification and classification of soil and rock should follow the principles in ISO 14688-1, ISO 14688-2 and ISO 14689-1.

Where no other information is available, the geotechnical characteristics set out in EN 50341-1 in CEN/CENELEC countries (see Table D.1) can used for foundation design when their validity has been verified.

Table D.1 – Geotechnical characteristic parameters of some standard soils according to EN 50341-1:2012, Table M.2

Soil	γ	γ'	**Φ′**	**c′**	**cu**
	kN/m^3	kN/m^3	degree	kN/m^2	kN/m^2
Marl, compact	20 ± 2	11 ± 2	25 ± 5	30 ± 5	60 ± 20
Marl, altered	19 ± 2	11 ± 2	20 ± 5	10 ± 5	30 ± 10
Gravel, graded	19 ± 2	10 ± 2	38 ± 5	-	-
Sand, loose	18 ± 2	10 ± 2	30 ± 5	-	-
Sand, semi-dense	19 ± 2	11 ± 2	32 ± 5	-	-
Sand, dense	20 ± 2	12 ± 2	35 ± 5	-	-
Sandy silt	18 ± 2	10 ± 2	25 ± 5	10 ± 5	30 ± 10
Clayey silt	19 ± 2	11 ± 2	20 ± 5	20 ± 10	40 ± 10
Loam, Silt, malleable	17 ± 2	7 ± 2	20 ± 5	-	20 ± 10
Clay, soft	17 ± 2	7 ± 2	12 ± 5	6 ± 2	19 ± 5
Clay, semi-stiff	19 ± 2	9 ± 2	15 ± 5	11 ± 3	37 ± 12
Clay, stiff	20 ± 2	10 ± 2	20 ± 5	22 ± 8	75 ± 25
Clay Till	20 ± 2	10 ± 2	30 ± 5	12 ± 7	400 ± 350
Clay, with organic addition	15 ± 2	5 ± 2	15 ± 5	-	-
Peat, Marsh	12 ± 2	2 ± 2	-	-	-
Backfill, embankment, medium compaction	19 ± 2	10 ± 2	25 ± 5	-	15 ± 5

Annex E
(informative)

Overhead contact line for electric vehicles with pantographs on electrified roads

E.1 General OCL properties and road characteristics

To achieve cross-national interoperability and functionality of electric road systems (ERS), the informative Annex E provides exemplary specifications for the design of an overhead contact line system for ERS.

Electric road system is a system that enables power transfer to electric road vehicles whilst they are driving and during standstill.

The ERS comprises a bi-polar overhead contact line (OCL) system with feeding and return circuits for power supply of electric trucks especially on highways, which should be designed in accordance with Annex E. The maximum design speed of the OCL system (OCLS) is 100 km/h.

The following road characteristics and operational requirements for electrification with OCLS can be considered as a reference:

- multiple lanes per direction in separated driveways and lanes running in opposite directions separated by guards;
- hard shoulders;
- electrified sections fulfil additionally minimum clearance according to Clause E.6;
- no major surface unevenness on the electrified lane, within a 4 m long measuring section, deviation of evenness of maximum 7 mm is not exceeded in longitudinal and transverse direction;
- the longitudinal slope of the carriageway is a maximum of 4,5 %;
- cross carriageway gradient maximum 6 %;
- minimum radius of curves: 720 m; the tightest curves that can be used for a given transit mode, measured as the radius of the curve at the centre line of the electric truck;
- maximum permitted vehicle speed connected to OCLS: v_{max} = 80 km/h;
- all height dimensions are measured perpendicular to the idealized top of the road.

E.2 Electrical properties of the OCL

- Polarity: The right contact wire pole in the direction of travel (x-direction) is the positive potential. The left contact wire pole is the negative potential.

  The type of traction power supply system is a symmetrical system.

  NOTE The positive and the negative terminals are connected to a voltage divider. Its mid-point will be connected to earth. Thereby the nominal output voltage is equally divided into a positive voltage and a negative voltage of same magnitude.
- Voltage: The nominal system voltage is DC 1,5 kV.
- Insulation: The safety requirements regarding insulation coordination should be met in accordance with IEC 62497-1.

  Insulators exposed to salt spray, for example, from road de-icing, shall be dimensioned with greater creeping distances according to local conditions.
- Electric clearances: Clearances between live uninsulated parts of OCLs and structures or vehicles should at least comply with 5.1.3. The safety distances specified in IEC 62128-1 and creeping distances are dimensioned according to IEC 62497-1.

E.3 Capacity and service life of the OCL system

The entire OCLS should be designed for vehicle sequences up to 17 vehicles (with pantograph) per minute at v_{max} = 80 km/h.

For the design of the contact wire system, a planned service life of the system of 20 years with up to 14 million driving cycles within these 20 years is projected.

E.4 OCL properties

E.4.1 OCL mechanical properties, horizontal and vertical dimensions

- The tensile forces of the conductor wires should be selected from a range between 15 kN and 25 kN in such a way that the position parameter requirements in Table E.2 and Table E.3 are met. It is recommended to use a value of 20 kN.
- Unless specified otherwise, the following contact wire specifications in Table E.1 are used.

Table E.1 – Standard contact wire specifications

Parameter	Definition
Contact wire type and profile	IEC 62917 type AC-150 – CuMg0,5 [a]
Maximum permissible wear	20 % in average with local exceptions permissible with up to 30% at for example hard points, side supports or contact wire splices.

[a] Other contact wire profiles can be used as long as the overall pantograph-and OCL interaction, traction power requirements, material pairing in the contact surface and infrastructure lifetime and compliance of the remaining system with this document are assured and proven.

See 5.3 for permissible tensile stress and safety factor of the contact wire.

- If overhead contact lines with catenary suspension are used for highway applications, the dropper spacing should be 3 m to 4 m to reduce the risk of broken wires to contact road vehicles. The vertical and horizontal position parameters of the OCLS are given in Table E.2 and Table E.3.

Table E.2 – Contact wire vertical position parameters, all values measured perpendicular to the idealized top of the road surface

Symbol	OCLS characteristics	Value
HCW_{min}	Minimum contact wire height, should always be greater than the height of the reference profile (area for traffic beneath the OCLS). At no point in time the contact wire may violate this limit. The value shall be defined within a specific project in accordance with local regulations. It may be equal or greater than the minimum height for an OCLS as specified by national regulations.	n. a.
HCW_{n}	Nominal height of contact wire The value should be defined in project planning based on remaining space between HCW_{min} and $HCW_{\text{max,stat}}$.	n. a.
HCW_{safe}	Safety clearance height/safety height of vehicle and pantograph	6,00 m
$HCW_{\text{max,stat}}$	Maximum contact wire height (static, in resting position). Maximum static height of contact wire without PAN contact. May be calculated for each span by infrastructure supplier based on OCL design and nominal PAN contact forces.	n. a.
$UL_{\text{CW.max}}$	Maximum contact wire uplift during normal operation. This applies for the uplift at the support as well as in the span.	100 mm
$HCW_{\text{max,op}}$	Maximum operation height of contact wire (incl. contact wire uplift UL_{CW}). This also represents the upper limit of the PANs working range at nominal contact force.	5,70 m
$\Delta HCW_{\text{max,stat}}$	Maximum height deviation between the two contact wires (static, in resting position)	50 mm
$\Delta HCW_{\text{max,op}}$	Maximum height deviation between the two contact wires (dynamic, in operation)	80 mm
	Maximum longitudinal inclination of contact wire between neighbouring support points Measured relation to the idealized road surface, and based on the projected contact wire height	6 ‰
	Maximum change of the longitudinal inclination of the contact wire at the support points Measured as the change between two contact wire supports, and based on the projected contact wire height	3 ‰

– The two contact wires are positioned equidistant and parallel relative to the middle of the electrified lane. The OCLS does not feature a contact wire stagger.

Table E.3 – Contact wire horizontal position parameters

Horizontal dimensions	Value
Nominal distance The nominal distance between the feeding and return contact wires, measured between the middle-axes of the wires; except for overlap spans	1,15 m
Construction and operating tolerance for nominal distance between contact wires in relation to the nominal contact wire spacing along the span (Exact value used for engineering in planning tools, on site however for practicability ±160 mm may be applied)	±158 mm
Construction and operational tolerance of horizontal position of contact wires Describes the maximum permissible deviation of the centre of both contact wires at the same time towards the centre of the electrified lane, for example, due to wind downforce; includes requirements for planned structures (e.g., overlap spans)	±250 mm

– In case of overlap spans, see Figure E.1, two equipotential catenaries feature a nominal distance of max. 10 cm.

– The OCLS features only uninsulated overlaps.

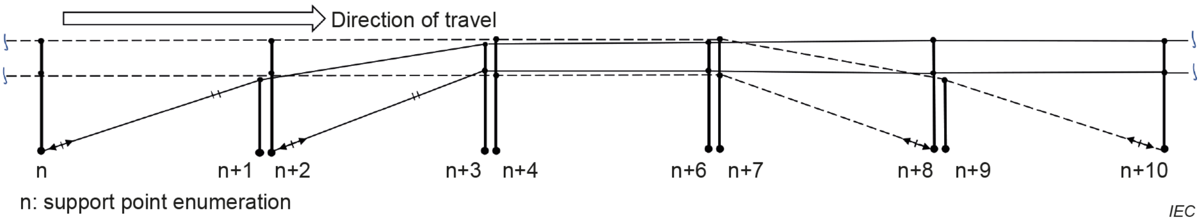


Figure E.1 – Overlap span (plan view, exemplary design for anchoring, representation without electrical connections)

E.4.2 Design of begin and end of OCLS

The following specific points are defined for an OCLS (see Figure E.2). The values given may be considered as a reference and can be different due to project specifics.

0 First support of the OCLS – Starting point of the system

- The overhead contact lines are fed in from the side at a height > 6,0 m (safety height).

1 First OCLS support above electrified lane contact wire height at > 6,0 m

- The OCLS is from here on further lowered towards the maximum operational height.

2 Contact wire lowers below maximum operational height (5,80 m)

- The OCLS from this point on should comply to the specifications described in this document, for example, nominal position, distances between contact wires, clearances, and the maximum contact wire gradient

3 Contact wire at nominal height

4 Point after which a rising pantograph will not be able to reach the contact wire (at max. permitted vehicle speed, v_{max})

- If, at this point, the pantograph is raised, the pantograph-OCLS contact cannot be established prior to reaching the end of the system.
- Depending on the gradients, point 4 and point 5 may be reached in different sequence

5 Contact wire rises above nominal height,

6 Contact wire rises above maximum height (5,80 m). Pantographs in contact with the OCLS will detect this and lower automatically.

- At the end of the OCLS, the contact lines are first raised to a height of > 6,0 m before being led out to the side.
- For the defined end of the OCLS, the maximum gradient is 8 % until the height of 6,0 m is reached.

7 Last support of the OCLS – end of the system.

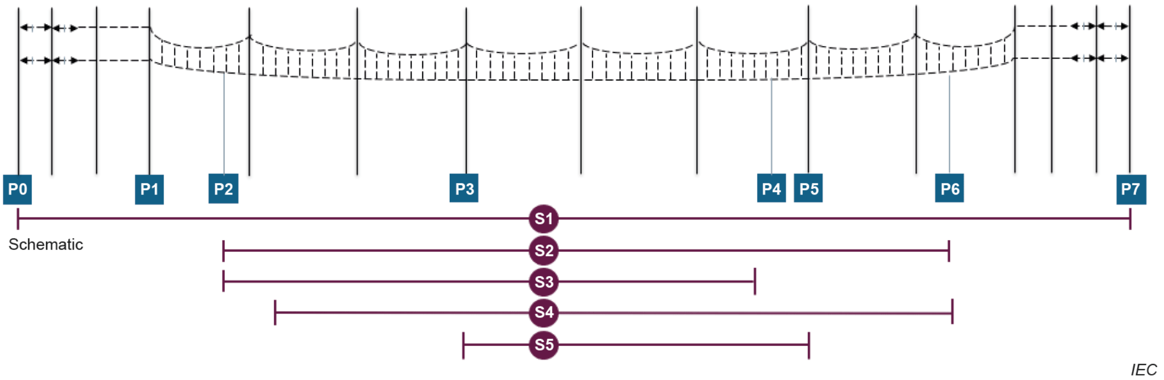


Figure E.2 – Defined points along the OCL (side view, idealized)

For simplification, areas of lowered contact wires, for example under bridges, have not been considered in Figure E.2.

The specific distances showed in Table E.4 are defined for an OCL section (see Figure E.2).

Table E.4 – Defined points along the OCL (side view)

Number	Definition
P0	First pole of the OCL – starting point of the system
P1	First support of the OCL above electrified lane height ≥ 6,0 m
P2	Contact wire at maximum operational height (5,8 m). Start of contact wire area where connection with a pantograph is possible.
P3	Contact wire at nominal height
P4	Point after which a raising pantograph will not be able to reach the contact wire (at $v_{\max}$)
P5	Contact wire rises above nominal height
P6	Contact wire rises above maximum height (5,8 m). Pantographs will detect this and lower automatically.
P7	Last support of the OCL – end of the system
S1	Overall OCL length – also system length
S2	Section theoretically available for connected operation
S3	Section where raising a pantograph is to be permitted
S4	Section available for connected operation
S5	Section with contact wire at nominal height

E.4.3 Uplift and dynamic properties of the OCL

The OCL system is designed in such a way that the resulting catenary uplift in normal operation is limited to ≤ 100 mm, if the pantograph contact force remains within the permissible range as in Table E.5, which ensures the maximum height of 5.80 m is not exceeded.

During evasive manoeuvres, the pantograph might push towards one contact line only. For such situations, the OCLS should be designed in a way that the resulting catenary uplift is limited to ≤ 150 mm in case the pantograph contact force increases to 300 N for a short period (max. 0,1 s). This applies over the entire operating life of the system and thus also at maximum contact wire wear.

E.5 Contact forces

The OCLS should be designed to accommodate the contact forces of ERS pantographs without exceeding the OCL operational tolerances.

Table E.5 – Contact forces pantograph – OCL

Definition	Contact force limits	
	Minimum	**Maximum**
	N	N
Dynamic contact force while connected	30	300
Static contact force at standstill	70	140

Values are valid if the height difference between the collector heads stays within the defined limits including the following special situations.

- Dynamic contact force can be 0 N (= contact is lost), for example, at section insulators or due to potholes.
- Dynamic contact force may be above 300 N for less than 300 ms while connecting/disconnecting to the OCL or due to for example, potholes.
- If the vehicle lowers this height for operation (e.g., pneumatic springs are used to adapt to trailer type), the maximum operating height of pantograph will be reduced as well. The contact forces as defined above refer to the highest height of the vehicle as defined in an interface between pantograph and vehicle. Thus, a reduced static and dynamic contact force of the pantograph are permissible for the maximum operating height of the pantograph.

E.6 ERS clearance requirements

E.6.1 General

The clearance should always be kept free for OCLS traffic. This also includes safety distances to live parts.

The standard clearance space is divided in the transverse plane of the lane into an area (clearance space) below the contact wire and an area next to and above the contact wire, which is defined by possible movements of the pantograph.

In addition to the clearance for the pantograph and the vehicle, the components of the overhead contact line, in particular wires and cables, should also maintain a minimum electrical-mechanical clearance, both in height and width, from the vehicle and pantograph. This minimum distance can be understood as the clearance around and above the components in the overhead line.

In general, the overhead contact line system should be designed in such a way that the structure gauge is kept clear under all operating conditions.

Figure E.3 shows an overview of the clearances and the surrounding of ERS vehicles. A more detailed view is content of Figure E.4; see also Table E.6.

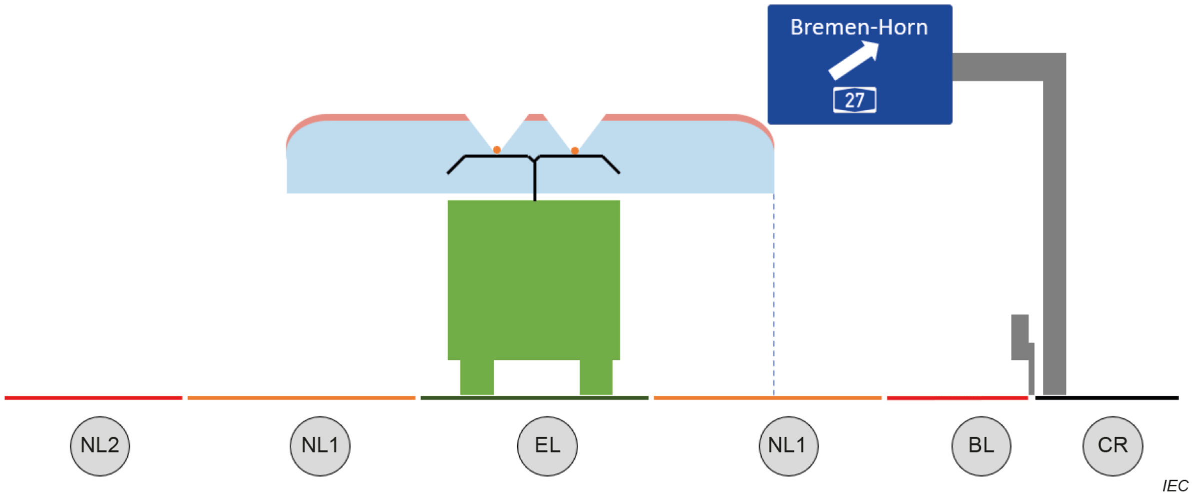


Figure E.3 – Clearance gauge overview

Table E.6 – Clearance gauge overview description

No.	Description
NL1	1st neighbouring lane – regular trafficable lanes, could also be, for example, an exit ramp or break down lane opened to traffic
NL2	2nd neighbouring lane – passable in exceptional cases
EL	Electrified lane
BL	Breakdown lane – passable in exceptional cases
CR	Central reservation – impassable area

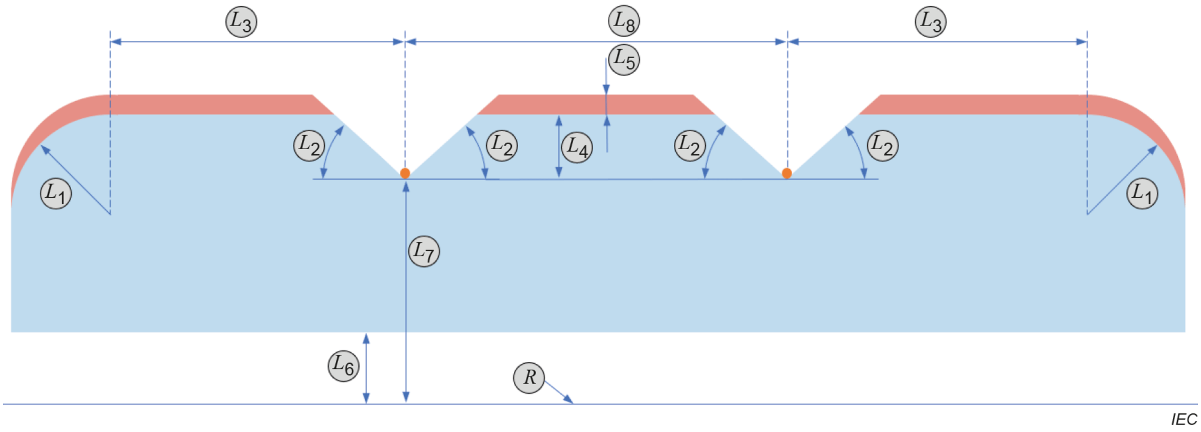


Figure E.4 – Clearance gauge detail

The blue (lower) area in Figure E.4 is defined as the mechanical clearance profile for the pantograph, the red (upper) area is the electrical clearance profile for the pantograph. Table E.7 contains the defined values for the symbols in Figure E.4. The pantograph may only use the blue area during operation. The red area and all areas above the red area should be kept clear by any installation to prevent collisions.

Table E.7 – Pantograph clearance definitions

No.	Value	Description
L_1	Maximum 800 mm	Radius of clearance area for pantograph at the sides
L_2	Minimum 49°	Angle of the clearance profile to the side of the contact wires in any height.
L_3	Minimum 5 200 mm	Width of the clearance profile to the side of the contact wires in any height This value includes the lateral electrical clearance. NOTE This value is dimensioned for an evasive manoeuvre at a maximum permissible vehicle speed of 80 km/h in combination with a rapid lowering of the pantograph. For different speeds L3 is recalculated accordingly.
L_4	Minimum 150 mm	Height of the mechanical clearance profile above the contact wires in any height
L_5	Minimum 50 mm	Height of the electrical clearance profile above the mechanical clearance profile
L_6	4 000 mm (see description)	Height of the mechanical clearance profile above the road surface. First definition for the value is 4 000 mm in CEN/CENELEC countries according to European Council Directive 96/53/EC, other values might be applicable, for example for snow covered road surfaces or special regulations in some countries.
L_7	See description	Lifted height of the contact wires when in contact to pantograph above the road surface, depends on un-lifted height.
L_8	1 150 mm	Nominal contact wire distance between their centres
R	n.a.	Idealized road surface as reference

In addition to the angles of attack defined here for the pantograph clearance, further operating angles should be considered for the design of the overhead contact line, for example, for the possible inclination of the contact wire terminals.

- The clearance height is the vertical height measured perpendicular to the idealized road surface from the projected nominal position of the lower edge of the contact wire.
- The specified clearance profiles apply under the operating conditions as designed in the specific project. Alternatively, it should be ensured in the project that the use of the system is prevented if the defined values (e.g., in strong wind) can no longer be maintained.

E.6.2 Contact wire clamps

Since butt connector clamps, Z-rope clamps and current clamps are only used at individual locations on the overhead contact line, the defined angle of attack may be reduced here, if it is ensured by design that a pantograph contact horn can slide past the clamp without any impact. The functionality of the solution should be proven using sufficient tests or simulations.

E.6.3 Miscellaneous structure gauges and clearance requirements

If the construction and operating tolerances are demonstrably lower due to the overhead contact line construction (e.g., in the case of overhead conductor rails or lowering with 2nd contact wire), the value for the maximum uplift in the event of an accident and for the construction and operating tolerances of the contact wire for the clearance gauge may be adjusted.

Individual verification should be provided for this purpose.

E.6.4 Structure gauge width – Lateral clearance requirements

The described clearance profiles apply over the entire installation area of their reference points and parts and over a lateral area next to the electrified lane to ensure safe operation when lowering the pantograph. The time until the pantograph starts lowering should be considered in case no lowering command is sent by the vehicle during unexpected and fast lateral driving manoeuvres.

Therefore, height-limiting structures in regularly or exceptionally used traffic space (including hard shoulders) should also be considered when designing overhead contact line systems even if they are not located directly above the electrified lane (e.g., cantilevers on exit lanes).

The clearance gauge profiles contain the specifications for the clearance width (see Figure E.4 and Table E.7). Height-limiting structures over non-trafficable space are not relevant.

E.6.5 Clearance under bridges or height-limiting structures

In case of unavailability of clearances as described in this Annex E, viable solutions may still be designed by limiting the OCLS tolerances as well as the maximum OCL lift. However, the mechanical clearance height of the pantograph of 150 mm and the electrical safety distance of 50 mm above the highest overhead contact wire layer should be maintained in any case. A reduction of the clearance required for electrification above the projected position of the contact wire can be achieved by special measures in the overhead contact line system. The lowering and guiding of the overhead contact line at height-limiting structures should always be evaluated project specific for each structure, as angle of inclination, installation options and the resulting contact wire position tolerances vary.

Annex F
(informative)

Information on uniformity of elasticity of OCL within a span length

In case of high-speed lines, a parameter u as low as possible should be aimed at.

Table F.1 gives values for u, which are reasonable for specific types of overhead contact lines.

Table F.1 – Uniformity u of elasticity

			In %
Type of contact line	**Running speed**		
	km/h		
	200 to 230	230 to 300	Above 300
Without stitch wire	< 50	< 40	< 30
With stitch wire	< 20	< 15	< 10

Annex G
(informative)

Seismic actions for OCS poles on viaducts

The following evaluation method for the safety of overhead contact line poles on viaducts may be used in earthquake-prone areas (see Figure G.1).

a) Evaluate the response wave of the crown of the viaduct to the ground motion.

b) Calculate the acceleration from the waveform of the crown of the viaduct, and then input this acceleration into the foundation of the pole and evaluate the response acceleration of the support. The calculation results of the above-mentioned steps need to be provided by the party responsible for the viaduct or substructure. This calculation cannot be performed by the designer of the overhead contact line supports.

c) Evaluate the maximum moment of the support generated by this acceleration.

d) Compare the maximum moment of the support with its limit moment to evaluate the safety.

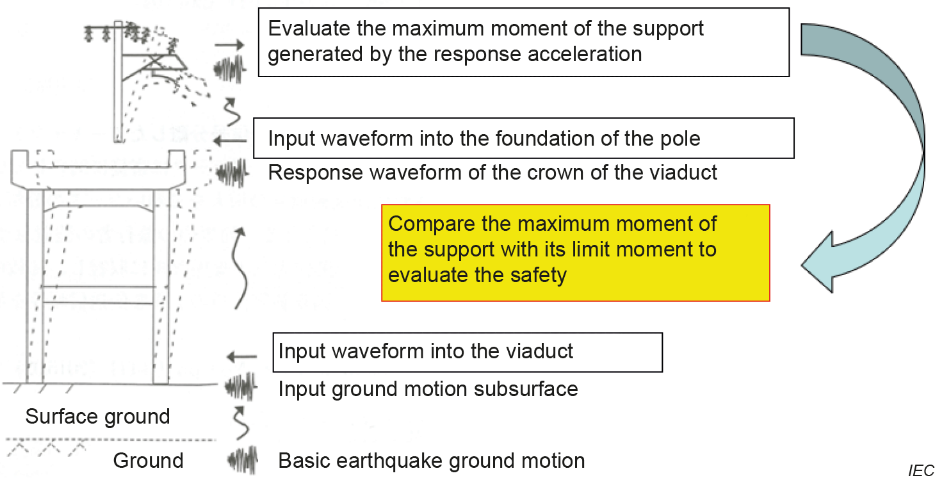


Figure G.1 – Simulation method for evaluation for the safety of poles against earthquakes

If the estimated maximum moment of the support exceeds its breaking strength, measures should be taken to assure the safety of poles.

Annex H
(normative)

Special national conditions

Special national condition are national characteristic or practice that cannot be changed even over a long period, for example climatic conditions, electrical earthing conditions.

For the countries in which the relevant special national conditions apply, these provisions are normative.

Clause Special national condition

5.14 China

Typical tolerances of overhead contact line system

In order to achieve better behaviour between the pantograph and OCS to satisfy the safety requirement of the operation, the tolerances of overhead contact line system should be complied with the values in Table H.1.

Table H.1 – Typical tolerances of overhead contact line system

No	**Description**	**Running speed km/h**			
		≤ 120	> 120 to < 200	= 200 to < 300	≥ 300
1	Tolerance of the height of contact wire [a,b,c]				
1.1	At register points	±60	±30	± 30	0, + 20
1.2	Between adjacent register points	±50	±20	± 20	0, + 10
1.3	Between adjacent dropper points per 10 m	±20	±10	± 10	0, + 10
2	Tolerance of stager	±50	±50	+30, −50	0, −50
3	Permissible lateral deflection of the contact wire under action of cross-wind (3)	400 ± 50	400 ± 50	450 ± 50	450 ± 50

[a] For connecting lines with mixed freight and passenger traffic for operation of trailers with oversized gauge, the contact wire height may be higher provided the pantograph is suited to collect the current with the specified quality and the development of the pantograph is sufficient as specified in the IEC 60494 series.

[b] At level crossings, the contact wire height shall be designed according to national directives.

[c] The contact wire height and wind speed to be considered will be defined in the register of infrastructure defined in IEC 62498-2.

5.1.3 Japan

Clearances between live parts of contact lines and earth

The value for the typical dynamic clearance (ECd) in AC 25 kV (30 kV) is 300 mm.

Whole document **CEN/CENELEC countries**

Normative references

Normative references are made to ISO and IEC standards. For some necessary references, ISO and IEC standards do not exist. In these cases, references are made to European Standards which are normative for countries which are members of CEN/CENELEC. For countries which are not members of CEN/CENELEC, these references are only informative and listed in the Bibliography.

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[3] This publication has been withdrawn.

[4] IEC 60721-2 (all parts) is harmonised as HD 478.2 (all parts).

[5] This publication has been withdrawn.

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[6] This publication has been withdrawn.

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