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Railway applications – Current collection systems – Validation of simulation of the dynamic interaction between pantograph and overhead contact line

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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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RAILWAY APPLICATIONS – CURRENT COLLECTION SYSTEMS – VALIDATION OF SIMULATION OF THE DYNAMIC INTERACTION BETWEEN PANTOGRAPH AND OVERHEAD CONTACT LINE

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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.

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RAILWAY APPLICATIONS – CURRENT COLLECTION SYSTEMS – VALIDATION OF SIMULATION OF THE DYNAMIC INTERACTION BETWEEN PANTOGRAPH AND OVERHEAD CONTACT LINE

1 Scope

Simulation techniques are used to assess the dynamic interaction between overhead contact lines and pantographs, as part of the prediction of current collection quality. This document specifies functional requirements for the validation of such simulation tools to ensure confidence in, and mutual acceptance of the results of the simulations.

This document deals with:

– input and output parameters of the simulation;
– comparison with line test measurements, and the characteristics of those line tests;
– validation of pantograph models;
– comparison between different simulation tools;
– limits of application of validated methods to assessments of pantographs and overhead contact lines.

This document applies to the current collection from an overhead contact line by pantographs mounted on railway vehicles. It does not apply to trolley bus 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 60494-1:2013, *Railway applications – Rolling stock – Pantographs – Characteristics and tests – Part 1: Pantographs for main line vehicles*

IEC 60913:2024, *Railway applications – Fixed installations – Electric traction overhead contact line systems*

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

3 Terms and definitions

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
contact point
<for a pantograph> location of mechanical contact between a pantograph contact strip and a contact wire

3.2
contact force
F
<for a pantograph> vertical force applied by a pantograph to the overhead contact line

Note 1 to entry: The contact force is the sum of forces of all contact points of one pantograph.

3.3
static contact force
vertical force exerted upward by the collector head on the overhead contact line system at standstill

[SOURCE: IEC 60494-1:2013, 3.3.5]

3.4
aerodynamic force
additional vertical force applied by the pantograph as a result of air flow around the pantograph assembly

3.5
mean contact force
F_m
statistical mean value of the contact force

Note 1 to entry: Fm is formed by the static and aerodynamic components of the pantograph contact force.

[SOURCE: IEC 62486:2017, 3.11]

3.6
standard deviation
<of contact force> square root of the sum of the squared sample variance divided by the number of output values minus 1

3.7
skewness
sk
parameter that quantifies the symmetry of the shape of a data distribution

$$\text{sk} = \frac{\sum \frac{(F - F_\text{m})^3}{n}}{\left(\sum \frac{(F - F_\text{m})^2}{n}\right)^{\frac{3}{2}}} \tag{1}$$

3.8
excess of kurtosis
ek
parameter that quantifies whether the shape of the data distribution matches the Gaussian distribution

$$\text{ek} = \frac{\sum \frac{(F - F_\text{m})^4}{n}}{\left(\sum \frac{(F - F_\text{m})^2}{n}\right)^{2}} - 3 \tag{2}$$

3.9
minimum contact force
minimum value of the contact force while the pantograph passes over the analysis section

3.10
maximum contact force
maximum value of the contact force while the pantograph passes over the analysis section

3.11
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 will immediately disappear and then the condition will shift to "current loss".

[SOURCE: IEC 62486:2017, 3.22]

3.12
simulation method
numerical method that uses a fixed set of input parameters describing a system (e.g. pantograph and overhead contact line system) to calculate a set of output values representative of the dynamic behaviour of this system

3.13
simulation tool
software implementing one or more simulation methods

3.14
pantograph model
mathematical model in a one- or more-dimensional geometry describing the dynamic characteristics of the pantograph

3.15
mass–spring–damper model
lumped parameter model
method representing a dynamic mechanical system (e.g. pantograph) as a series of discrete concentrated masses connected together by spring and damper elements

3.16
transfer function
<of a pantograph> ratio of an applied input on pantograph head to the response of the pantograph, depending on frequency

3.17
apparent mass
<of a pantograph> transfer function describing the relation between applied contact force and resulting acceleration at the contact point for the frequency range of interest

3.18
hardware in the loop
hybrid method (simulation and dynamic laboratory test), where a real pantograph responds interacting with a simulation model of the overhead contact line

3.19
multi-body model
method representing a dynamic mechanical system (e.g. pantograph) based on interconnected rigid or flexible bodies

3.20
pantograph head
pantograph pan
part of the pantograph comprising the contact strips and their mountings, horns and possibly a suspension

[SOURCE: IEC 60050-811:2017, 811-32-05]

3.21
overhead contact line model
mathematical model in a two- or three-dimensional geometry describing the characteristics of an overhead contact line for interaction with pantographs

3.22
compound catenary
overhead contact line with one or two contact wires suspended from an auxiliary messenger wire which is suspended from the main messenger wire

[SOURCE: IEC 60050-811:2017, 811-33-12 modified: catenary wire to messenger wire, deleted: equipment]

3.23
messenger wire
longitudinal cable supporting the contact wire or wires either directly or indirectly

[SOURCE: IEC 60050-811:2017, 811-33-06, deleted: catenary wire]

3.24
wave propagation velocity
<of the contact wire> speed of a transversal wave, which runs along the contact wire

3.25
contact wire height
distance from the top of the rail to the lower face of the contact wire at rest position without pantograph contacted

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

[SOURCE: IEC 60050-811:2017, 811-33-62 modified; added: at rest position; deleted: (or road surface for overhead contact line system for trolleybus applications)]

3.26
maximum uplift at the support
maximum value of the vertical uplift of the contact wire at a support

3.27
analysis section
subset of the total overhead contact line model length over which the simulation will be evaluated

3.28
frequency range of interest
frequency range within which the dynamic performance of the overhead contact line and pantograph system is considered

Note 1 to entry: For validation with measurements this range correlates with the frequency range defined in IEC 62846.

3.29
dynamic interaction
behaviour between pantograph(s) and overhead contact line when in contact, described by contact forces and vertical displacements of contact point(s)

3.30
frequency band analysis
analysis inside a frequency range of interest using subranges of frequencies to study special topics

3.31
elasticity of overhead contact line
uplift divided by the force applied to the contact wire in a static state

3.32
range of vertical position of the point of contact
difference between maximum and minimum dynamic height of the contact point, relative to the track, during dynamic interaction between the pantograph and the contact wire

3.33
operation height
vertical distance between actual operating position of the pantograph and pantograph’s housed height

3.34
active pantograph
pantograph fitted with any type of active control system which enhances or alters its dynamic response

4 Symbols and abbreviated terms

For the purpose of this document, the following symbols and abbreviated terms apply.

Abbreviated terms:

AC	Pertaining to alternating electric quantities such as voltage or current, to devices operated with these, or to quantities associated with these devices
CT	Centre of the track
CW	Contact wire
CWH	Contact wire height
CW1H	Height of contact wire 1
CW2H	Height of contact wire 2
DC	Pertaining to time-independent electric quantities such as voltage or current, to devices operated with direct voltage and current, or to quantities associated with these devices
FFT	Fast Fourier transformation
HIL	Hardware in the loop
MT	Mast type
MW	Messenger wire
Mxx	Support or mast number
OCL	Overhead contact line
ROCL	Rigid overhead contact line
SDx	Number of dropper to stitch wire
STx	Span type number as reference to figure span number
SW	Stitch wire

Symbols:

$a_{\mathrm{cp,meas}}$	Measured vertical acceleration at the contact point
$a_{\mathrm{cp,model}}$	Simulated vertical acceleration at the contact point
C_{s}	Structural damping matrix
c_{n}	Damping of element n
Dx	Dropper number
E	Modulus of elasticity
e	Elasticity of overhead contact line
ek	Excess of kurtosis of contact force
F	Contact force
$F_{\mathrm{applied,meas}}$	Measured vertical force applied at the contact point
$F_{\mathrm{applied,model}}$	Simulated vertical force applied at the contact point
F_{m}	Mean contact force
F_{sa}	Lateral force at steady arm
f_{i}	Actual frequency
f_{n}	Maximum frequency

Symbols:

f_1	Minimum frequency
K	Stiffness matrix
k_n	Stiffness of element n
L_{dr}	Dropper length
$L\text{x}_{dr}$	Dropper length (for CW no. x)
L_{sa}	Length of steady arm
M	Mass matrix
$m_{app,meas}$	Measured apparent mass
$m_{app,model}$	Apparent mass of the model
m_n	Mass of element n
n	Number of contact force values
Q	Accuracy of the pantograph simulation model
sk	Skewness of contact force
X	Distance between left mast and dropper no. x
α, β	Proportional damping coefficients
σ	Standard deviation of contact force

5 General

5.1 Overview of the validation process

The theoretical study of the dynamic interaction between pantograph and overhead contact line by computer simulation makes it possible to obtain much information about the system and to minimize the costs of line tests.

To be used with confidence the simulation tool shall be validated. The validation for a simulation tool shall be done in a process described in Figure 1.

A simulation tool validated according to this document, shall be considered for application to overhead contact line/pantograph combinations and conditions only within the limits of validity defined in 10.3.

A new validation shall be made when the conditions to apply simulation are outside the limitations defined in 10.3 for existing validations.

The validation for a simulation tool shall be done with the steps which are shown in Figure 1. The steps are:

1) A first validation step shall be done by a "desktop assessment" in accordance with Clause 11. The most relevant reference model data shall be chosen from the reference models in Annex A for the conditions for which validation is required.

   NOTE 1 This desktop assessment will improve the confidence in the simulation tool. As Annex A cannot cover all possible solutions and combinations, a choice from this subset is possible.

   For validation of simulation tools implemented for new technologies in ways that are totally different from the current state of the art, and which are not able to use models with the data according to Annex A, the "desktop assessment" may be omitted.

   NOTE 2 Typically, all simulation tools for OCL from type "Flexible overhead contact line" according to IEC 60913 can use models with data according to Annex A.

2) The final assessment shall be done by a "line test data validation" based on test results according to 10.1 to demonstrate the accuracy of simulation according to 10.2.

   Annex B provides data sets from line test measurements in accordance with IEC 62846 to allow for a validation for a given model within the limitations according to 10.3.

If the accuracy according to either 10.2 or to 11.4 cannot be achieved, then the simulation tool shall be improved according to 6.3 for pantograph model adjustments and according to 7.3 for overhead contact line model before revalidation.

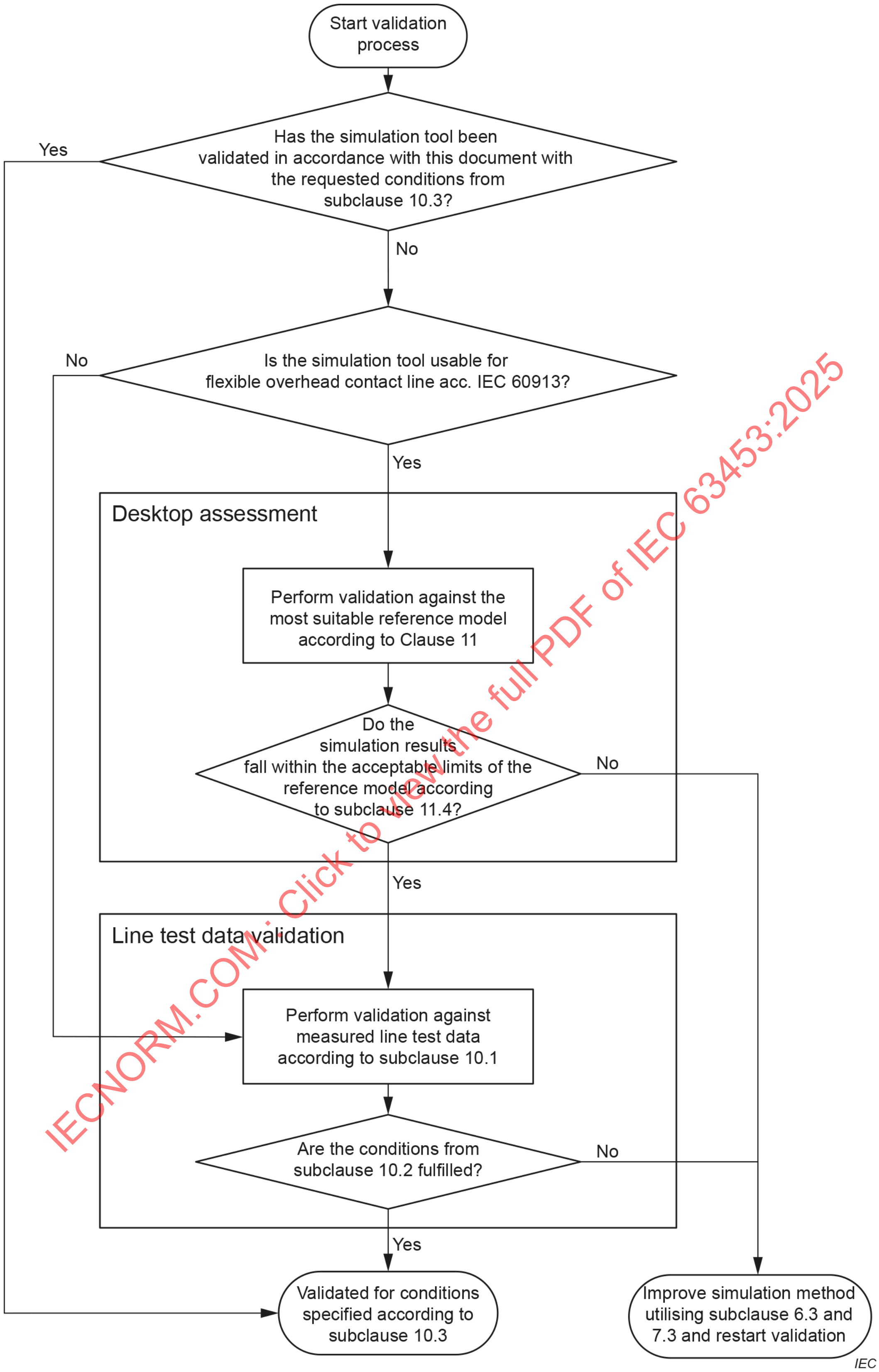

Figure 1 – Evaluation process

5.2 Typical application

The main purpose of the application of this document is to inform the process for seeking authorization for an OCL or pantograph design in the context of dynamic interaction.

Annex C shows examples for an assessment process of the elements OCL and pantograph, using simulation of interaction in the framework of interoperability.

NOTE 1 Examples in Annex C are derived from the authorization process used in Europe for information.

NOTE 2 Other applications, not related to authorizations (e.g., research, technical development), can require a different process.

6 Modelling of the pantograph

6.1 General requirements

A pantograph model shall describe the dynamic characteristics of a pantograph, regarding interaction with overhead contact lines, in the frequency range of interest.

Commonly used pantograph models are:

- mass – spring – damper models (lumped parameter models);
- transfer function models;
- multi-body models;
- physical pantographs, when hardware in the loop (HIL) is adopted.

The pantograph may be modelled with one or more dimensional geometry, depending on the phenomena to be investigated.

For the modelling of active pantographs, the characteristics of control and the dynamic characteristics shall be available.

Aerodynamic effects on the pantograph shall as a minimum be considered by adjusting the mean contact force as a function of speed.

6.2 Input data requirements

6.2.1 General

Depending on the modelling method and the individual pantograph characteristics, the relevant parameters appropriate to fully describe the pantograph shall be available for simulation.

These parameters shall take into account other dependencies (operation height, contact wire height, stagger, nonlinearities, frequency), as required.

Common parameters of pantographs are:

– kinematics;
– transfer function;
– natural frequencies;
– mass distribution;
– degree of freedom of joints;
– damping characteristics;
– spring characteristics;
– friction values;

– stiffness;
– bump stops;
– location of application of the static contact force;
– location of application of the aerodynamic forces.

NOTE Aerodynamic forces usually depend on the running direction of the pantograph, operation height, contact wire height and position of the pantograph and the type of train and the line conditions as open section/tunnel section.

6.2.2 Mass – spring – damper models (lumped parameter models)

For mass – spring – damper – models (lumped parameter models), the following input is required:

- mass values of discrete mass element(s);
- stiffness characteristics of joints connecting the discrete masses, including any nonlinearity (if applicable);
- damping characteristics of joints connecting the discrete masses, including any nonlinearity (if applicable);
- friction values (if applicable);
- bump stops (if applicable).

NOTE The number of mass elements are in line with the degree of freedom of the system in the frequency range of interest.

6.2.3 Multi-body models

For multi-body models, the input set out in 6.2.2 and the following additional input is required:

– definition of all parts of the model including mass distributions, inertia characteristics, flexibility (if applicable);
– kinematics, describing transmission of movements, kinds of joints and their position and limitations (if applicable);
– internal forces applied to the system and their application points for springs, dampers and friction elements.

6.2.4 Transfer function models

Transfer function models require as input an analytical definition of the Laplace transform function, e.g. zeros and poles affecting the behaviour in the frequency range of interest, between the vertical displacement of the contact point and the contact force.

6.2.5 Hardware in the loop

Hardware in the loop uses the pantograph in its final configuration on the test rig. Aerodynamic effects shall be implemented as an adjusted static contact force.

6.3 Validation of pantograph models

The validation of the pantograph models shall be carried out by comparison of the dynamic properties of the pantograph model with those of the real pantograph as measured with a pantograph test rig. The comparison shall be carried out using the same principle as used in the procedure "Calibration of the measurement system" defined in IEC 62846:2016, 7.5.

The test shall be carried out with the pantograph of interest and with its extension at a typical height inside of 20 % to 80 % of the working range, as defined in IEC 60494-1. The force shall be applied centrally to the pantograph head.

The results are usable for 20 % to 80 % of the pantograph working range. Values outside this range require additional investigations.

This test shall be carried out at the predicted mean contact force appropriate to the maximum design speed for the pantograph. The mean contact force shall fulfil the requirements of IEC 62486:2017, 7.3, for the designated speed.

Measurements of the applied vertical force (F_{applied}) and the resulting vertical acceleration at the contact point (a_{cp}) shall be taken applying sinusoidal excitations for the frequency range of interest in suitable steps. For comparison and validation purposes the excitation shall be from 0,5 Hz up to 20 Hz in 0,5 Hz steps.

The intervals may be reduced at resonant frequencies.

The amplitude of excitation shall be high enough to overcome the static friction in the pantograph.

NOTE 1 A range of amplitude of the greater between ± 15 % of the mean contact force and ± 20 N usually gives representative results.

Based on the measurements of the applied force and the acceleration at the contact point, the measured apparent mass ($m_{\text{app,meas}}$) in kilograms shall be determined for the frequency range of interest:

$$m_{\text{app.meas}} = \frac{F_{\text{applied,meas}}}{a_{\text{head,meas}}} \tag{3}$$

The apparent mass of the simulation model shall be determined in the same way as for the test rig measurement based on the values for applied force and resulting acceleration at the contact point identified in the simulation environment:

$$m_{\text{app.model}} = \frac{F_{\text{applied,model}}}{a_{\text{head,model}}} \tag{4}$$

The apparent mass of the pantograph model ($m_{\text{app,model}}$) shall be calculated in kilograms using the same frequencies in the same frequency range as the measurements.

The accuracy (Q) of the pantograph simulation model shall be calculated by using the following formula based on the magnitudes of the apparent mass:

$$Q = \left(1 - \frac{1}{f_{\text{n}} - f_{1}} \left(\sum_{i=1}^{n-1} \left(f_{\text{i+1}} - f_{\text{i}}\right) \left| 1 - \frac{log\left|m_{\text{app,model,i}}\right|}{log\left|m_{\text{app,meas,i}}\right|} \right| \right)\right) \times 100\ (\%) \tag{5}$$

For the calculation of Q, frequencies with measured apparent mass below 2 kg shall be excluded.

NOTE 2 The limit of 2 kg is defined to avoid the denominator approaching zero.

The accuracy Q of the simulation model shall be greater than 90 % for the whole frequency range 0,5 Hz to 20 Hz and for the band 0,5 Hz to 5 Hz.

NOTE 3 The accuracy value Q quantifies the differences between test rig measurements and pantograph model in the shape of the logarithmic curves used to represent the apparent mass. This value does not describe an absolute accuracy.

Any change in a pantograph component demonstrated to be directly connected to a model parameter shall be accepted without requiring a new validation of the pantograph model. New validation of the pantograph model is necessary for all other changes.

NOTE 4 For example, in a mass – spring – damper (lumped mass) model as per Figure A.4, the parameters m_3 and k_3 have equivalents in the real pantograph (mass of pantograph head and the spring constant of its suspension). Therefore, a new validation of the model is not necessary when either parameters m_3 or k_3, or both, are modified because of modification of corresponding components of the real pantograph.

A comparison between different pantograph models for the same pantograph may be performed by comparing the transfer function calculated from the different models.

7 Modelling of the overhead contact line

7.1 General requirements

The model of the overhead contact line shall describe the dynamic characteristics, regarding interaction with pantographs, in the frequency range of interest.

The overhead contact line may be modelled with two- or three-dimensional geometry, depending on the phenomena to be investigated.

Rigid overhead contact lines (ROCL) have very small vertical displacements in operation. The validation of these models and interaction simulations is only possible for the contact force in direct comparison with the measured results.

NOTE The displacement of a rigid overhead contact line during operation is currently not measured with acceptable accuracy.

7.2 Data requirements

The length of overhead contact line model shall be greater than the analysis section, so that the passage of the pantographs is not influenced by initial transients and end effects of the model. To investigate special sections of overhead contact line (e.g. overhead contact line over turnouts, etc.) the length of analysis section may be reduced. Depending on the modelling method and the individual overhead contact line characteristics, the relevant geometrical and mechanical parameters of the overhead contact line shall be available for simulation:

– length of each span;
– position of droppers;
– contact wire height at rest position (sag, dropper length, wire gradients);
– encumbrance at the supports;
– geometry and mass distribution of steady arms;
– stagger and offset of all wires;
– number and types of wires (contact wire, messenger wire, auxiliary messenger wire, stitch wire, droppers, etc.);
– mass per unit length of each wire or density and cross-section;
– mechanical tension of wires. Where the tension depends on temperature, this relationship shall be specified;
– section properties and stiffness for the beams of rigid overhead contact line;
– mass of links between wires and droppers (clamps);
– the mechanical characteristics of the supports and structures;

– the stiffness characteristic of droppers;

– damping of all components of the overhead contact line or a damping rate of the system, if available.

NOTE Typical damping rates (ratio of damping vs. critical damping) of overhead contact lines are between 0,05 % and 0,2 %.

7.3 Static check of overhead contact line model

The usability of the overhead contact line model shall be checked by comparing the results of a static behaviour calculated with this model with measurements or design calculations.

The outcome of the calculation based on the overhead contact line model in the static condition shall be evaluated to validate the implemented numerical calculations in the addressed simulation tool. The following results shall be extracted to evaluate the method:

– static position of the contact wire at each dropper and at the steady arm;

– elasticity of overhead contact line at the same points;

– dropper length.

The numerical results shall be compared to reference results from Annex A and Annex B, measurements or design calculations.

Those results shall be compared to the numerical model for one span which shall remain within the accuracy limits given in Table 1.

Table 1 – Required accuracy of simulated static values

Parameter	Required accuracy
Contact wire position	±5 mm
Elasticity	±0,1 mm/N or ± 10 % whichever is greater
Dropper length	±10 mm

NOTE 1 The values in Table 1 are not applicable to rigid overhead contact line.

NOTE 2 The ranges for deviation of elasticity is to cover overhead contact lines with high and low tension forces.

This validation shall be renewed if the parameters of the overhead contact line differ more than the limitations given in 10.3.3.

8 Parameters of simulation

The parameters of the pantograph and overhead contact line shall be given according to Clause 6 and Clause 7.

Depending on the modelling method and the problem to be investigated by simulation, the relevant parameters appropriate to fully describe the simulation shall be available.

Common parameters of simulations are:

- train speed;
- analysis section;

  The analysis section shall consist of those parts of the overhead contact line model over which the passage of the pantographs is not influenced by initial transients and end effects of the model.

  Depending on the phenomena to be studied, the analysis section should be defined accordingly. For validation purposes see Clause 10 and for the reference models see Clause 11.
- number of and distances between pantographs;
- static contact force of each pantograph;
- aerodynamic effects on each pantograph, taking into account the pantograph orientation;

NOTE Aerodynamic effects can be covered by specifying the applied mean contact force as a function of speed.

- operating height of the pantograph if needed by the pantograph model;
- wire temperatures if relevant to the overhead contact line model;
- damping of the overhead contact line (if not provided according to 7.2);
- frequency range of interest.

Depending on the phenomena to be studied, the frequency range of interest shall be defined in advance and shall be consistent with the pantograph model, overhead contact line model and simulation tool and with the measurement system.

9 Output

9.1 General

The simulation shall calculate the variation of the contact forces, the contact wire displacements and the pantograph displacements when the pantograph passes along the overhead contact line model.

The output parameters shall be filtered to exclude frequencies outside the frequency range of interest.

Filter characteristics and type depend on the problem to be investigated. For validation purposes see Clause 10 and for comparison with benchmark see Clause 11.

Information about filters used shall be given with results as output.

The outputs from the simulation shall be analysed over the analysis section.

Subclauses 9.2 to 9.4 specify the outputs for a single pantograph. If the train has more than one pantograph, then the output shall be available for each pantograph.

9.2 Contact force

Within the frequency range of interest, outputs should be analysed within two additional frequency bands, relating to span passing and dropper passing frequencies.

For validation and comparison purposes the frequency range of interest shall be 0 Hz to 20 Hz and the bands shall be 0 Hz to 5 Hz and 5 Hz to 20 Hz.

If it is necessary to calculate the standard deviation of the contact force in several bands, the calculation can be performed in the time domain by applying proper pass-band filters or in the frequency domain. When comparing different values, e.g. numerical and measured values, the same calculation method shall be adopted.

Required outputs:

- the time history of the contact force;
- the mean contact force F_{m};
- the standard deviation of contact force σ;
- actual maximum and minimum of contact force, F_{min} and F_{max};
- statistical distribution (histogram) of contact force including information about skewness and excess of kurtosis.

NOTE The statistical distribution with the base figures of skewness and kurtosis will give information about the variation from Gaussian distribution.

9.3 Contact wire displacement

Requires as output the maximum uplift of the contact wire at all supports of the analysis section for each pantograph separately. The time history of the vertical position of the contact wire at any specified point shall be available for output.

Where it is necessary to check at special locations for the minimum height of the contact wire according to IEC 60913:2024, 5.10.4, the maximum downwards movement of the contact wire and the location where this occurs for those special sections shall be calculated during the simulation run.

9.4 Pantograph displacement

The time history of the vertical displacement of any specified point of the pantograph model shall be available for output.

Where it is necessary to check at special locations for the maximum contact wire height according to IEC 60913:2024, 5.10.4, the maximum upwards movement of the contact point and the location where this occurs for those special sections shall be calculated during the simulation run.

10 Validation with measured values

10.1 General

The validation of a simulation tool shall be carried out by comparison of simulated results with equivalent measured values from a line test. The line test shall be carried out with measurement equipment according to IEC 62846. The conditions for the validation are given in 10.2.

The simulation results shall be filtered in the same frequency range and using the same kind of filter as the measured values and in accordance with IEC 62846:2016, 7.6.

The measured values are necessary as time histories if the statistical values necessary for validation are not completely elaborated during the measurement phase.

Annex B provides data sets from line test measurements in accordance with IEC 62846 to allow for a validation for a given model within the limitations according to 10.3. Any other measurement data fulfilling the requirements can be used for validation.

NOTE The results in Annex B are analysed based on a proper statistical basis. The time history for these results is not necessary.

10.2 Comparison values

The validation shall be done by comparison between simulated and measured values of contact forces and displacements in the overhead contact line.

The comparison shall be done for:

– the standard deviation of the contact force σ;
– maximum uplift at the support for all measured supports;
– if measured values are available, the range of vertical position of the point of contact for the span with maximum length (excluding overlaps).

The comparison for the standard deviation of the contact force shall be performed considering also a frequency band analysis in the 0 Hz to 5 Hz and 5 Hz to 20 Hz frequency ranges, in order to achieve increased confidence in the simulation model.

The time history of measured contact force is required to perform the frequency band analysis.

The deviation of the simulated values from the measured values shall be within the tolerances given in Table 2.

The accuracy of standard deviation in Table 2 is valid for all three frequency bands.

For simulation of systems with rigid overhead contact line only the limits for standard deviation of contact force are applicable.

Table 2 – Required accuracy of simulated dynamic values

Parameter	Required accuracy
Standard deviation of the contact force σ	±20 %
Maximum uplift at the support	−10 mm; +20 mm
Range of vertical position of the point of contact	±20 mm
Mean contact force F_m	±2,5 N

NOTE 1 The accuracies in this Table 2 include an allowance for the accuracy of the measurement system and the repeatability of the measurement values, and allow for actual conditions occurring in the line test which have not been incorporated in the model such as:

– span to span variation in tension of conductors;
– random variations in dropper length;
– across track wind affecting pantograph aerodynamics;
– track irregularities and vehicle dynamics;
– local inaccuracies in dropper spacing or span length;
– actual state of contact strip wear affecting contact strip mass;
– actual state of contact wire wear affecting contact wire mass.

NOTE 2 The accuracies in this Table 2 are empirically determined values based on the many years of experience of European railways.

For the validation with measurements, the analysis section shall at least cover two half tension lengths and one overlap.

10.3 Limits of validation

10.3.1 Application of simulation tool to other conditions

To use a simulation tool under conditions that differ from those for which it was validated, limits for the differences are necessary.

A simulation tool validated according to 10.2 may be applied to other pantographs according to 10.3.2, to other overhead contact lines according to 10.3.3 and to other simulation parameters according to 10.3.4.

10.3.2 Permissible changes of pantograph characteristics

The usability of a different pantograph may be demonstrated by assessing the pantograph model according to 6.3.

Changes in the configuration of the pantograph such as number of independent contact strips, or pantographs with and without active components, shall not be accepted.

10.3.3 Permissible changes of overhead contact line parameters

Changes of the values of parameters of the overhead contact line (e.g. tensile forces, material, type of droppers, cross-sections, mechanical characteristics of the supports and structures, etc.) shall be accepted.

Changes in the number of contact wires, messenger wires, auxiliary wires and stitch wires shall not be accepted.

10.3.4 Permissible changes of the simulation parameters

Changes in the simulation speed shall be accepted up to the validation speed increased by 5 % of the wave propagation velocity of the contact wire of the validated model as described in IEC 60913:2024, 5.2.4.

Changes in the distance between the pantographs per train shall be accepted.

Changes in the static and aerodynamic forces of the pantographs shall be accepted.

Changes in wire temperatures shall be accepted.

Changes in the height of the contact wire shall be accepted.

Changes in the frequency range of interest shall not be accepted.

Changes between one or more than one pantograph per train shall not be accepted.

NOTE 1 The speed step of 5 % of the wave propagation is an empirically determined value based on the many years of experience of European railways.

NOTE 2 For Japan see national Annex D.

11 Reference model

11.1 Purpose of reference model

Before using a simulation tool, it is important to gain confidence in its accuracy.

For a simulation tool, it is first necessary to check the simulation tool by using an appropriate reference model.

11.2 Reference model data

The data for the overhead contact line reference models are given in Annex A according to Clause 7. The data for the pantograph reference models are given in Annex A, according to Clause 6.

Different models are provided for different types of overhead contact line and pantographs in common use. As the benchmarking against a reference model is the first step before comparison with line tests, the benchmarking shall be done using a reference model that is representative of the actual overhead contact line and pantograph being used for the line tests.

The OCL and pantograph models shall be chosen from the combinations defined in Table 3.

11.3 Parameters of simulation

The calculations shall be carried out for:

– speeds as given in Table 3;

– two pantographs with a spacing as shown in Table 3;

– a frequency range of interest from 0 Hz to 20 Hz.

The damping of the overhead contact line shall be considered.

For comparison with the reference models the analysis section is defined as a length of 10 spans, including the boundary supports, in the middle of the overhead contact line-model.

Table 3 – Combinations of OCL and pantograph reference models

Reference model combination ID	OCL type see Clause A.2	Pantograph see Clause A.3	Speed [km/h]	Mean force [N]	Number of pantographs	Pantograph distance [m]	Acceptable range of results
1	AC simple	AC	275	143	2	200	Table A.6
2	AC simple	AC	320	169	2	200	Table A.6
3	AC stitched	AC	275	143	2	200	Table A.7
4	AC stitched	AC	320	169	2	200	Table A.7
5	DC simple	DC	200	149	2	200	Table A.8

11.4 Reference model results

The simulation tool calculations using the reference model data shall produce output results according to Clause 9.

Additionally the results shall be compared based on a frequency band analysis for 0 Hz to 5 Hz and 5 Hz to 20 Hz.

Simulation results shall be filtered in the frequency domain with the defined cut off frequencies.

The results shall be within ranges given in Table A.6 to Table A.8.

Annex A
(normative)

Reference model specification

A.1 General

The data of reference models allows for the checking of a simulation tool in comparison to others for typical models for different basic types of overhead contact lines and pantographs.

The data of reference models may be extended to further models (e.g. compound catenaries or ROCL-system, etc.), with the development of simulation models and measurements.

A.2 Overhead contact line data

A.2.1 General data

This annex covers the model data for theoretical models of overhead contact lines based on common real systems, actually used for new lines.

This data can be used to do a first check about usability for simulation software.

The basic data for the overhead contact line types are listed in Table A.1.

If an overhead contact line model requires additional parameters, the derived mathematical model values shall be consistent with the table data.

The model consists of more than ten identical spans.

For purposes of reference model calculations, to compare with the ranges of results given in Clause A.4, the analysis section consists of 10 uniform spans.

The support of the messenger wire is connected to a fixed point via a spring-damping element with the parameters in Table A.1. The contact wire is connected to a fixed point via a steady arm with the parameters in Table A.1.

The tensioning forces for the contact wire and the messenger wire are constant.

Heights are given in relation to the nominal contact wire height. The contact wire at the support defines the nominal contact wire height.

The damping of the overhead contact line shall be adjusted to a non-dimensional damping rate (ratio of damping vs. critical damping) of 0,1 % to 0,15 %, for the overhead contact line.

This damping rate can be achieved by using a structural damping matrix C_s defined as:

$$C_s = \alpha M + \beta K \qquad \text{(A.1)}$$

where:

M and K are the mass and stiffness matrices of the overhead contact line (contact wire and messenger wire terms) and where:

α $= 1{,}25 \times 10^{-2}\ \mathrm{s}^{-1}$

β $= 1{,}0 \times 10^{-4}\ \mathrm{s}$

For software that does not consider proportional damping in the form described above, other forms of damping can be used. The damping forms used shall be calibrated to provide similar damping ratio values.

Table A.1 – Data for reference overhead contact lines

		Type of overhead contact line		
		AC – Simple	**AC – Stitched**	**DC – Simple**
Geometrical arrangement		Figure A.1	Figure A.2	Figure A.3
span length	[m]	55	65	56
Encumbrance	[m]	1,20	1,80	1,650
length of stitch wire	[m]	-	18	-
maximum pre-sag at midspan	[mm]	55	0	32
stagger of contact wire	[m]	±0,20	±0,30	±0,20
stagger of auxiliary messenger wire	[m]	-	-	-
stagger of messenger wire	[m]	±0,20	±0,30	±0,20
details for droppers		Table A.2	Table A.3	Table A.4
Contact wires				
number of contact wires		1	1	2
tension per wire	[N]	22 000	27 000	14 850 (each)
mass per length unit	[kg/m]	1,35	1,07	1,07 (each)
Young's Modulus E	[kN/mm^2]	100	120	120
cross section	[mm^2]	150	120	120
Messenger wires				
number of messenger wires		1	1	1
Young's Modulus E	[kN/mm^2]	97	110	100
cross section	[mm^2]	120	117	94
tension	[N]	16 000	21 000	13 000
mass per length unit	[kg/m]	1,080	1,060	0,880
Stitch wire				
Young's Modulus E	[kN/mm^2]	-	110	-
cross section	[mm^2]	-	35	-
tension	[N]	-	3 500	-
mass per length unit	[kg/m]	-	0,31	-
clamp to messenger wire	[kg]	-	0,38	-
Droppers				
stiffness for tension	[N/m]	see Table A.2	100 000	100 000
stiffness for compression	[N/m]	0	0	0
clamp on messenger wire	[kg]	0,195	0,155	0,11
clamp on contact wire	[kg]	0,165	0,140	0,11
mass per length unit	[kg/m]	0,117	0,089	0,155

		Type of overhead contact line		
		AC – Simple	**AC – Stitched**	**DC – Simple**
geometry and arrangement		see Table A.2	see Table A.3	see Table A.4
Steady arm / Contact wire support				
number of steady arms per support		1	1	2
length	[m]	1,2	1,15	1,2
mass per length unit	[kg/m]	0,730	0,780	1,375
mass of clamp	[kg]	0	0,460	0,240
Messenger wire support				
stiffness	[kN/m]	500	fixed	fixed
damping	[Ns/m]	1 000	fixed	fixed

A.2.2 Special data for the overhead contact line reference model – AC – Simple

The overhead contact line is defined by a simple catenary equipment with a single contact wire according to Figure A.1.

Dimensions in millimetres

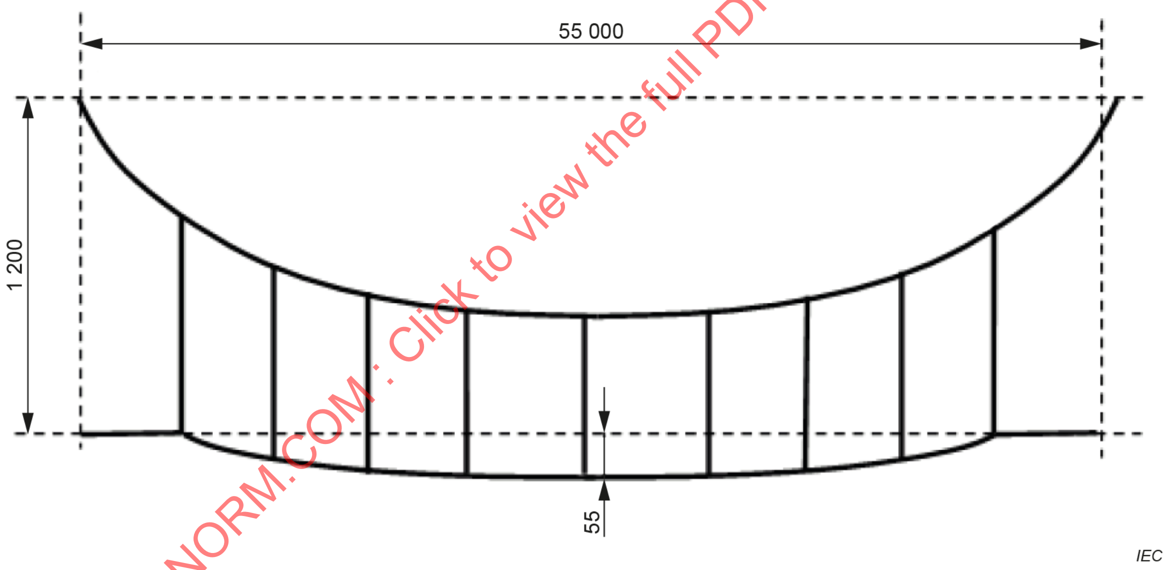

Figure A.1 – AC – Simple – Overhead contact line model

The support of the messenger wire is a vertical spring-damper element with the data given in Table A.1.

The connection of the steady arm with the registration arm or equivalent is a fixed point.

Table A.2 shows the elasticity (e) of the system at each dropper and at the steady arm obtained by applying a constant vertical force of 200 N.

Table A.2 – AC – Simple – Overhead contact line model – Geometry and elasticity of droppers

	support	1	2	3	4	5	6	7	8	9	support
X [m]	0	4,50	10,25	16,0	21,75	27,50	33,25	39,00	44,75	50,50	55
pre-sag [mm]	0	0	24	41	52	55	52	41	24	0	0
dropper stiffness for tension [kN/m]	-	197	223	247	264	269	264	247	223	197	-
e [mm/N]	0,206	0,165	0,273	0,345	0,388	0,400	0,388	0,345	0,273	0,165	0,206
dropper length [m]	-	1,023	0,902	0,815	0,764	0,747	0,764	0,815	0,902	1,023	-

NOTE For the catenary referred to in this Table A.2 it is operational practice to adjust both the height at support and the height at first dropper to pre-sag 0, by regulating the steady arm. Other catenaries can have different design requirements.

A.2.3 Special data for the reference model of overhead contact line AC – Stitched

The overhead contact line is defined by a simple catenary equipment with a single contact wire and stitched catenary suspensions according to Figure A.2.

The support of the messenger wire and the connection of the steady arm with the registration arm or equivalent are fixed points.

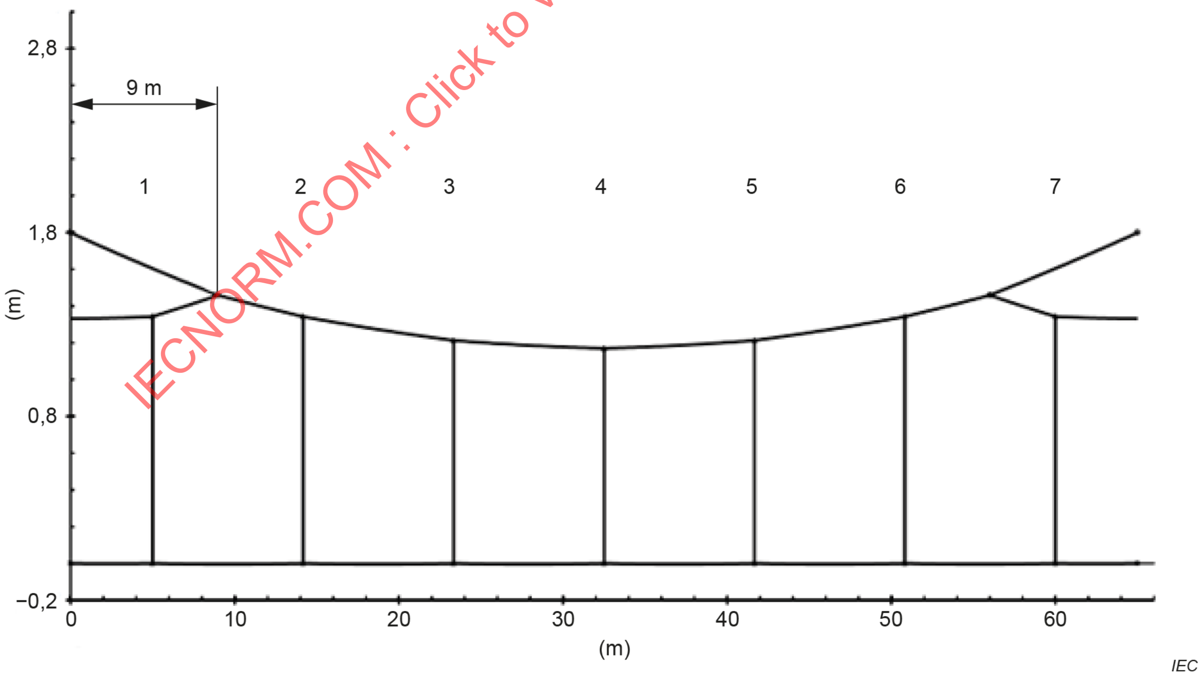

Figure A.2 – AC – Stitched catenary overhead contact line model

Table A.3 shows the elasticity (e) of the system at each dropper and at the steady arm obtained by applying a constant vertical force of 200 N.

Table A.3 – AC – Stitched catenary overhead contact line model – Geometry and elasticity of droppers

Dropper	support	1	2	3	4	5	6	7	support
X [m]	0	5,000	14,167	23,333	32,500	41,667	50,833	60,000	65
pre-sag [mm]	0	0	0	0	0	0	0	0	0
e [mm/N]	0,361	0,350	0,328	0,388	0,407	0,388	0,328	0,350	0,361
dropper length [m]	-	1,354	1,352	1,225	1,182	1,225	1,352	1,354	-

NOTE For the catenary referred to in this Table A.3 it is operational practice to adjust both the height at support and at first dropper to pre-sag 0, by regulating the steady arm. Other catenaries can have different design requirements.

A.2.4 Special data for the reference model of overhead contact line DC – Simple

The overhead line is defined by a simple catenary equipment with twin contact wires (two contact wires suspended from a single messenger wire). The dropper scheme according to Figure A.3 alternates successive droppers on the separate contact wires.

The support of the messenger wire and the connection of the steady arms with the registration arm or equivalent are fixed points.

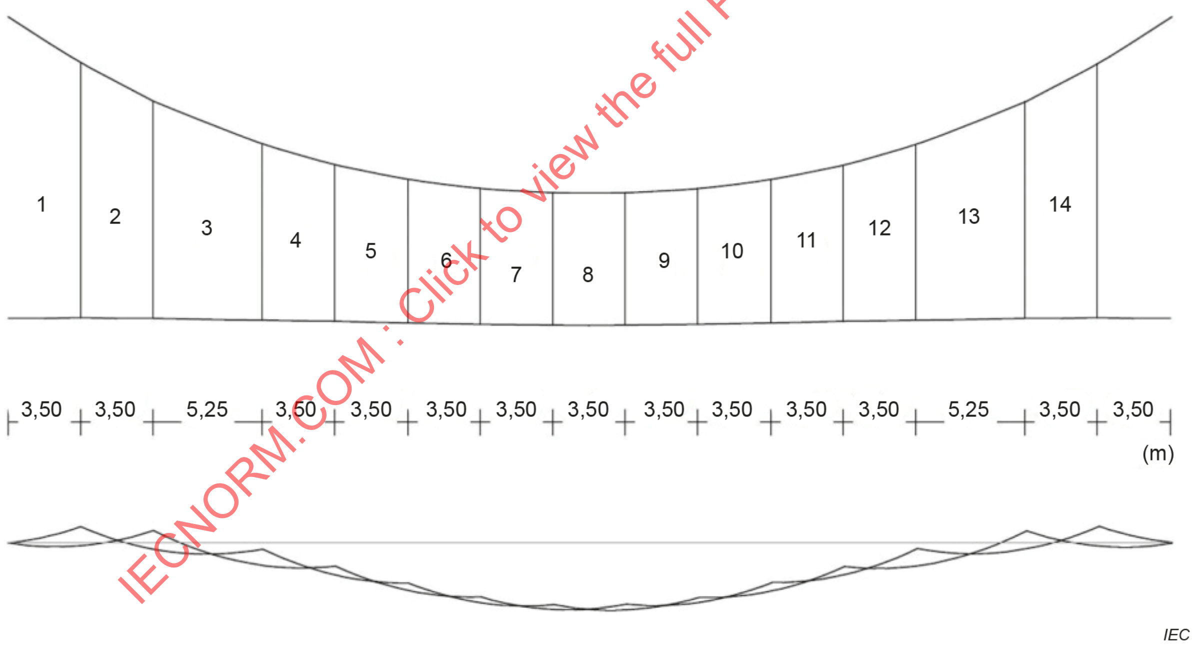

Figure A.3 – DC – Simple catenary overhead contact line model

The dropper lengths provoke a sinusoidal pre-sag with a value of 32 mm at mid-span.

Each contact wire is supported by individual contact wire steady arms with the parameters given in Table A.1.

The elasticity values of the system shown in Table A.4 at each dropper and at the steady arm are obtained by applying a constant vertical force of 200 N.

Table A.4 – DC – Simple catenary overhead contact line model – Geometry and elasticity of overhead contact line

Dropper	support	1	2	3	4	5	6	7
X [m]	0,00	3,50	7,00	12,25	15,75	19,25	22,75	26,25
CW		1	2	1	2	1	2	1
sag [mm]	0	−8	−6	3	11	19	26	29
e [mm/N]	0,176	0,170	0,209	0,280	0,316	0,344	0,363	0,373
Dropper length [m]		1,422	1,243	1,047	0,957	0,897	0,861	0,844
Dropper	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**support**
X [m]	29,75	33,25	36,75	40,25	43,75	49,00	52,50	56,00
CW	2	1	2	1	2	1	2	
sag [mm]	29	26	19	11	3	−6	−8	0
e [mm/N]	0,373	0,363	0,344	0,316	0,280	0,209	0,170	0,176
Dropper length [m]	0,844	0,861	0,897	0,957	1,047	1,243	1,422	

A.3 Pantograph data

This Clause A.3 covers the model data for theoretical models of pantographs based on common real systems, actually used on vehicles.

The model data covers both a lightweight AC pantograph and a heavy DC pantograph.

This data can be used in combination with the overhead contact line data in Clause A.2 to do a first check regarding usability of simulation software.

The data are given in Table A.5 for a discrete mass-spring-damper model (lumped parameter model) with three masses according to Figure A.4.

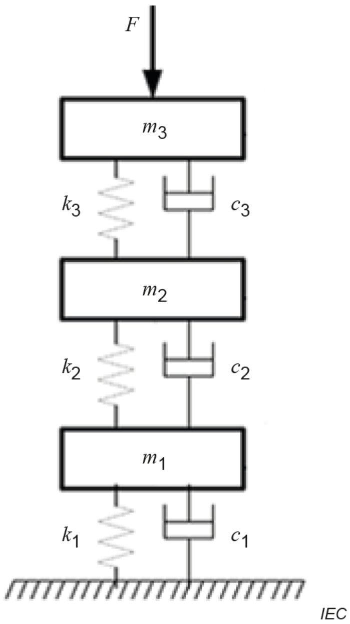

Figure A.4 – Pantograph model

The pantograph model is a linear model with one vertical degree of freedom for each mass.

The basic data for the pantographs are listed in Table A.5.

Table A.5 – Pantograph model parameters

		AC	DC
Reduced dynamic mass [kg]	m_1	6,00	10,93
	m_2	9,00	11,28
	m_3	7,50	15,12
Damping [Ns/m]	c_1	100	121
	c_2	0,1	0,0
	c_3	45,0	20,0
Stiffness [N/m]	k_1	160,0	1,0
	k_2	15 500	10 600
	k_3	7 000	4 500

A.4 Results of simulations for reference models

The simulation tool calculations using the reference model data shall produce output results according to Clause 9.

As specified in IEC 62846, the filter order should be at least 6.

The results shall be within ranges given in the Table A.6 to Table A.8.

NOTE 1 The values in Table A.6 are based on results from independent simulation tools. These results are calculated independently which explains the wider ranges of results. These methods have been successfully checked with results from line tests [1] [2] [1].

NOTE 2 Pantograph 1 is the leading pantograph; pantograph 2 is the trailing pantograph.

1 Numbers in square brackets refer to the Bibliography.

Table A.6 – Ranges of results from reference model AC simple

	Range of results			
Reference model ID according to Table 3	1		2	
Speed [km/h]	275		320	
Nr of Pantograph	1	2	1	2
Pantograph distance [m]	200		200	
F_m [N]	141,5 to 146,5		166,5 to 171,5	
σ [N] [a]	31,9 to 34,8	50,0 to 54,5	49,5 to 62,9	30,2 to 43,8
σ (0 Hz to 5 Hz) [N] [b]	26,4 to 28,9	41,2 to 45,4	38,7 to 44,4	14,3 to 23,3
σ (5 Hz to 20 Hz) [N] [b]	16,2 to 22,4	25,2 to 34,7	29,0 to 46,2	26,7 to 38,2
Actual maximum of contact force [N] [a]	219 to 244	241 to 290	295 to 343	252 to 317
Actual minimum of contact force [N] [a]	71 to 86	14 to 50	55 to 82	21 to 86
Range of vertical position of the point of contact [mm]	38 to 49	53 to 70	39 to 51	18 to 35
Maximum uplift at support [mm]	39 to 48	45 to 54	57 to 64	50 to 61
Percentage of contact loss [%]	0	0	0	0

[a] Analysed in time domain.

[b] Analysed in frequency domain by FFT.

NOTE The range given in this Table A.6 are empirically determined values based on the results of several simulation tools used of European railways.

Table A.7 – Ranges of results from reference model AC stitched

	Range of results			
Reference model ID according to Table 3	3		4	
Speed [km/h]	275		320	
Nr of Pantograph	1	2	1	2
Pantograph distance [m]	200		200	
F_m [N]	143 to 144	142 to 144	169	169
σ [N] [a]	20,2 to 24,7	24,4 to 36,2	20,5 to 24,7	30,4 to 38,3
σ (0 Hz to 5 Hz) [N] [b]	11,7 to 15,2	17,0 to 18,2	11,8 to 13,3	20,4 to 24,2
σ (5 Hz to 20 Hz) [N] [b]	16,5 to 19,0	16,4 to 27,4	15,2 to 20,9	21,5 to 29,8
Actual maximum of contact force [N] [a]	185 to 199	203 to 252	210 to 232	239 to 255
Actual minimum of contact force [N] [a]	92 to 102	56 to 88	105 to 128	43 to 78
Range of vertical position of the point of contact [mm]	18 to 25	26 to 36	13 to 23	38 to 63
Maximum uplift at support [mm]	55 to 79	51 to 79	74 to 95	69 to 95
Percentage of contact loss [%]	0	0	0	0

[a] Analysed in time domain.

[b] Analysed in frequency domain by FFT.

NOTE The range given in this Table A.7 are empirically determined values based on the results of several simulation tools used of European railways.

Table A.8 – Ranges of results from reference model DC simple

	Range of results	
Reference model ID according to Table 3	5	
Speed [km/h]	200	
Nr of pantograph	1	2
Pantograph distance [m]	200	
F_m [N]	149 to 150	149 to 150
σ [N] [a]	28,0 to 33,3	35,4 to 45,3
σ (0 Hz to 5 Hz) [N] [b]	22,4 to 27,8	21,0 to 34,2
σ (5 Hz to 20 Hz) [N] [b]	15,5 to 22,7	24,5 to 31,3
Actual maximum of contact force [N] [a]	232 to 255	228 to 307
Actual minimum of contact force [N] [a]	46 to 88	34 to 52
Range of vertical position of the point of contact [mm]	31 to 45	24 to 69
Maximum uplift at support [mm]	35 to 52	35 to 53
Percentage of contact loss [%]	0	0

[a] Analysed in time domain.

[b] Analysed in frequency domain by FFT.

NOTE The range given in this Table A.8 are empirically determined values based on the results of several simulation tools used of European railways.

Annex B
(normative)

Model specifications and measurement results for validation

B.1 Measurement results of simple AC high speed overhead contact line

B.1.1 Simulation data for overhead contact line model

B.1.1.1 General

Subclause B.1.1.2 to B.1.1.7 contain data of a real existing overhead contact line section for high speed. The results are given at the maximum design speed of this OCL.

B.1.1.2 Parameters of simulation

The calculation shall be carried out for:

– a speed of 300 km/h (in accordance with line test);
– one pantograph;
– a frequency range of interest from 0 Hz to 20 Hz.

The overhead contact line is defined by a simple catenary equipment with a single contact wire and a single messenger wire. The analysis section is determined as a length of 1 113,5 m from support 6 of tension length 2 to support 6 of tension length 3. The analysis section includes the data of a real OCL and one 4-span-overlap.

NOTE The model includes two 4-span-overlaps.

B.1.1.3 Model parameter and mechanical data of OCL

The mechanical tension and the mass per unit length are defined in Table B.1:

Table B.1 – Mechanical values of wires

Wires and ropes	Tension [N]	Mass/unit length [kg/m]	Young's Modulus E [kN/mm^2]	Cross section [mm^2]
Contact wire	20 000	1,334	120	150
Messenger wire	14 000	0,605	84,70	65,50
Dropper wire	-	0,11	84,70	12,00
Steady arms	-	1,067	71,00	120,0

Mechanical values of clamp are defined in Table B.2.

Table B.2 – Mechanical values of clamps and other OCL-components

No. according to Figure B.1	Element	mass [kg]	Remark
-	Lower dropper clamp	0,165	Mass of dropper clamps including thimbles, crimped connectors, screws, screw nuts, rope loops and so on.
-	Upper dropper clamp to messenger wire	0,195	
1	Contact wire clip at steady arm	0,200	

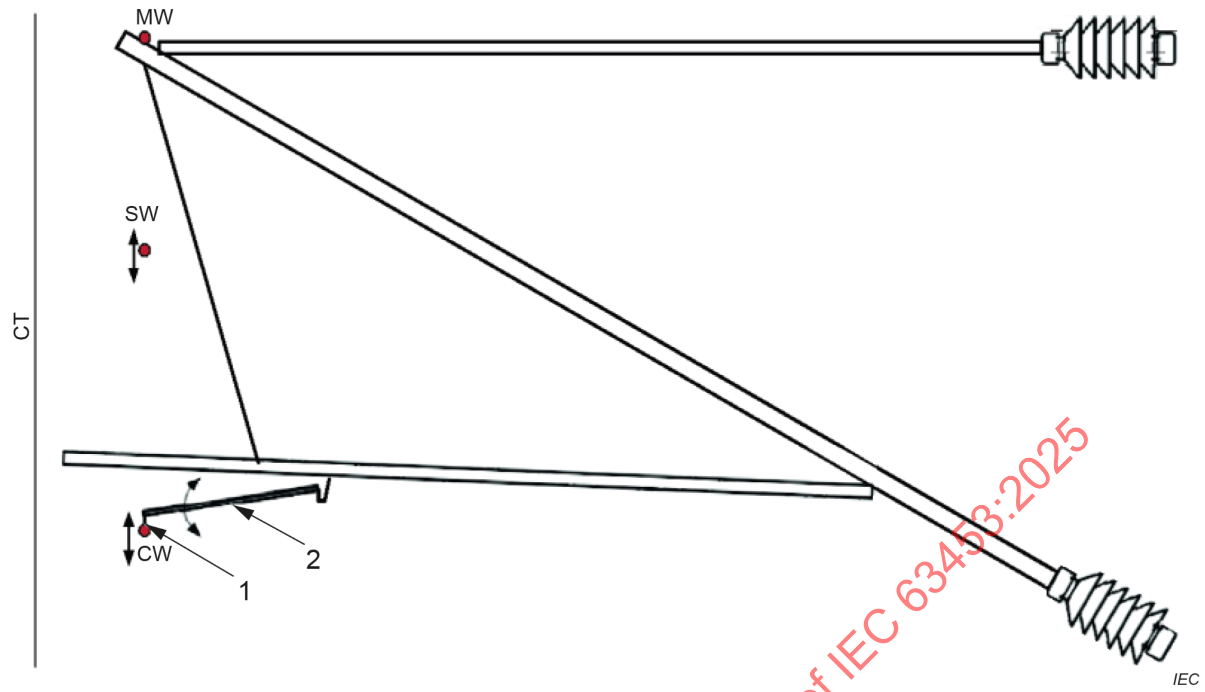

Figure B.1 – Cantilever model elements in Table B.2, Table B.42 and Table B.49

The pre-sag characteristics are specified in Table B.3. Dropper tables with the dropper length to respect this geometry for each span case are provided further in B.1.1.7.

Table B.3 – Pre-sag information in open route and overlap

Configuration	Pre-sag
Open route	1/1 000 of span length between contact wire height at the first dropper and mid-span. Parabolic shape.
Overlap	Parabolic shape.

The cantilever characteristics are defined by the steady arm geometry as the messenger wire is to be modelled as fixed at its defined height. Those characteristics are specified in Table B.4.

Table B.4 – Cantilever information in open route and overlap: steady arm geometry

Characteristic	Value
Length	1,220 m
Inclination	10°

B.1.1.4 Geometrical data of overhead contact line

The overhead contact line is defined by a simple catenary equipment with a single contact wire and a single messenger wire on straight track. The whole overhead contact line model consists of more than the following described spans of the analysis section. Location and length of droppers are described in B.1.1.7.

B.1.1.5 Span definition

The definitions of spans are given in Table B.5 to Table B.7. Dropper table numbers refer to Table B.11 to Table B.38.

Table B.5 – Span definition of tension length 1

Span number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Span length [m]	42,25	44,7	45,3	45,5	45	45	45	45	45	49,5	49,5	49,5	49,5
Dropper table	-	B.11	B.12	B.13	B.14	B.14	B.14	B.14	B.14	B.15	B.15	B.15	B.15
Span number	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**		
Span length [m]	49,5	49,5	49,5	49,5	49,5	49,5	49,5	50	49,8	49,2	49		
Dropper table	B.15	B.15	B.15	B.15	B.15	B.15	B.15	B.16	B.17	B.18	-		

Table B.6 – Span definition of tension length 2

Span number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Span length [m]	49	49,2	49,8	50	48,5	49,5	49,5	54	54	54	54	54	54
Dropper table	-	B.19	B.20	B.21	B.22	B.23	B.23	B.24	B.24	B.24	B.24	B.24	B.24
Span number	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Span length [m]	54	54	54	54	49,5	49,5	49,5	49,5	49,5	50	49,8	49,2	40
Dropper table	B.24	B.24	B.24	B.24	B.23	B.23	B.23	B.23	B.23	B.25	B.26	B.27	-

Table B.7 – Span definition of tension length 3

Span number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Span length [m]	49	49,2	49,8	41	38	45	40	47,5	49,5	49,5	49,5	49,5	49,5	49,5
Dropper table	-	B.28	B.29	B.30	B.31	B.32	B.33	B.34	B.35	B.35	B.35	B.35	B.35	B.35
Span number	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	
Span length [m]	54	54	54	54	54	54	54	54	54	49,5	49,8	49,2	49	
Dropper table	B.36	B.36	B.36	B.36	B.36	B.36	B.36	B.36	B.36	B.35	B.37	B.38	-	

B.1.1.6 Support definition

Table B.8 to Table B.10 show the support definitions for the three tension lengths.

Table B.8 – Support definition of tension length 1

Support number	1	2	3	4	5	6	7	8	9	10
Cumulative position [m]	0,00	42,25	86,95	132,25	177,75	222,75	267,75	312,75	357,75	402,75
CW height [m]	6,35	5,63	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08
MW height [m]	6,85	6,88	7,08	6,48	6,48	6,48	6,48	6,48	6,48	6,48
CW stagger [m]	-	0,65	0,3	−0,25	0,1	−0,2	0,1	−0,2	0,1	−0,2
MW stagger [m]	-	0,65	0,3	−0,25	0,1	−0,2	0,1	−0,2	0,1	−0,2

Support number	11	12	13	14	15	16	17	18	19	20
Cumulative position [m]	452,25	501,75	551,25	600,75	650,25	699,75	749,25	798,75	848,25	897,75
CW height [m]	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08
MW height [m]	6,48	6,48	6,48	6,48	6,48	6,48	6,48	6,48	6,48	6,48
CW stagger [m]	0,1	−0,2	0,1	−0,2	0,1	−0,2	0,1	−0,2	0,1	−0,2
MW stagger [m]	0,1	−0,2	0,1	−0,2	0,1	−0,2	0,1	−0,2	0,1	−0,2

Support number	21	22	23	24	25
Cumulative position [m]	947,25	997,25	1 047,05	1 096,25	1 145,25
CW height [m]	5,08	5,08	5,08	5,63	6,35
MW height [m]	6,48	6,48	7,08	6,88	6,85
CW stagger [m]	0,2	−0,15	0,1	0,35	-
MW stagger [m]	0,2	−0,15	0,1	0,35	-

Table B.9 – Support definition of tension length 2

Support number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Cumulative position [m]	947,25	996,25	1 045,45	1 095,25	1 145,25	1 193,75	1 243,25	1 292,75	1 346,75	1 400,75
CW height [m]	6,35	5,63	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08
MW height [m]	6,85	6,88	6,38	6,48	6,48	6,48	6,48	6,48	6,48	6,48
CW stagger [m]	-	−0,35	−0,1	0,15	−0,2	0,2	−0,2	0,2	−0,2	0,2
MW stagger [m]	-	−0,35	−0,1	0,15	−0,2	0,2	−0,2	0,2	−0,2	0,2

Support number	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Cumulative position [m]	1 454,75	1 508,75	1 562,75	1 616,75	1 670,75	1 724,75	1 778,75	1 832,75	1 882,25	1 931,75
CW height [m]	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08
MW height [m]	6,48	6,48	6,48	6,48	6,48	6,48	6,48	6,48	6,48	6,48
CW stagger [m]	−0,2	0,2	−0,2	0,2	−0,2	0,2	−0,2	0,2	−0,2	0,2
MW stagger [m]	−0,2	0,2	−0,2	0,2	−0,2	0,2	−0,2	0,2	−0,2	0,2

Support number	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Cumulative position [m]	1 981,25	2 030,75	2 080,25	2 130,25	2 180,05	2 229,25	2 269,25
CW height [m]	5,08	5,08	5,08	5,08	5,08	5,63	6,35
MW height [m]	6,48	6,48	6,48	6,48	6,38	6,88	6,85
CW stagger [m]	−0,2	0,2	−0,2	0,15	−0,1	−0,35	-
MW stagger [m]	−0,2	0,2	−0,2	0,15	−0,1	−0,35	-

Table B.10 – Support definition of tension length 3

Support number	1	2	3	4	5	6	7	8	9	10
Cumulative position [m]	2 080,25	2 129,25	2 178,45	2 228,25	2 269,25	2 307,25	2 352,25	2 392,25	2 439,75	2 489,25
CW height [m]	6,35	5,63	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08
MW height [m]	6,85	6,88	7,08	6,48	6,48	6,48	6,48	6,48	6,48	6,48
CW stagger [m]	-	0,35	0,1	−0,15	0,2	−0,2	0,2	−0,2	0,2	−0,2
MW stagger [m]	-	0,35	0,1	−0,15	0,2	−0,2	0,2	−0,2	0,2	−0,2

Support number	11	12	13	14	15	16	17	18	19	20
Cumulative position [m]	2 538,75	2 588,25	2 637,75	2 687,25	2 736,75	2 790,75	2 844,75	2 898,75	2 952,75	3 006,75
CW height [m]	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08	5,08
MW height [m]	6,48	6,48	6,48	6,48	6,48	6,48	6,48	6,48	6,48	6,48
CW stagger [m]	0,2	−0,2	0,2	−0,2	0,2	−0,2	0,2	−0,2	0,15	−0,2
MW stagger [m]	0,2	−0,2	0,2	−0,2	0,2	−0,2	0,2	−0,2	0,15	−0,2

Support number	21	22	23	24	25	26	27	28
Cumulative position [m]	3 060,75	3 114,75	3 168,75	3 222,75	3 272,25	3 322,05	3 371,25	3 420,25
CW height [m]	5,08	5,08	5,08	5,08	5,08	5,08	5,63	6,35
MW height [m]	6,48	6,48	6,48	6,48	6,48	6,38	6,88	6,85
CW stagger [m]	0,15	−0,2	0,15	−0,2	0,15	−0,1	−0,35	-
MW stagger [m]	0,15	−0,2	0,15	−0,2	0,15	−0,1	−0,35	-

B.1.1.7 Droppers

B.1.1.7.1 Tension length 1 (first and last span without any droppers, with a support S on each side)

The dropper definitions for the spans of tension length 1 are given in Table B.11 to Table B.18.

Table B.11 – Span length = 44,7 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	4,35	4,35	6,75	6,75	4,5	
dropper length [m]	-	1,338	1,466	1,586	1,659	1,728	1,828	1,919	-

Table B.12 – Span length = 45,3 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	4,65	4,65	6,75	6,75	4,5	
dropper length [m]	-	1,800	1,634	1,503	1,434	1,380	1,332	1,319	-

Table B.13 – Span length = 45,5 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	4,75	4,75	6,75	6,75	4,5	
dropper length [m]	-	1,259	1,182	1,140	1,131	1,140	1,182	1,259	-

Table B.14 – Span length = 45 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	4,5	4,5	6,75	6,75	4,5	
dropper length [m]	-	1,260	1,186	1,145	1,137	1,145	1,186	1,260	-

Table B.15 – Span length = 49,5 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	6,75	6,75	6,75	6,75	4,5	
dropper length [m]	-	1,246	1,151	1,094	1,075	1,094	1,151	1,246	-

Table B.16 – Span length = 50 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	4,7	4,6	4,7	6,75	6,75	4,5	
dropper length [m]	-	1,244	1,145	1,085	1,067	1,067	1,085	1,145	1,244	-

Table B.17 – Span length = 49,8 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	4,6	4,6	4,6	6,75	6,75	4,5	
dropper length [m]	-	1,299	1,283	1,305	1,342	1,397	1,471	1,611	1,790	-

Table B.18 – Span length = 49,2 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	6,6	6,6	6,75	6,75	4,5	
dropper length [m]	-	1,893	1,725	1,549	1,368	1,247	1,188	1,193	-

B.1.1.7.2 Tension length 2 (first and last span without any droppers, with a support S on each side)

The dropper definitions for the spans of tension length 2 are given in Table B.19 to Table B.27.

Table B.19 – Span length = 49,2 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	6,6	6,6	6,75	6,75	4,5	
dropper length [m]	-	1,129	1,028	0,991	1,018	1,105	1,185	1,257	-

Table B.20 – Span length = 49,8 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	4,6	4,6	4,6	6,75	6,75	4,5	
dropper length [m]	-	1,154	1,070	1,024	1,015	1,024	1,052	1,124	1,236	-

Table B.21 – Span length = 50 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	4,7	4,6	4,7	6,75	6,75	4,5	
dropper length [m]	-	1,244	1,145	1,085	1,067	1,067	1,085	1,145	1,244	-

Table B.22 – Span length = 48,5 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	6,25	6,25	6,75	6,75	4,5	
dropper length [m]	-	1,249	1,159	1,105	1,089	1,105	1,159	1,249	-

Table B.23 – Span length = 49,5 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	6,75	6,75	6,75	6,75	4,5	
dropper length [m]	-	1,246	1,151	1,094	1,075	1,094	1,151	1,246	-

Table B.24 – Span length = 54 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	6,75	4,5	6,75	6,75	6,75	4,5	
dropper length [m]	-	1,231	1,114	1,038	1,004	1,004	1,038	1,114	1,231	-

Table B.25 – Span length = 50 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	4,7	4,6	4,7	6,75	6,75	4,5	
dropper length [m]	-	1,244	1,145	1,085	1,067	1,067	1,085	1,145	1,244	-

Table B.26 – Span length = 49,8 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	4,6	4,6	4,6	6,75	6,75	4,5	
dropper length [m]	-	1,236	1,124	1,052	1,024	1,015	1,024	1,070	1,154	-

Table B.27 – Span length = 49,2 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	6,6	6,6	6,75	6,75	4,5	
dropper length [m]	-	1,257	1,185	1,105	1,018	0,991	1,028	1,129	-

B.1.1.7.3 Tension length 3 (first and last span without any droppers, with a support S on each side)

The dropper definitions for the spans of tension length 3 are given in Table B.28 to Table B.38.

Table B.28 – Span length = 49,2 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	6,6	6,6	6,75	6,75	4,5	
dropper length [m]	-	1,193	1,188	1,247	1,368	1,549	1,725	1,893	-

Table B.29 – Span length = 49,8 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	4,6	4,6	4,6	6,75	6,75	4,5	
dropper length [m]	-	1,790	1,611	1,471	1,397	1,342	1,305	1,283	1,299	-

Table B.30 – Span length = 41 m

No. of the dropper	S	1	2	3	4	5	6	S
inter-droppers distance [m]	4,5	6,75	6,75	5	6,75	6,75	4,5	
dropper length [m]	-	1,273	1,218	1,192	1,192	1,218	1,273	-

Table B.31 – Span length = 38 m

No. of the dropper	S	1	2	3	4	5	6	S
inter-droppers distance [m]	4,5	6,75	5,2	5,1	5,2	6,75	4,5	
dropper length [m]	-	1,282	1,241	1,226	1,226	1,241	1,282	-

Table B.32 – Span length = 45 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	4,5	4,5	6,75	6,75	4,5	
dropper length [m]	-	1,260	1,186	1,145	1,137	1,145	1,186	1,260	-

Table B.33 – Span length = 40 m

No. of the dropper	S	1	2	3	4	5	6	S
inter-droppers distance [m]	4,5	6,75	6,75	4	6,75	6,75	4,5	
dropper length [m]	-	1,276	1,226	1,203	1,203	1,226	1,276	-

Table B.34 – Span length = 47,5 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	5,75	5,75	6,75	6,75	4,5	
dropper length [m]	-	1,252	1,166	1,117	1,103	1,117	1,166	1,252	-

Table B.35 – Span length = 49,5 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	6,75	6,75	6,75	6,75	4,5	
dropper length [m]	-	1,246	1,151	1,094	1,075	1,094	1,151	1,246	-

Table B.36 – Span length = 54 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	6,75	4,5	6,75	6,75	6,75	4,5	
dropper length [m]	-	1,231	1,114	1,038	1,004	1,004	1,038	1,114	1,231	-

Table B.37 – Span length = 49,8 m

No. of the dropper	S	1	2	3	4	5	6	7	8	S
inter-droppers distance [m]	4,5	6,75	6,75	4,6	4,6	4,6	6,75	6,75	4,5	
dropper length [m]	-	1,236	1,124	1,052	1,024	1,015	1,024	1,070	1,154	-

Table B.38 – Span length = 49,2 m

No. of the dropper	S	1	2	3	4	5	6	7	S
inter-droppers distance [m]	4,5	6,75	6,75	6,6	6,6	6,75	6,75	4,5	
dropper length [m]	-	1,257	1,185	1,105	1,018	0,991	1,028	1,129	-

B.1.2 Pantograph model

The pantograph is defined as a discrete mass-spring-damper model as shown in Figure A.4. The model parameters are defined in Table B.39.

Table B.39 – Pantograph model parameters

Reduced dynamic mass [kg]	m_1	4,80
	m_2	4,63
	m_3	8,50
Damping [Ns/m]	c_1	32
	c_2	5
	c_3	20
Stiffness [N/m]	k_1	1
	k_2	5 400
	k_3	6 045
Mean contact force at 300 km/h [N]	F_m	182
NOTE These pantograph model parameters fulfil the requirements of 6.3.		

B.1.3 Measured data of dynamic interaction for validation

The data shown in Table B.40 are the results of line tests according to IEC 62846, filtered with a 6th order filter and a cut off frequency of 20 Hz.

Table B.40 – Measurement result from line test

	Measurement results
Speed [km/h]	300
F_m [N]	182
σ [N] (including low pass filter 20 Hz) [a]	48,0
σ (0 Hz to 5 Hz) [N] [b]	32,2
σ (5 Hz to 20 Hz) [N] [b]	36,5
σ (0 Hz to 20 Hz) [N] [b]	48,7
Actual maximum of contact force [N] [a,c]	345
Actual minimum of contact force [N] [a,c]	52
Percentage of contact loss [%] [c]	0
Max. uplift [mm]	88

[a] Analysed in time domain.

[b] Analysed in frequency domain by FFT.

[c] Values not used for validation.

B.2 Measurement results of a stitched AC high speed overhead contact line

B.2.1 General

Subclauses B.2.2 to B.2.5 contain data from real existing overhead contact line section for high speed, which is certified as an interoperable constituent for the European network.

B.2.2 Simulation data for overhead contact line model

B.2.2.1 Parameters of simulation

The calculation shall be carried out for:

– speed of 302 km/h (in accordance with line test);

– two pantographs with a distance of 192 m between consecutive pantographs;

– a frequency range of interest from 0 Hz to 20 Hz.

The overhead contact line is defined by a simple catenary equipment with single contact wire and stitched catenary suspensions. The analysis section is determined as a length of 1 230,74 m including 32 spans (S1 to S32) and the supports (M1 to M35). The analysis section covers the data of a real OCL with two 5-span-overlaps and other special catenary arrangements. The analysis section starts on a straight track. It follows a section as a transition curve type clothoid starting at chainage 78,421 m and ending at chainage 348,378 m. Thereafter follows a track with a constant radius of 6 997,75 m to the right with a cant of 90 mm between the chainage 348,378 m and 1 230,74 m.

NOTE The defined analysis section is defined with two overlaps to align with the measured data set.

B.2.2.2 Model parameter and mechanical data of OCL

The mechanical tension and the mass per unit length are given in Table B.41. The mechanical data of clamps and other components are given in Table B.42.

Table B.41 – Mechanical values of wires and tubes

Wires and ropes	Tension [N]	mass/unit length [kg/m]	Young's Modulus E [kN/mm^2]	Cross section [mm^2]
Contact wire	27 000	1,067	120	120
Messenger wire	21 000	1,060	113	117
Stitch wire	3 500	0,310	113	35
Dropper wire	-	0,089	103	10
Steady arms (Standard Cantilevers)	-	0,780	70	275 (rectangle 40 × 20 × 2,5)
Steady arm (Cantilevers according to Figure B.1)	-	2,494	70	923,63 (tube 55 × 6)

Table B.42 – Mechanical values of clamps and other OCL-components

No. according to Figure B.1	Element	mass [kg]	Remark
-	Lower dropper clamp	0,140	Mass of dropper clamps including thimbles, crimped connectors, screws, screw nuts, rope loops and so on.
-	Upper dropper clamp to messenger wire	0,155	
-	Upper dropper clamp to stitch wire	0,101	
-	Clamp between stitch and messenger wire	0,380	
2	Mass per unit length for tube steady arm	2,494 kg/m	
1	Contact wire clip at steady arm	0,460	

B.2.2.3 Geometrical data of overhead contact line

The overhead contact line is defined by a simple catenary equipment with single contact wire and stitched catenary suspensions.

NOTE To ensure that all pantographs can completely pass the analysis section, additional spans can be necessary in front of and behind the analysis section.

For parts of the model outside the analysis section, model data may be generated based on the given data for the analysis section.

Positions of dropper (X) along the span and the contact wire height (CWH) at each dropper are given in Table B.43.

In Table B.43:

– mast positions refer to the first mast (M1) in overhead contact line model;
– dropper positions refer to the left mast in mentioned span length;
– left and right stitch wire positions refer to the left mast in mentioned span length.

Table B.43 – Position of droppers and CW-height at dropper

Span number	Left mast	Left stitch wire	Dropper	SD1	D1	D2	D3	D4	D5	SD2	Right stitch wire	Right mast	Remark
Span length [m]	Position [m]	Position [m]									Position [m]	Position [m]	
Catenary 1													
S1	**M1**		X [m]	4,00	12,16	20,31	28,47	36,62		44,78		**M2**	See Figure B.2
			L_{dr} [m]	1,499	1,493	1,429	1,434	1,509		1,526			
48,78	0,0	7,0	CWH [m]	5,3	5,3	5,3	5,3	5,3		5,3	41,78	48,78	
S2	**M2**		X [m]	4,00	13,75	23,49	33,24			42,98		**M3**	See Figure B.2
			L_{dr} [m]	1,531	1,518	1,474	1,526			1,571			
46,98	48,78	7,0	CWH [m]	5,3	5,3	5,3	5,3			5,3	39,98	95,76	
S3	**M3**		X [m]	4,00	13,76	23,52	33,27	43,03				**M4**	Overlap span See Figure B.3
			L_{dr} [m]	1,642	1,718	1,770	1,889	2,078					
46,03	95,76	7,0	CWH [m]	5,301	5,313	5,339	5,378	5,431			-	141,79	
S4	**M4**		X [m]		3,00	11,99	20,98	29,98	38,97			**M5**	Uplifted span See Figure B.4
			L_{dr} [m]		2,063	1,856	1,726	1,674	1,698				
47,96	141,79	-	CWH [m]		5,470	5,530	5,594	5,660	5,729		-	189,75	
S5	**M5**		X [m]		9,44	18,88	28,32					**M6**	Span to tensioning device See Figure B.5
			L_{dr} [m]		1,258	0,809	0,453						
48,32	189,75	-	CWH [m]		5,878	5,956	6,034				-	238,07	
Catenary 2													
S6	**M7**		X [m]		20,00	29,09	38,19					**M8**	Span from tensioning device See Figure B.6
			L_{dr} [m]		0,480	0,834	1,274						
47,28	0,0	-	CWH [m]		6,031	5,954	5,877				-	47,28	
S7	**M8**		X [m]		8,80	17,59	26,39	35,18	43,98			**M9**	Uplifted span See Figure B.7
			L_{dr} [m]		1,706	1,686	1,740	1,867	2,065				
46,98	47,28	-	CWH [m]		5,728	5,659	5,593	5,530	5,470		-	94,26	

Span number	Left mast	Left stitch wire	Dropper	SD1	D1	D2	D3	D4	D5	SD2	Right stitch wire	Right mast	Remark
Span length [m]	**Position** [m]	**Position** [m]									**Position** [m]	**Position** [m]	
S8	**M9**		X [m]		3,00	12,76	22,52	32,27		42,03		**M10**	Overlap span See Figure B.8
			L_{dr} [m]		2,062	1,821	1,649	1,546		1,425			
46,03	94,26	-	CWH [m]		5,431	5,378	5,339	5,313		5,301	39,030	140,29	
S9	**M10**		X [m]	4,00	13,99	23,98	33,97			43,96		**M11**	See Figure B.2
			L_{dr} [m]	1,330	1,269	1,215	1,263			1,290			
47,96	140,29	7,0	CWH [m]	5,3	5,3	5,3	5,3			5,3	40,96	188,25	
S10	**M11**		X [m]	4,00	12,36	20,73	29,09	37,46		45,82		**M12**	See Figure B.2
			L_{dr} [m]	1,309	1,329	1,302	1,350	1,470		1,523			
49,82	188,25	7,0	CWH [m]	5,3	5,3	5,3	5,3	5,3		5,3	42,82	238,07	
S11	**M12**		X [m]	4,00	13,20	22,40	31,59	40,79		49,99		**M13**	See Figure B.2
			L_{dr} [m]	1,535	1,500	1,409	1,404	1,485		1,453			
54,99	238,07	7,0	CWH [m]	5,3	5,3	5,3	5,3	5,3		5,3	45,99	293,06	
S12	**M13**		X [m]	5,00	13,83	22,66	31,49	40,32	49,15	57,98		**M14**	See Figure B.2
			L_{dr} [m]	1,435	1,440	1,327	1,295	1,344	1,474	1,472			
62,98	293,06	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	53,98	356,04	
S13	**M14**		X [m]	5,00	13,83	22,66	31,49	40,32	49,15	57,98		**M15**	See Figure B.2
			L_{dr} [m]	1,475	1,479	1,350	1,302	1,333	1,444	1,427			
62,98	356,04	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	53,98	419,02	
S14	**M15**		X [m]	5,00	13,83	22,66	31,49	40,32	49,15	57,98		**M16**	See Figure B.2
			L_{dr} [m]	1,418	1,419	1,292	1,244	1,277	1,389	1,377			
62,98	419,02	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	53,98	482,0	
S15	**M16**		X [m]	5,00	13,83	22,66	31,49	40,32	49,15	57,98		**M17**	See Figure B.2
			L_{dr} [m]	1,373	1,380	1,262	1,225	1,266	1,388	1,381			
62,98	482,0	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	53,98	544,98	
S16	**M17**		X [m]	5,00	13,83	22,66	31,49	40,32	49,15	57,98		**M18**	See Figure B.2
			L_{dr} [m]	1,381	1,389	1,268	1,226	1,276	1,418	1,425			
62,98	544,98	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	53,98	607,96	

Span number	Left mast	Left stitch wire	Dropper	SD1	D1	D2	D3	D4	D5	SD2	Right stitch wire	Right mast	Remark
Span length [m]	Position [m]	Position [m]									Position [m]	Position [m]	
S17	**M18**		X [m]	5,00	13,66	22,33	30,99	39,65	48,32	56,98		**M19**	See Figure B.2
			L_{dr} [m]	1,430	1,434	1,301	1,257	1,301	1,422	1,415			
61,98	607,96	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	52,98	669,94	
S18	**M19**		X [m]	5,00	13,83	22,66	31,49	40,32	49,15	57,98		**M20**	See Figure B.2
			L_{dr} [m]	1,422	1,439	1,331	1,303	1,355	1,486	1,484			
62,98	669,94	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	53,98	732,92	
S19	**M20**		X [m]	5,00	13,83	22,66	31,49	40,32	49,15	57,98		**M21**	See Figure B.2
			L_{dr} [m]	1,481	1,477	1,341	1,284	1,307	1,410	1,391			
62,98	732,92	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	53,98	795,9	
S20	**M21**		X [m]	5,00	13,83	22,66	31,49	40,32	49,15	57,98		**M22**	See Figure B.2
			L_{dr} [m]	1,388	1,401	1,293	1,264	1,316	1,446	1,448			
62,98	795,9	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	53,98	858,88	
S21	**M22**		X [m]	5,00	13,83	22,66	31,49	40,32	49,15	57,98		**M23**	See Figure B.2
			L_{dr} [m]	1,452	1,459	1,337	1,294	1,331	1,447	1,440			
62,98	858,88	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3	5,3	5,3	53,98	921,86	
S22	**M23**		X [m]	5,00	14,8	24,59	34,39	44,18		53,98		**M24**	See Figure B.2
			L_{dr} [m]	1,449	1,462	1,369	1,373	1,474		1,467			
58,98	921,86	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3		5,3	49,98	980,84	
S23	**M24**		X [m]	5,00	13,75	22,49	31,24	39,98		48,73		**M25**	See Figure B.2
			L_{dr} [m]	1,459	1,458	1,333	1,286	1,316		1,303			
52,73	980,84	9,0	CWH [m]	5,3	5,3	5,3	5,3	5,3		5,3	45,73	1 033,57	
S24	**M25**		X [m]	4,00	12,2	20,39	28,59	36,78		44,98		**M26**	See Figure B.2
			L_{dr} [m]	1,290	1,275	1,209	1,211	1,283		1,331			
48,98	1 033,57	7,0	CWH [m]	5,3	5,3	5,3	5,3	5,3		5,3	41,98	1 082,55	
S25	**M26**		X [m]	4,00	12,2	20,39	28,59	36,78	44,98			**M27**	Overlap span See Figure B.3
			L_{dr} [m]	1,422	1,518	1,581	1,692	1,852	2,061				
47,98	1 082,55	7,0	CWH [m]	5,301	5,31	5,327	5,353	5,388	5,432		-	1 130,53	

Span number	Left mast	Left stitch wire	Dropper	SD1	D1	D2	D3	D4	D5	SD2	Right stitch wire	Right mast	Remark
Span length [m]	Position [m]	Position [m]									Position [m]	Position [m]	
S26	**M27**		X [m]		3,00	12,2	21,39	30,59	39,78			**M28**	Uplifted span See Figure B.4
			L_{dr} [m]		2,063	1,852	1,720	1,667	1,694				
48,98	1 130,53	-	CWH [m]		5,469	5,529	5,592	5,658	5,728		-	1 179,51	
S27	**M28**		X [m]		7,81	15,61	23,42	31,23				**M29**	Span to tensioning device See Figure B.5
			L_{dr} [m]		1,350	0,963	0,640	0,380					
51,23	1 179,51	-	CWH [m]		5,861	5,922	5,983	6,044			-	1 230,74	
Catenary 3													
S28	**M30**		X [m]		20,00	27,81	35,61	43,42				**M31**	Span from tensioning device See Figure B.6
			L_{dr} [m]		0,380	0,640	0,963	1,350					
51,23	980,84	-	CWH [m]		6,044	5,983	5,922	5,861			-	1 032,07	
S29	**M31**		X [m]		9,20	18,39	27,59	36,78	45,98			**M32**	Uplifted span See Figure B.7
			L_{dr} [m]		1,694	1,667	1,720	1,852	2,063				
48,98	1 032,07	-	CWH [m]		5,728	5,658	5,592	5,529	5,469		-	1 081,05	
S30	**M32**		X [m]		3,00	11,2	19,39	27,59	35,78	43,98		**M33**	Overlap span See Figure B.8
			L_{dr} [m]		2,076	1,909	1,791	1,721	1,701	1,636			
47,98	1 081,05	-	CWH [m]		5,432	5,388	5,353	5,327	5,310	5,301	40,98	1 129,03	
S31	**M33**		X [m]	4,00	12,2	20,39	28,59	36,78		44,98		**M34**	See Figure B.2
			L_{dr} [m]	1,566	1,527	1,456	1,453	1,519		1,520			
48,98	1 129,03	7,0	CWH [m]	5,3	5,3	5,3	5,3	5,3		5,3	41,98	1 178,01	
S32	**M34**		X [m]	4,00	12,75	21,49	30,24	38,98		47,73		**M35**	See Figure B.2
			L_{dr} [m]	1,490	1,422	1,295	1,247	1,278		1,215			
52,73	1 178,01	7,0	CWH [m]	5,3	5,3	5,3	5,3	5,3		5,3	43,73	1 230,74	

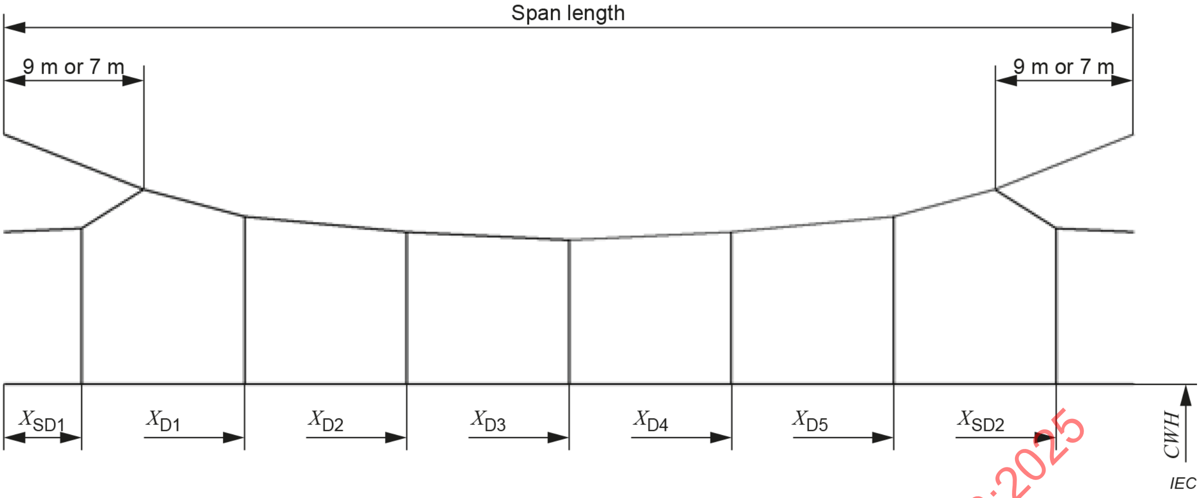

Figure B.2 – Basic dropper arrangement span type ST1

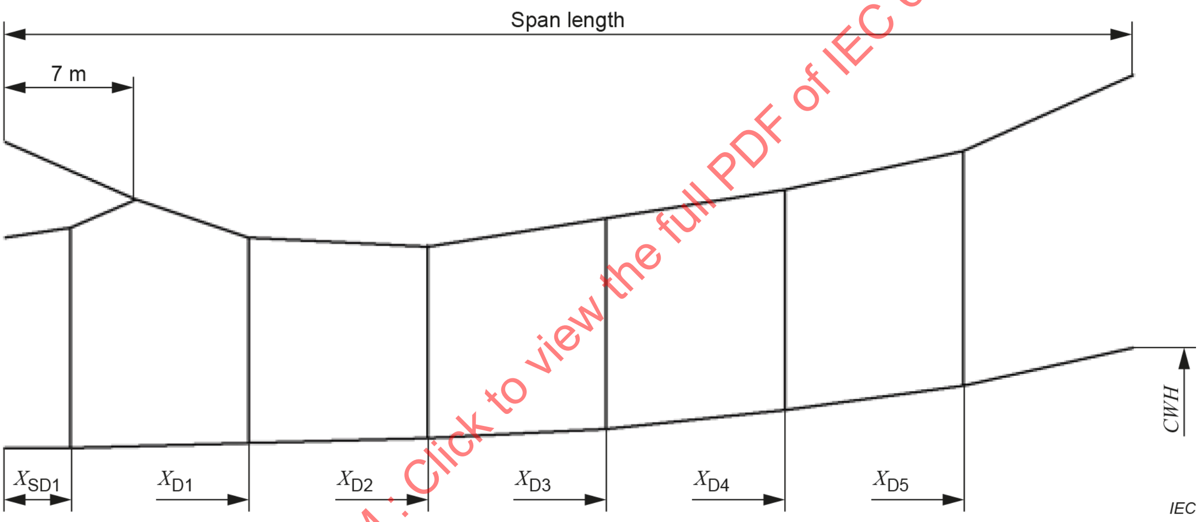

Figure B.3 – Basic dropper arrangement span type ST2

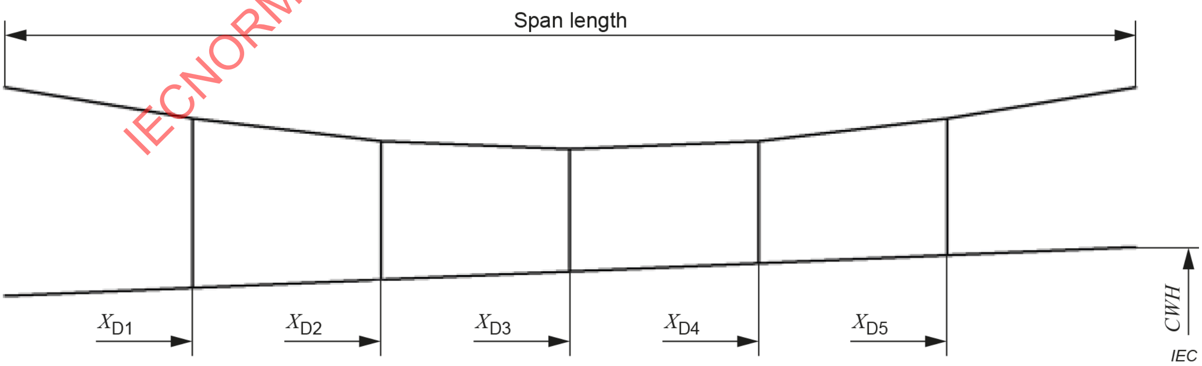

Figure B.4 – Basic dropper arrangement span type ST3

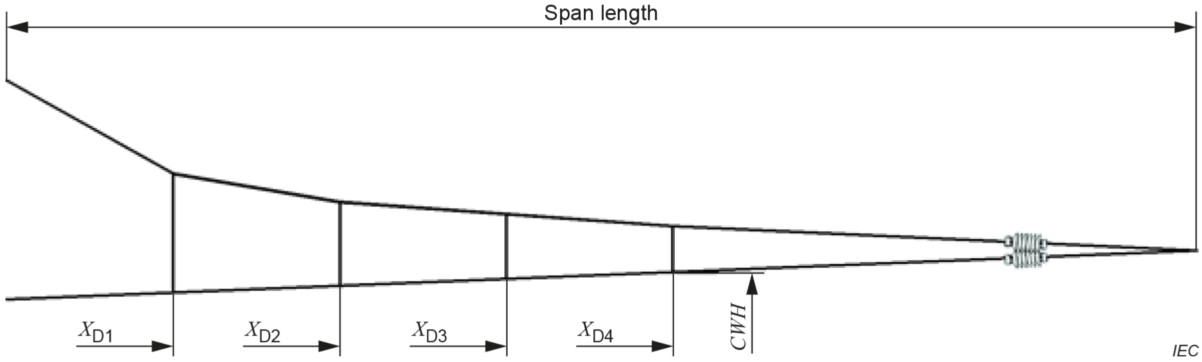

Figure B.5 – Basic dropper arrangement span type ST4

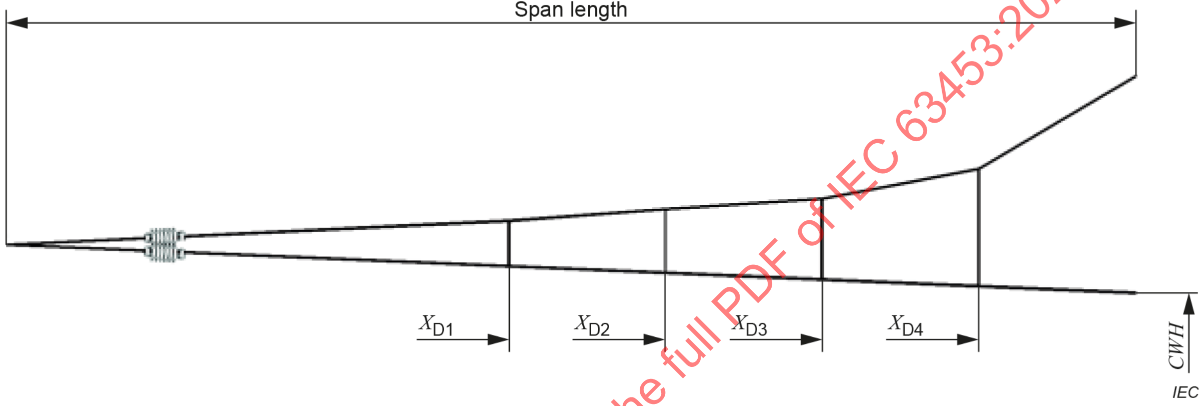

Figure B.6 – Basic dropper arrangement span type ST5

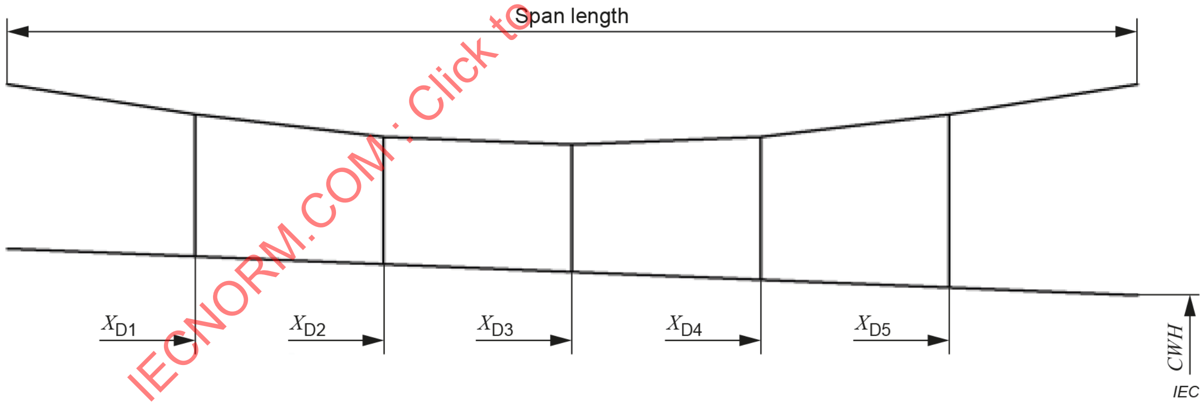

Figure B.7 – Basic dropper arrangement span type ST6

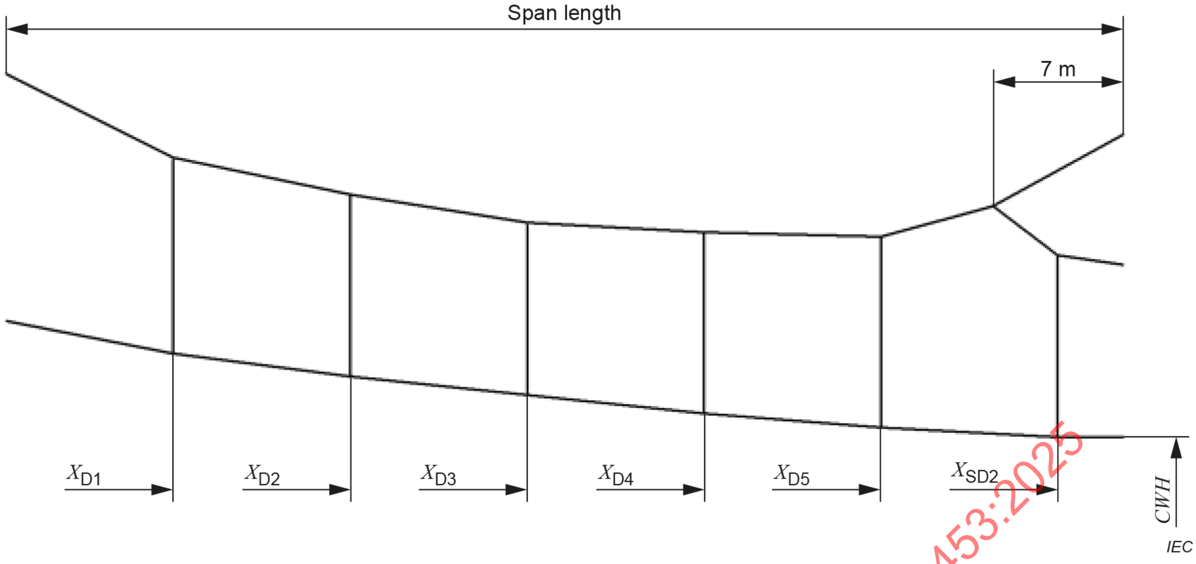

Figure B.8 – Basic dropper arrangement span type ST7

B.2.2.4 Support data

The support data are given in Table B.44. The encumbrances at each support are the differences between messenger wire and contact wire height, see Table B.44.

Table B.44 – Data of supports

Left span	Mast number	Heights		Stagger		Tension force SW	L_{sa}	F_{sa}	Right span	Remark
Span length [m]	Position [m]	CW [m]	MW [m]	CW [m]	MW [m]	[N]	[m]	[N]	Span length [m]	
					Catenary 1					
variable	**M1**	5,3	7,069	−0,3	−0,3	3 500	1,15	656	**S1**	Start of analysis section
variable	0,0								48,78	See Figure B.10
S1	**M2**	5,3	7,1	0,3	0,3	3 500	1,15	665	**S2**	
48,78	48,78								46,98	See Figure B.9
S2	**M3**	5,3	7,1	−0,3	−0,3	3 500	1,15	467	**S3**	
46,98	95,76								46,03	See Figure B.10
S3	**M4**	5,45	7,6	−0,15	−0,15	-	1,35	378	**S4**	Uplifted support
46,03	141,79								47,96	See Figure B.9
S4	**M5**	5,8	7,6	−0,75	−0,75	-	1,35	2 923	**S5**	Uplifted support
47,96	189,75								48,32	See Figure B.11
S5	M6	6,2	6,2	3,7	4,2	-	-	-	-	Tensioning device
48,32	238,07								-	

Left span	Mast number	Heights		Stagger		Tension force SW	L_{sa}	F_{sa}	Right span	Remark
Span length	Position	CW	MW	CW	MW				Span length	
[m]	[m]	[m]	[m]	[m]	[m]	[N]	[m]	[N]	[m]	
Catenary 2										
-	**M7**	6,2	6,2	3,7	4,2	-	-	-	**S6**	Tensioning device
-	0,0								47,28	
S6	**M8**	5,8	7,6	0,75	0,75	-	1,35	1 494	**S7**	Uplifted support
47,28	47,28								46,98	See Figure B.11
S7	**M9**	5,45	7,6	0,15	0,15	-	1,35	465	**S8**	Uplifted support
46,98	94,26								46,03	See Figure B.10
S8	**M10**	5,3	6,85	0,3	0,3	3 500	1,15	383	**S9**	
46,03	140,29								47,96	See Figure B.9
S9	**M11**	5,3	6,85	−0,3	−0,3	3 500	1,15	740	**S10**	
47,96	188,25								49,82	See Figure B.10
S10	**M12**	5,3	7,141	0,3	0,3	3 500	1,15	498	**S11**	
49,82	238,07								54,99	See Figure B.9
S11	**M13**	5,3	7,156	−0,3	−0,3	3 500	1,15	709	**S12**	Uplift measurement equipment
54,99	293,06								62,98	See Figure B.10
S12	**M14**	5,3	7,222	0,25	0,25	3 500	1,25	262	**S13**	Uplift measurement equipment
62,98	356,04								62,98	See Figure B.9
S13	**M15**	5,3	7,159	−0,3	−0,3	3 500	1,15	714	**S14**	
62,98	419,02								62,98	See Figure B.10
S14	**M16**	5,3	7,103	0,25	0,25	3 500	1,25	228	**S15**	
62,98	482,0								62,98	See Figure B.9
S15	**M17**	5,3	7,121	−0,3	−0,3	3 500	1,15	714	**S16**	
62,98	544,98								62,98	See Figure B.10
S16	**M18**	5,3	7,184	0,25	0,25	3 500	1,25	233	**S17**	Fix-Point
62,98	607,96								61,98	See Figure B.9
S17	**M19**	5,3	7,15	−0,3	−0,3	3 500	1,15	716	**S18**	
61,98	669,94								62,98	See Figure B.10
S18	**M20**	5,3	7,234	0,25	0,25	3 500	1,25	228	**S19**	
62,98	732,92								62,98	See Figure B.9
S19	**M21**	5,3	7,11	−0,3	−0,3	3 500	1,15	714	**S20**	
62,98	795,9								62,98	See Figure B.10
S20	**M22**	5,3	7,194	0,25	0,25	3 500	1,25	228	**S21**	
62,98	858,88								62,98	See Figure B.9
S21	**M23**	5,3	7,17	−0,3	−0,3	3 500	1,15	722	**S22**	
62,98	921,86								58,98	See Figure B.10
S22	**M24**	5,3	7,194	0,25	0,25	3 500	1,25	317	**S23**	
58,98	980,84								52,73	See Figure B.9
S23	**M25**	5,3	6,85	−0,3	−0,3	3 500	1,15	807	**S24**	
52,73	1 033,57								48,98	See Figure B.10
S24	**M26**	5,3	6,85	0,3	0,3	3 500	1,15	363	**S25**	
48,98	1 082,55								47,98	See Figure B.9
S25	**M27**	5,45	7,6	−0,1	−0,1	-	1,35	748	**S26**	Uplifted support
47,98	1 130,53								48,98	See Figure B.10
S26	**M28**	5,8	7,6	0,5	0,5	-	1,35	1487	S27	Uplifted support
48,98	1 179,51								51,23	See Figure B.11

Left span	**Mast number**	**Heights**		**Stagger**		**Tension force SW**	L_{sa}	F_{sa}	**Right span**	**Remark**
Span length	**Position**	**CW**	**MW**	**CW**	**MW**				**Span length**	
[m]	[m]	[m]	[m]	[m]	[m]	[N]	[m]	[N]	[m]	
S27	M29	6,2	6,2	3,7	4,2	-	-	-	-	Tensioning device
51,23	1 230,74								-	
Catenary 3										
-	**M30**	6,2	6,2	3,7	4,2	-	-	-	**S28**	Tensioning device
-	980,84								51,23	
S28	**M31**	5,8	7,6	−0,5	−0,5	-	1,35	2673	**S29**	Uplifted support
51,23	1 032,07								48,98	See Figure B.11
S29	**M32**	5,45	7,6	0,1	0,1	-	1,35	361	**S30**	Uplifted support
48,98	1 081,05								47,98	See Figure B.9
S30	**M33**	5,3	7,1	−0,3	−0,3	3 500	1,15	747	**S31**	
47,98	1 129,03								48,98	See Figure B.10
S31	**M34**	5,3	7,1	0,3	0,3	3 500	1,15	441	**S32**	
48,98	1 178,01								52,73	See Figure B.9
S32	**M35**	5,3	6,85	−0,3	−0,3	3 500	1,25	776	variable	End of analysis section
52,73	1 230,74								variable	See Figure B.10

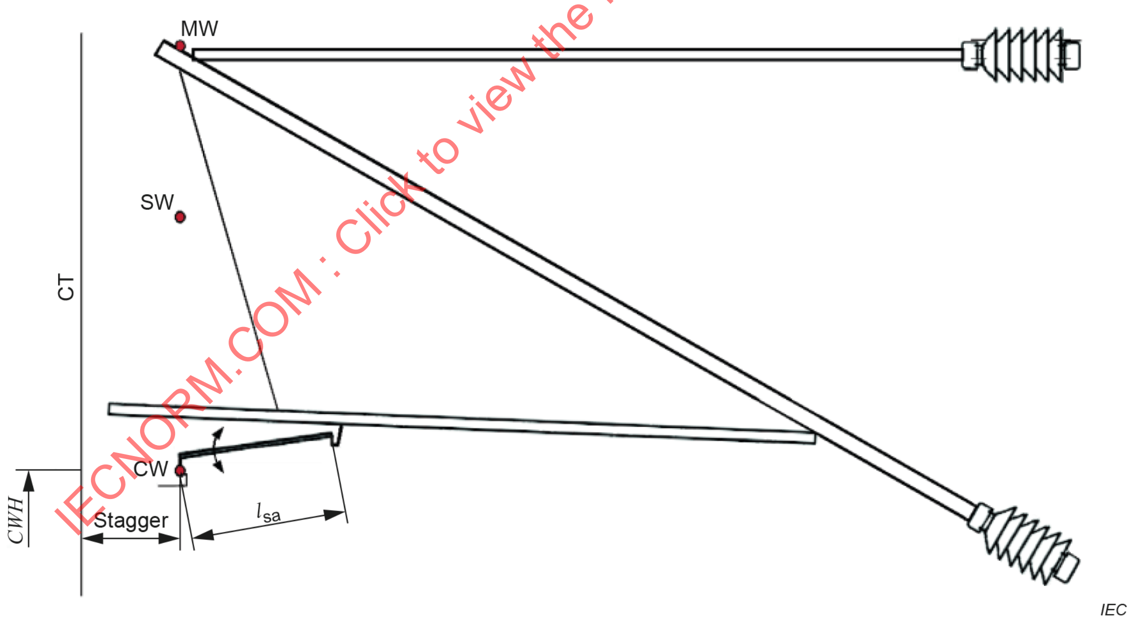

Figure B.9 – Basic support arrangement Mast Type MT1 (pull-off)

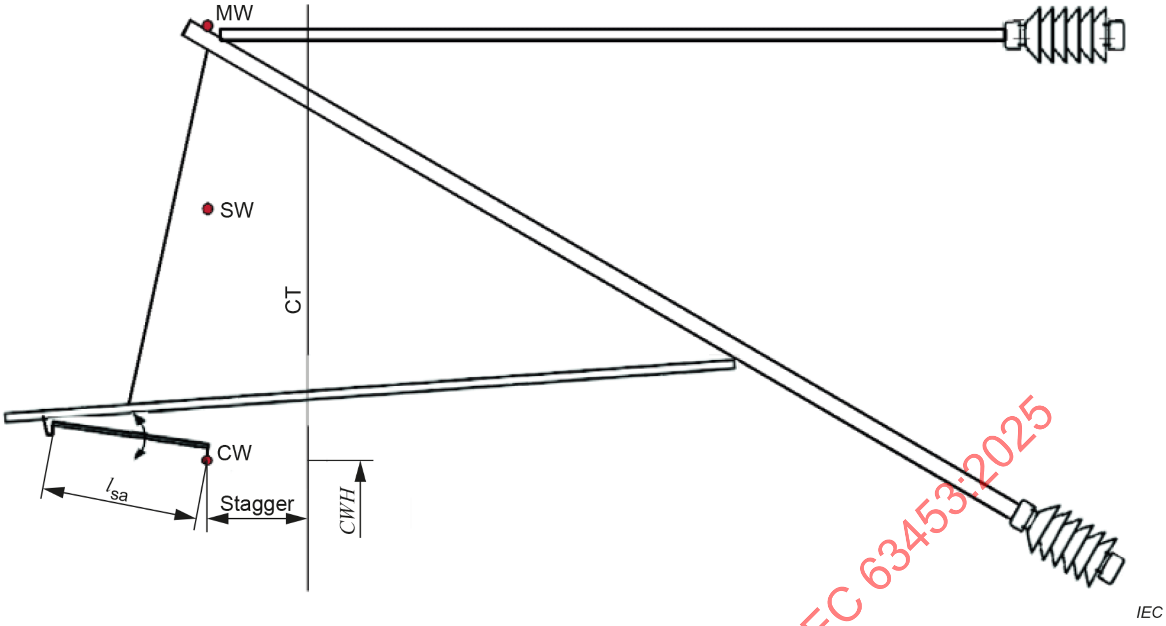

Figure B.10 – Basic support arrangement Mast Type MT2 (push-off)

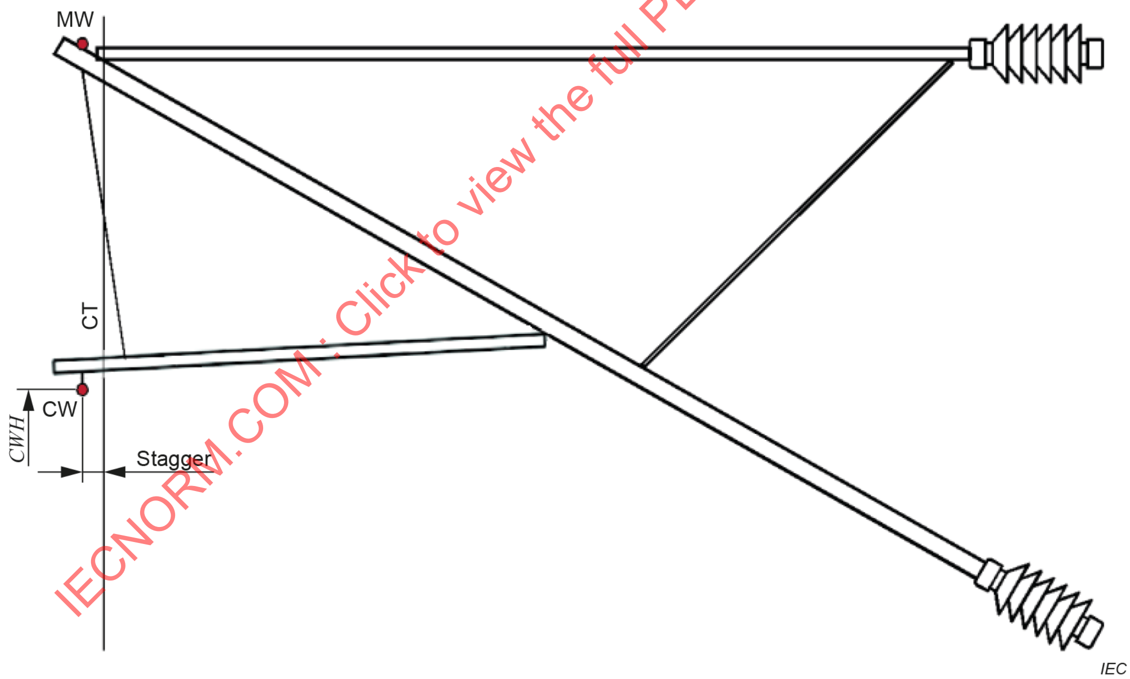

Figure B.11 – Basic support arrangement mast type MT3 (tube steady arm)

B.2.3 Pantograph data

Table B.45 contains data of a real existing pantograph for high speed, which is certified as an interoperable constituent according to the TSI LOC & PAS [3].

The pantograph is defined as a discrete mass-spring-damper-model as shown in Figure A.4. The model parameters are given in Table B.45. For the distance between pantographs see B.2.2.1.

Table B.45 – Pantograph model parameters

Reduced dynamic mass [kg]	m_1	1,31
	m_2	9,00
	m_3	8,50
Damping [Ns/m]	c_1	13,10
	c_2	0,00
	c_3	30,00
Stiffness [N/m]	k_1	0,00
	k_2	2 200,00
	k_3	7 000,00
Mean contact force at 302 km/h leading pantograph [N]	F_m	143,00
Mean contact force at 302 km/h trailing pantograph [N]		161,00
NOTE These pantograph model parameters fulfil the requirements of 6.3.		

B.2.4 Calculated and measured data of OCL-rest position for validation

The data in Table B.46 shall be used for comparison with the results of the simulation software for the calculation of the overhead contact line rest position, and its static lift position. Dropper lengths are based on a calculation of an independent software for design and assembly of catenaries and cantilevers. The elasticity values in Table B.46 are measured at each support and dropper position applying an uplift of 100 mm.

For the comparison, data from spans S14 and S15 was used, see Table B.43. Each span (see Figure B.2) is 62,98 m long with 18 m stitch wires at mast and one dropper to stitch wire on both sides and five droppers to messenger wire in the middle.

Table B.46 – Dropper length and system elasticity

Dropper	Support	1	2	3	4	5	6	7	Support
Position inside of span [m]	0,0	5,00	13,83	22,66	31,49	40,32	49,15	57,98	62,98
Span/Support	**M15**				**S14**				**M16**
Dropper length [m]	-	1,418	1,419	1,292	1,244	1,277	1,389	1,377	-
System elasticity [mm/N]	0,299	0,308	0,357	0,358	0,374	0,358	0,346	0,323	0,346
Span/Support	**M16**				**S15**				**M17**
Dropper length [m]	-	1,373	1,380	1,262	1,225	1,266	1,388	1,381	-
System elasticity [mm/N]	0,346	0,328	0,364	0,355	0,367	0,349	0,353	0,294	0,289

B.2.5 Measuring data of dynamic interaction for validation

The data shown in Table B.47 are the results of line test according to EN 50317, filtered with a 6^{th} order filter and a cut off frequency of 20 Hz.

Data for uplift at support M13 and M14 are measured with the help of a stationary uplift measurement equipment according to EN 50317.

Table B.47 – Measurement result from line test

	Measurement results	
Speed [km/h]	302	
Pantograph	1	2
Pantograph distance [m]	192	
F_m [N]	143,0	161,0
σ [N] (incl. low pass filter 20 Hz) [a]	27,0	32,6
σ (0 Hz to 5 Hz) [N] [b]	19,8	22,7
σ (5 Hz to 20 Hz) [N] [b]	17,3	22,0
σ (0 Hz to 20 Hz) [N] [b]	26,3	31,6
Actual maximum of contact force [N] [a,c]	230,0	254,0
Actual minimum of contact force [N] [a,c]	27,0	42,0
Uplift at support M13 [mm]	47,0	49,0
Uplift at support M14 [mm]	52,0	56,0
Percentage of contact loss [%] [c]	0,0	0,0

[a] Analysed in time domain.

[b] Analysed in frequency domain by FFT.

[c] Values not used for validation.

B.3 Measurement results of simple DC high speed overhead contact line

B.3.1 General

Subclauses B.3.2 to B.3.4 contain data from real existing DC overhead contact line section for high speed, which is certified as an interoperable constituent for the European network.

B.3.2 Simulation data for overhead contact line model

B.3.2.1 Parameters of simulation

The calculation shall be carried out for:

– a speed of 250,6 km/h (in accordance with line test),
– two pantographs with a distance of 243 m between consecutive pantographs;
– a frequency range of interest from 0 Hz to 20 Hz.

The overhead contact line is defined by two parallel simple catenary systems with one messenger wire and one contact wire each. The analysis section is determined as a length of 1 736 m including 35 spans (S1 to S35) and the supports (M1 to M38). The analysis section includes the data of a real OCL, two 3-span-overlaps, on straight track.

B.3.2.2 Model parameter and mechanical data of OCL

The mechanical tension and the mass per unit length are given in Table B.48. The mechanical data of clamps and other components are given in Table B.49.

Table B.48 – Mechanical values of wires

Wires and ropes	Tension N	mass/unit length kg/m	Young's Modulus E kN/mm^2	Cross section mm^2
Contact wires	18 750	1,335	120	150
Messenger wires	15 000	1,070	120	117
Dropper wire	-	0,152	113	16
Steady arms	-	0,730	70	270

Table B.49 – Mechanical values of clamps and other OCL-components

No.	Element	Mass kg	Remark
-	Lower dropper clamp	0,145	
-	Upper dropper clamp to messenger wire	0,170	
1	Contact wire clip at steady arm	0,350	

B.3.2.3 Geometrical data of overhead contact line

The overhead contact line is defined by two parallel simple catenary systems with one messenger and one contact wire each.

NOTE To ensure that all pantographs can completely pass the analysis section, additional spans can be necessary in before of and after the analysis section.

For parts of the model outside the analysis section, model data may be generated based on the given data for the analysis section.

Positions of droppers (X) along the span and the contact wire height (CWH) at each dropper are given in Table B.50.

In Table B.50:

– mast positions refer to the first mast (M1) in overhead contact line model;
– dropper positions refer to the left mast of the mentioned span length.

Table B.50 – Position of droppers and CW-height at dropper

Span number / Span length [m]	Left mast / Position [m]	Dropper	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	Right mast / Position [m]	Remark
Catenary 1																
S1	**M1**	X1 [m]	4	9	14	18	22	26	30	34	38	42	47	52	**M2**	
		$L1_{dr}$ [m]	1,06	0,87	0,725	0,64	0,58	0,545	0,54	0,56	0,605	0,68	0,81	0,98		
		X2 [m]	6	11	16	20	24	28	32	36	40	44	49	54		
		$L2_{dr}$ [m]	0,98	0,81	0,68	0,605	0,56	0,54	0,545	0,58	0,64	0,725	0,87	1,06		
58	0	CW1H [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	58	
		CW2H [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		
S2	**M2**	X1 [m]	4	9	14	18	22	26	30	34	38	42	47	52	**M3**	
		$L1_{dr}$ [m]	1,06	0,87	0,725	0,64	0,58	0,545	0,54	0,56	0,605	0,68	0,81	0,98		
		X2 [m]	6	11	16	20	24	28	32	36	40	44	49	54		
		$L2_{dr}$ [m]	0,98	0,81	0,68	0,605	0,56	0,54	0,545	0,58	0,64	0,725	0,87	1,06		
58	58	CW1H [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	116	
		CW2H [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		
S3	**M3**	X1 [m]	4	9	14	19	24	28	33	37	42	47	52	57	**M4**	
		$L1_{dr}$ [m]	1,05	0,855	0,7	0,59	0,52	0,49	0,495	0,525	0,605	0,725	0,885	1,09		
		X2 [m]	6	11	16	21	26	30	35	39	44	49	54	59		
		$L2_{dr}$ [m]	0,97	0,79	0,65	0,555	0,5	0,485	0,505	0,555	0,65	0,785	0,965	1,185		
63	116	CW1H [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	179	
		CW2H [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		

Span number Span length [m]	Left mast Position [m]	Dropper	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	Right mast Position [m]	Remark
S4	**M4**	$X1$ [m]	4	9	14	19	23	27	31	35	39	44	49	54	**M5**	Overlap/Uplifted span
		$L1_{dr}$ [m]	1,23	1,065	0,945	0,86	0,83	0,82	0,84	0,875	0,91	0,95	0,995	1,045		
		$X2$ [m]	6	11	16	21	25	29	33	37	41	46	51	56		
		$L2_{dr}$ [m]	1,16	1,01	0,905	0,84	0,82	0,825	0,855	0,89	0,925	0,97	0,1015	0,106		
60	179	$CW1H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,107	5,127	5,167	5,226	5,303	239	
		$CW2H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,102	5,116	5,141	5,188	5,255	5,339		
S5	**M5**	$X1$ [m]	3,5												**M6**	Span from tensioning device
		$L1_{dr}$ [m]	0,855													
		$X2$ [m]	3,5													
		$L2_{dr}$ [m]	0,855													
57	239	$CW1H$ [m]	5,5												296	
		$CW2H$ [m]	5,5													
Catenary 2																
S6	**M7**	$X1$ [m]	56,5												**M8**	Span from tensioning device
		$L1_{dr}$ [m]	0,865													
		$X2$ [m]	56,5													
		$L2_{dr}$ [m]	0,865													
60	116	$CW1H$ [m]	5,5												176	
		$CW2H$ [m]	5,5													

Span number	Left mast	Dropper	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	Right mast	Remark
Span length [m]	Position [m]														Position [m]	
S7	**M8**	*X1* [m]	4	9	14	19	23	27	31	35	39	44	49	54	**M9**	Overlap/Uplifted span
		$L1_{dr}$ [m]	1,06	1,015	0,97	0,925	0,89	0,855	0,825	0,82	0,84	0,905	1,01	1,16		
		X2 [m]	6	11	16	21	25	29	33	37	41	46	51	56		
		$L2_{dr}$ [m]	1,045	0,995	0,95	0,91	0,875	0,84	0,82	0,83	0,86	0,945	1,065	1,23		
60	176	*CW1H* [m]	5,339	5,255	5,188	5,141	5,116	5,102	5,1	5,1	5,1	5,1	5,1	5,1	236	
		CW2H [m]	5,303	5,226	5,167	5,127	5,107	5,1	5,1	5,1	5,1	5,1	5,1	5,1		
S8	**M9**	*X1* [m]	4	9	14	19	23	27	31	35	39	44	49	54	**M10**	
		$L1_{dr}$ [m]	1,19	0,985	0,815	0,69	0,62	0,58	0,56	0,57	0,61	0,695	0,82	0,985		
		X2 [m]	6	11	16	21	25	29	33	37	41	46	51	56		
		$L2_{dr}$ [m]	1,105	0,915	0,765	0,655	0,595	0,565	0,565	0,585	0,635	0,735	0,88	1,06		
60	236	*CW1H* [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	296	
		CW2H [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		
S9	**M10**	*X1* [m]	4	9	14	19	23	27	31	35	39	44	49	54	**M11**	
		$L1_{dr}$ [m]	1,05	0,855	0,7	0,59	0,53	0,495	0,49	0,51	0,555	0,655	0,79	0,97		
		X2 [m]	6	11	16	21	25	29	33	37	41	46	51	56		
		$L2_{dr}$ [m]	0,97	0,79	0,655	0,555	0,51	0,49	0,495	0,53	0,59	0,7	0,855	1,05		
60	296	*CW1H* [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	356	
		CW2H [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		
S10	**M11**	*X1* [m]	4	9	14	19	23	27	31	35	39	44	49	54	**M12**	
		$L1_{dr}$ [m]	1,05	0,855	0,7	0,59	0,53	0,495	0,49	0,51	0,555	0,655	0,79	0,97		
		X2 [m]	6	11	16	21	25	29	33	37	41	46	51	56		
		$L2_{dr}$ [m]	0,97	0,79	0,655	0,555	0,51	0,49	0,495	0,53	0,59	0,7	0,855	1,05		
60	356	*CW1H* [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	416	
		CW2H [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		

Span number / Span length [m]	Left mast / Position [m]	Dropper	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	Right mast / Position [m]	Remark
S11	**M12**	$X1$ [m]	4	9	14	18	22	26	30	34	38	42	47	52	**M13**	
		$L1_{dr}$ [m]	1,06	0,87	0,725	0,64	0,58	0,545	0,54	0,56	0,605	0,68	0,81	0,98		
		$X2$ [m]	6	11	16	20	24	28	32	36	40	44	49	54		
		$L2_{dr}$ [m]	0,98	0,81	0,68	0,605	0,56	0,54	0,545	0,58	0,64	0,725	0,87	1,06		
58	416	$CW1H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	474	
		$CW2H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		
S12	**M13**	$X1$ [m]	4	9	14	18	22	26	29	33	37	41	46	51	**M14**	
		$L1_{dr}$ [m]	1,06	0,88	0,735	0,655	0,595	0,565	0,56	0,575	0,62	0,69	0,815	0,985		
		$X2$ [m]	6	11	16	20	24	28	31	35	39	43	48	53		
		$L2_{dr}$ [m]	0,985	0,815	0,69	0,62	0,575	0,56	0,565	0,595	0,655	0,735	0,88	1,06		
57	474	$CW1H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	531	
		$CW2H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		
S13	**M14**	$X1$ [m]	4	9	14	18	22	26	30	34	38	42	47	52	**M15**	
		$L1_{dr}$ [m]	1,06	0,87	0,725	0,64	0,58	0,545	0,54	0,56	0,605	0,68	0,81	0,98		
		$X2$ [m]	6	11	16	20	24	28	32	36	40	44	49	54		
		$L2_{dr}$ [m]	0,98	0,81	0,68	0,605	0,56	0,54	0,545	0,58	0,64	0,725	0,87	1,06		
58	531	$CW1H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	589	
		$CW2H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		
S14	**M15**	$X1$ [m]	4	9	14	19	23	27	31	35	39	44	49	54	**M16**	
		$L1_{dr}$ [m]	1,05	0,855	0,7	0,59	0,53	0,495	0,49	0,51	0,555	0,655	0,79	0,97		
		$X2$ [m]	6	11	16	21	25	29	33	37	41	46	51	56		
		$L2_{dr}$ [m]	0,97	0,79	0,655	0,555	0,51	0,49	0,495	0,53	0,59	0,7	0,855	1,05		
60	589	$CW1H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	649	
		$CW2H$ [m]	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1	5,1		