



BSI Standards Publication

Railway applications — Gauges

Part 5: Background, explanation and worked examples

National foreword

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European foreword

This document (CEN/TR 15273-5:2025) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

The EN 15273 series, *Railway applications — Gauges*, consists of the following parts:

- EN 15273-1:2025, *General — Common rules for rolling stock and infrastructure*, which gives the general explanations of gauging and defines the sharing of the space between rolling stock and infrastructure;
- EN 15273-2:2025, *Rolling stock*, which gives the rules for dimensioning vehicles;
- EN 15273-3:2025, *Infrastructure*, which gives the rules for positioning the infrastructure;
- EN 15273-4:2025, *Catalogue of defined gauges*, which includes a non-exhaustive list of reference profiles and parameters to be used by infrastructure and rolling stock; and
- CEN/TR 15273-5:2025, *Background, explanation and worked examples* (this document).

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

Introduction

The aim of this document is to define the rules for the calculation and verification of the dimensions of rolling stock and infrastructure from a gauging perspective.

This document gives gauging processes taking into account the relative movements between rolling stock and infrastructure and the necessary margins or clearances.

This part of the series EN 15273 is intended to be used in conjunction with the following parts:

- *Part 1: General — Common rules for rolling stock and infrastructure;*
- *Part 2: Rolling stock;*
- *Part 3: Infrastructure;*
- *Part 4: Catalogue of defined gauges.*

1 Scope

This document presents the background of some gauging methods, gives calculation examples for both rolling stock and infrastructure based on gauging methods from EN 15273-2:2025 and EN 15273-3:2025, and also demonstrates some relevant formulae.

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.

EN 15273-1:2025, *Railway applications — Gauges — Part 1: General common rules for rolling stock and infrastructure*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 15273-1:2025 apply.

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

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

4 Symbols and abbreviations

For the purposes of this document, the symbols and abbreviations given in EN 15273-1:2025 apply.

5 General

This document has been prepared by Technical Committee CEN/TC 256 “Railway applications” for better reading and understanding of EN 15273. All examples contained in this document are for guidance and are not contractual.

This document aims at providing background information and examples to complement the EN 15273 series. This includes infrastructure implementation, the tracks implementation and the sections for rolling stock in order to ensure the service safety. These rolling stock are designed according to the different types of existing or future configuration.

This document explains the general philosophy of the methods used and of the history of the evolution of the rules. Therefore, the reader is able to adapt the philosophy or formulae to their specific cases.

6 Historical background

6.1 Why gauging?

The following photographs demonstrate the importance of gauging.

Figure 1 shows where the top corner of a container has come into contact with the bridge creating a score through the underside of the arch. Clearance assessments undertaken correctly would have identified this container and wagon combination to be incompatible for operation on this route. In worse conditions, the railway vehicle coming into contact with the infrastructure could cause more damage to both sides of the interface, or possibly derailment.

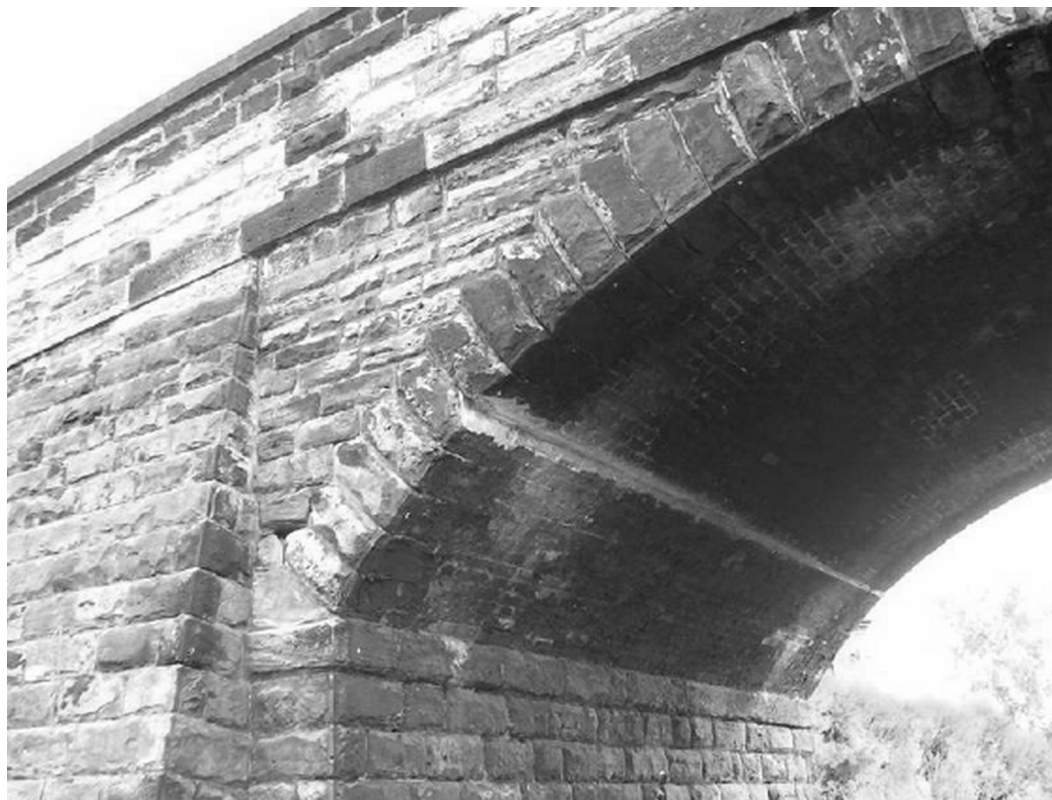


Figure 1 — Container contact on the bridge

Figure 2 shows the underside of a footstep of a passenger vehicle coming into contact with the platform. Whilst this scenario could be considered ideal for stepping purposes at the platform-train interface, sustained contact in this situation will result in damage to both sides of the interface.

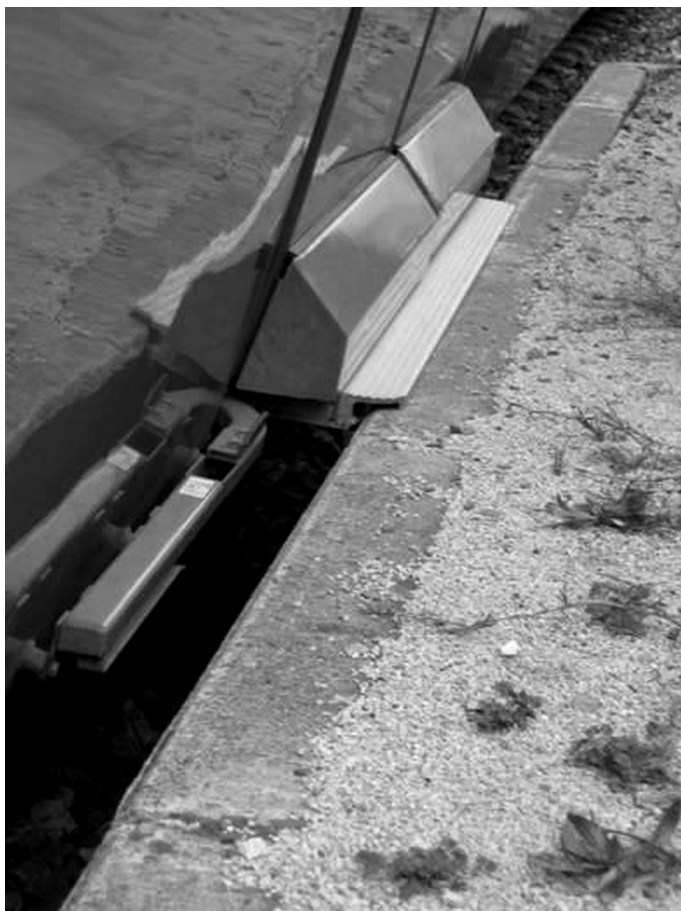


Figure 2 — Clearance between access door steps and platform

6.2 Defined gauges

The historical development of the rules of kinematic gauging is the subject of UIC 505-5. In summary, the needs of transport and of interoperability led railways operators in Continental Europe to adopt a common gauge in 1913.

This gauge was defined as the UT (Technical Unit) and was a static gauge.

Until then, the rules used by the networks were not unified and posed interoperability problems. The UT static gauge consists of a reference profile and associated rules, which allows the Infrastructure Manager to position infrastructure, and the Railway Undertaking to design vehicles which can safely pass through the infrastructure and pass other trains on adjacent lines.

Given the evolution of rolling stock, the lengthening of vehicle wheelbases and bogies, the increase of the speeds and passenger comfort, etc., many parameters have therefore had an impact on the increased flexibility of suspensions as well as the clearance between carriages and bogies. As a result, UIC was requested in 1953 to develop a kinematic gauge. A first version of UIC 505 was thus published in 1956, being completed in 1957 by a table defining the lateral projections.

The basic principle of the method used at the time was the use of a reference profile to allow the clear separation of responsibilities between the Railway Undertaking and the Infrastructure Manager, dividing the lateral movements so that they are taken into account just once.

This breakdown led to standard values, such as for cant that is shared between the Railway Undertaking and Infrastructure Manager. In this case, the first 50 mm of cant or cant deficiency is covered by the rolling stock. The rest of the cant or the cant deficiency is taken into account by the infrastructure.

The same goes for the flexibility coefficient, (e.g. for the G1 gauge its value is 0,4), except that its reference value in this case is limited by the infrastructure. If this value is exceeded by the designers of the rolling stock, it is their responsibility to adapt the vehicles' exterior dimensions to respect the space allowed by the infrastructure.

Thus, all parts of UIC 505 were developed for various type of rolling stock and for infrastructure.

In 1991, the 5th and 7th UIC Commissions decided to group the first three leaflets under the name UIC 505-1 and maintain UIC 505-4 and UIC 505-5.

Subsequently, the implementation of European Standards development led to the revising of these calculation methods whilst:

- optimizing, for example using generic formulae in the calculation of the lateral reductions;
- adapting;
 - because they were such striking passage reduction formulae on marshalling humps for special wagons;
 - creating rules for the area of the wheels and live parts on the roof.

Rolling stock sized according to UIC 505-1 and UIC 506 is compatible with the requirements of EN 15273 for kinematic gauges below:

- G1, GI1, GI2 and G2 for UIC 505-1;
- GA, GB, GB1, GB2, GC and GI3 for UIC 506.

6.3 Absolute and comparative process

The historical development of the absolute and comparative gauging process originated in the rail network of Great Britain (GB). Early trains and infrastructure built were small; it was only once their popularity was established that larger rolling stock was produced. Fortunately, the difference in size between structures built and the limiting structure gauge meant that larger trains could be easily accommodated. Today's railway is very different in GB; a requirement for larger, high-capacity trains, containerised freight (in 9'6" high boxes) presents quite a different problem to small goods wagons. The combination of cross-sectional area, shape, length and speed all place a space requirement on today's railway that could not be dreamed about in Victorian times, although GB continues to use much of the same infrastructure. Historically, not only were many structures built bigger than required, but the space allowed between trains and structures was large also. This space is known as clearance. Clearance is provided to accommodate movement of the train as it travels and to provide a safety margin to accommodate track maintenance, unknown situations, tolerances, etc. and sometimes to provide safe walking routes.

As GB has built progressively larger trains, they have reduced the clearance originally provided. Tracks have been moved to accommodate the often conflicting demands of wide passenger trains and tall freight container trains (which do not fit neatly through arched bridges and tunnels).

The simplest form originally used by GB was using static gauges. Following nationalisation, standard gauges for locomotives (L1), carriages (C1) and wagons (W1 to W5) were introduced in 1950, these being gauges that would fit virtually anywhere on the national railway network. The W6 gauge, larger than W5 and quickly replaced with W6a once issues regarding clearances to third rail electrified track were identified, was added later. The W6a gauge is now the most widely used wagon gauge on the modern GB railway network. W6a however does not guarantee route compatibility with the entire British railway network ('go-anywhere'), and assumes wagon type suspension parameters which makes it unsuitable for use in building other types of rolling stock such as passenger vehicles. Whilst GB retains the use of static gauges in some circumstances, their use has been superseded by more sophisticated analysis to make better use of space.

Following extensive research in the 1970-80s, a methodology was established by British Rail Mechanical and Electrical Engineering Department for the calculation of vehicle sways and drops named Design Guide 501 or “BASS 501”. This hand-calculated technique enabled the calculation of simple vehicle body sways from speed and cant deficiency or excess from which the dynamic space required could be calculated and compared to structures along a route.

Since then, increasingly sophisticated computer modelling systems were developed, together with more accurate tools for measuring the actual size of infrastructure. The systems and processes were adopted by the GB Rail Industry as the absolute and comparative process which allowed the understanding of how much trains move and how much safety margin to provide, to make more effective use of the existing Victorian built infrastructure.

It is through the use of these systems and processes and that tilting trains, large containerised freight trains and modern commuter rolling stock can be run in GB – this would not have been possible using traditional processes without vast expenditure in providing additional (and arguably unnecessary) space to accommodate them. Avoiding these large capital expenditures is traded off against a need to tightly control infrastructure position and maintain a high level of asset knowledge.

The absolute and comparative gauging process cover a series of techniques that ensure that sufficient space exists around a moving train (clearance) to provide safe operation. The complex, computer modelling processes used in the absolute dynamic gauging process provide the greatest level of 'fit' between trains and structures (and passing other trains).

Comparative gauging provides for the certification of compatibility by a process of demonstrating that new rolling stock can be operated in 'the shadow' of rolling stock which already has certification on the routes that new rolling stock will be operated on. In absolute gauging, the actual space required to run a vehicle along a route is compared with the actual size of structures and the position of adjacent tracks along that route.

In practice, both can only be done through computer simulation, where the dynamic swept envelopes of candidate and comparator vehicles are compared over the range of speeds and cant deficiencies / excesses that would be experienced on the route, where the route data is kept up to date by the Infrastructure Manager.

7 Technical background

7.1 Defined gauges

7.1.1 Rolling stock

7.1.1.1 How to calculate the maximum construction gauge using the kinematic method

Before beginning a gauge calculation, it is necessary to agree a reference profile and associated rules (see EN 15273-4:2025) as well as product-related data:

- the vehicle data: type of configuration, conventional or non- conventional (see 7.1.1.3), the pivot centre distance “ a ”, the length of the carbody, variation of lateral clearance between the carbody and bogies “ w ”, depending on the curve radius;
- characteristics of bogies (motor or trailing bogie) and their suspensions (flexibility coefficient “ s ”, downward displacements “ Aff ”, the semi-width between suspension springs “ b_1 ” or “ b_2 ”) wheelbase axle “ p ”, wheel wear “ U_{sr} ” and “ d ”;
- data on conditions of operation and maintenance.

EN 15273-1:2025, 5.2 gives further explanations and links between the different parts of this standard series.

7.1.1.2 Main steps to perform a gauge calculation

The generic procedure can be summarized as:

- know and assimilate standard(s) to respect any pertinent requirements;
- know and understand the rolling stock configuration;
- determine the relative position of the bump stops between the carbody and the bogies, check the interference-free movement of the bogies with the carbody in very small radius curves;
- determine clearances "w", as a function of the radius of the curve in the cross-section of the bogie pivot;
- determine the lateral reductions;
- determine the vertical reductions depending on the suspension characteristics and connections;
- determine the maximum construction gauge in the relevant cross-section;
- complete this calculation by taking into account the particular components: installation of the pantographs, sensor location, antenna, reducing gaps in access steps, etc.;
- present all results in a calculation file in order to obtain acceptance/approval;
- the calculated values can change according to the updating of the project: in this case, a new calculation is performed.

7.1.1.3 Train configuration

When developing new configurations such as an articulated vehicle with an offset articulation or other solution, it is necessary to apply the philosophy stated in the standard to carry out accurate calculations, equivalent to those used elsewhere in the process.

The aim of the calculations is to search, for a given configuration, the maximum size for vehicles, thereby improving passenger comfort and to increase freight vehicle capacity.

To take into account all criteria and the train architecture, it is necessary to design vehicles that make up the train according to the gauge rules. Caution is necessary to adapt the formulae of this standard according to the chosen configuration as the current edition of this standard only considers the two bogies on conventional vehicles and articulated vehicles (see EN 15273-2:2025, A.1.3) for example for tilting trains and for vehicles installation and track maintenance.

Figure 3 and Figure 4 show different classical configurations.

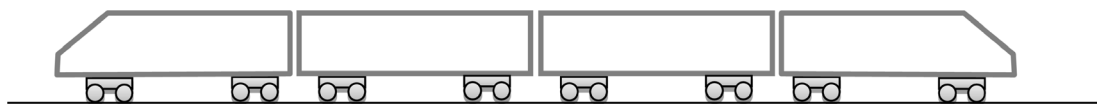


Figure 3 — Example of conventional vehicles with 2 bogies

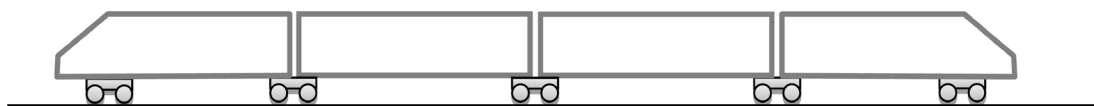
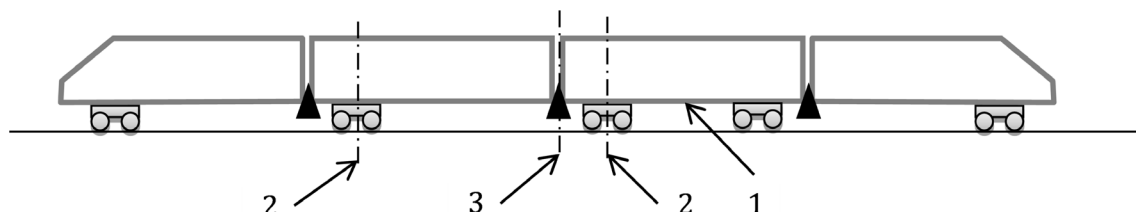


Figure 4 — Example of articulated trainset with standard and Jakobs bogies

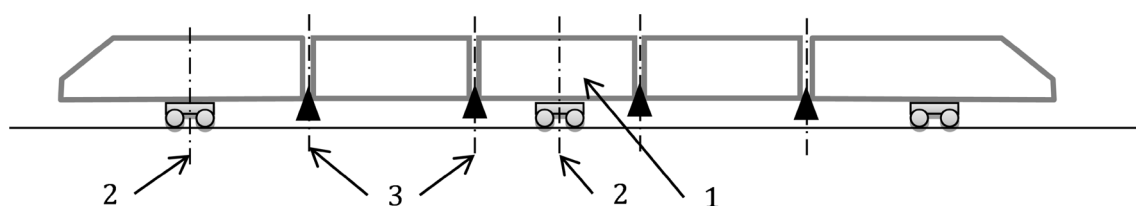
Figure 5 and Figure 6 show different hybrid configurations for which it is preferred to adapt the formulae.



Key

- 1 key vehicle
- 2 bogie pivot
- 3 articulation between car bodies

Figure 5 — Example of configuration with offset articulation



Key

- 1 key vehicle
- 2 bogie pivot
- 3 articulation between car bodies

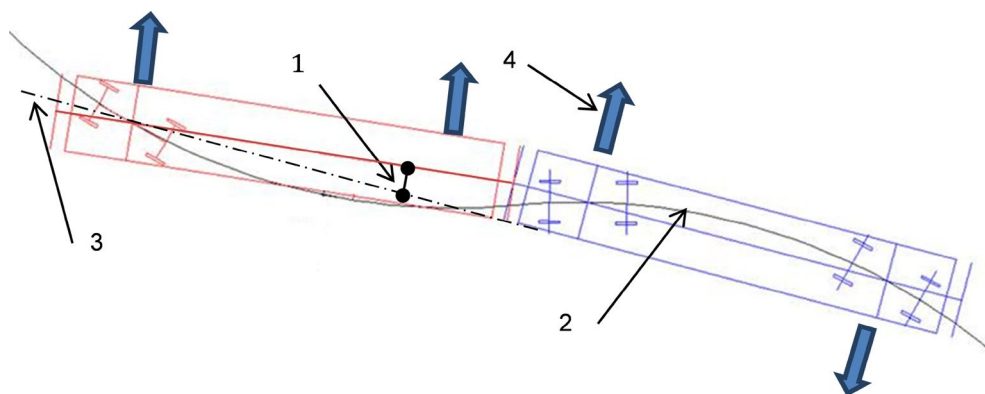
Figure 6 — Example of configuration with suspended carbody

An example of development of formulae is proposed in 8.2.12 of this document for the same conditions as conventional vehicles: straight line and constant radius.

It is necessary to check these configurations for other conditions such as reverse curves, switches and crossings in order to be sure that these vehicles do not infringe the infrastructure gauge. Two specific cases are checked:

- reverse curve of 190 m radius without an intermediate straight section;
- reverse curve of 150 m radius with an intermediate straight section of 6 m.

Figure 7 shows the difference in the geometric overthrow with respect a conventional vehicle when considering train configuration corresponding to Figure 5 in a reverse curve without intermediate straight track.

**Key**

- 1 additional geometric overthrow
- 2 reverse curve without an intermediate straight section corresponding to the case n°1
- 3 conventional vehicle centreline
- 4 direction of the additional lateral displacements of the carbody

Figure 7 — Example of configuration with offset articulation in a reverse curve

7.1.1.4 Running gear

7.1.1.4.1 General

The bogies and suspension systems support loads and distribute them generally on two axles, filter track defects and improve the comfort in vehicles, including sometimes with active or passive tilting devices.

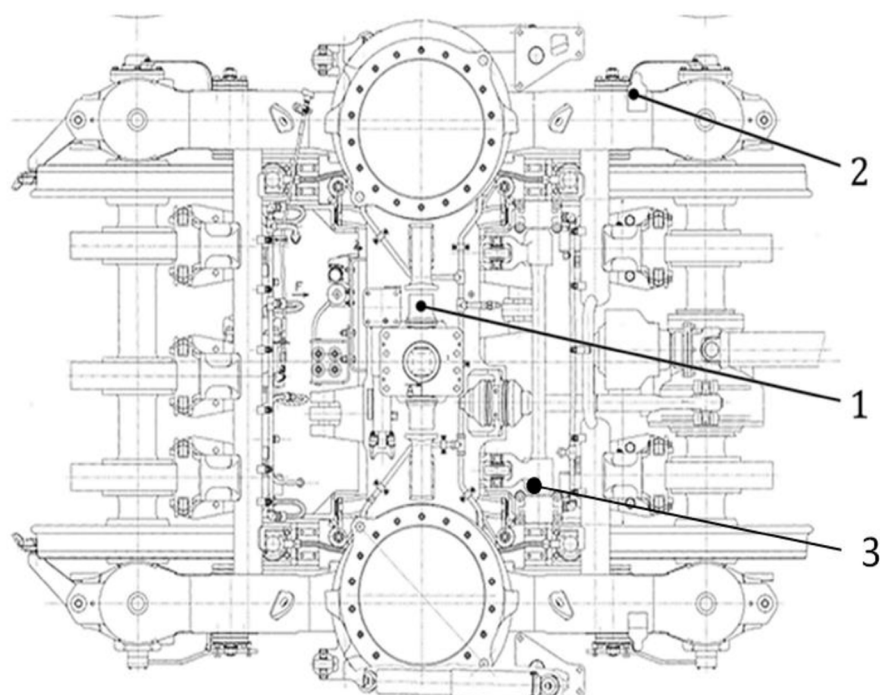
The gauging calculation of the bogie is similar to that of a vehicle on two axles but is only applicable in the lower parts of the reference profile (see EN 15273-4:2025).

Components linking the carbody and the bogie respect the gauge. Their worst positions are analysed case by case taking into account displacements of bogie and carbody (for example dampers, cables, deflated pneumatic suspension, etc.).

7.1.1.4.2 Type of bogies

Two types of bogies, motor bogies and trailer bogies, have the main function of supporting the suspended masses, to ensure the guidance on the track, and for our purpose to maintain the carbody within the limits set by the rules of the gauging process.

For that, some bump stops limit the lateral displacements between carbody and bogies (see Figure 8 and Figure 9 to Figure 14). The suspension systems limit the carbody rolling (via the flexibility coefficient) and the vertical displacements by filtering the track defects.

**Key**

- 1 bump stop by the bogie pivot
- 2 curve dependent bump stops
- 3 roll bar

Figure 8 — Example of position of the lateral bumps stops and the roll bar on a trailer bogie

(See EN 15273-2:2025, Figure D.1.)

7.1.1.4.3 Flexibility coefficient and height of roll centre

See a calculation example in UIC leaflet 505-5:2010, 10.4.

7.1.1.4.4 Behaviour of the bogie on the track

The behaviour of the bogie is dependent on the adhesion between the wheel and the rail.

For the purposes of this standard, the bogies are classified according to their adhesion factor μ on starting.

If $\mu \geq 0,19$ the bogie is designated “motor”.

If $\mu < 0,19$ the bogie is considered “trailer”.

Historical note:

Previously the formula for calculating the value of this coefficient was expressed for a stationary vehicle in a curve with a cant (D) 0,100 m and calculated as follows:

$$\mu = \sqrt{\left(\frac{F_w}{g \cdot M_e}\right)^2 + \left(\frac{D}{L}\right)^2}$$

Very often this formula has been written with $\left(\frac{D}{L}\right)^2 = 0,0044444 \dots (= \left(\frac{0,1}{1,5}\right)^2)$ and used with this numerical value for all European networks for all distances of L between the top of rails.

To avoid confusion, and mainly for vehicles equipped with bogies having the possibility to change their distance between wheels, this standard uses a simplified formula leading to the same result:

$$\mu = \frac{F_w}{g \cdot M_e} \text{ with a limit value} = 0,19$$

$$\sqrt{(0,19^2 + 0,0044444 \dots)} = 0,20 \text{ as in the previous version of the standard.}$$

In the new calculation of this ratio, the effects of cant are negligible, and thus:

$$\mu = \frac{F_w}{g \cdot M_e}$$

The resulting positions of the bogies in the track are given in EN 15273-2:2025, (see coefficient *A* in EN 15273-2:2025).

7.1.1.4.5 Specific bogies calculation and particular elements

The gauge calculation involves specific calculations and checking in accordance with technologies used for example:

- dampers; anti-yaw dampers;
- with or without anti-roll bars;
- sanding systems;
- the lubrication systems;
- grounding of braids (current return);
- tilting bogie;
- electrical and pneumatic flexible connections between carbody and bogie.

7.1.1.5 Lateral clearance between carbody and bogies

7.1.1.5.1 General

The lateral clearance *w* is limited by lateral bump stops which are located between carbody and the bogies.

Depending on the bump stop design, "*w*" sometimes has a fixed value or a value variable with curve radius.

For the purposes of this document, these values are transposed at the bogie pivot.

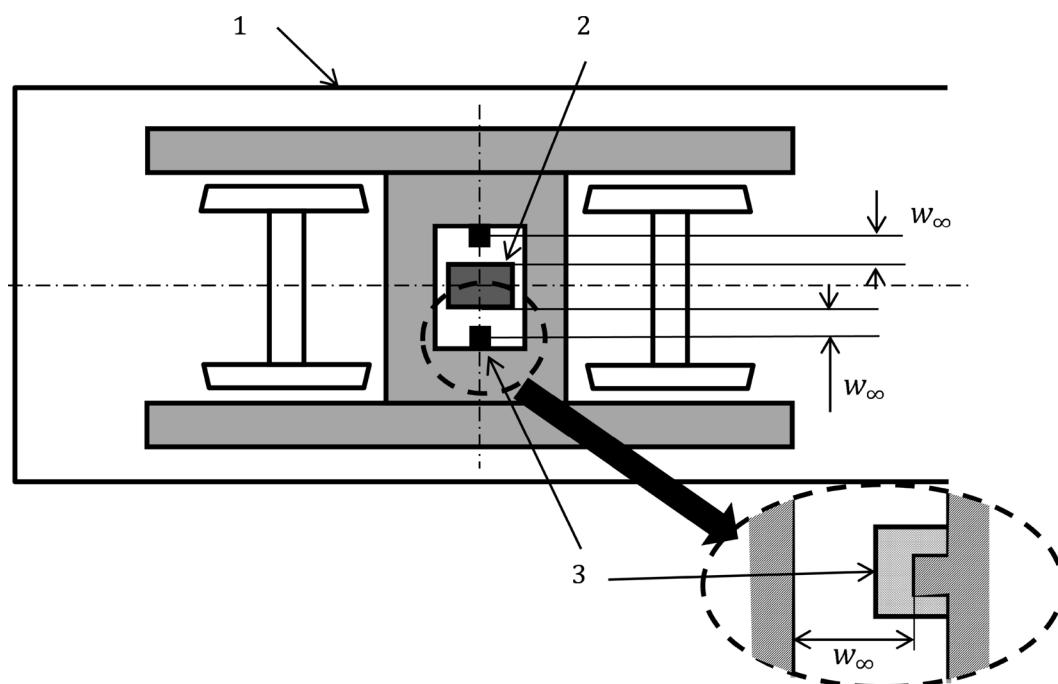
7.1.1.5.2 The bump stops

7.1.1.5.2.1 Bump stop on the bogie pivot

In most cases, bump stops are located in the lateral axis of the bogie pivot. Their design can vary, generally they use an elastic element to maintain passenger comfort in case of contact. In this case, the deformation of the latter is included in *w*.

NOTE The amount of deformation to be taken into account depends on the gauging method (see EN 15273-2:2025).

Figure 9 gives an example of the position of this bump stop.

**Key**

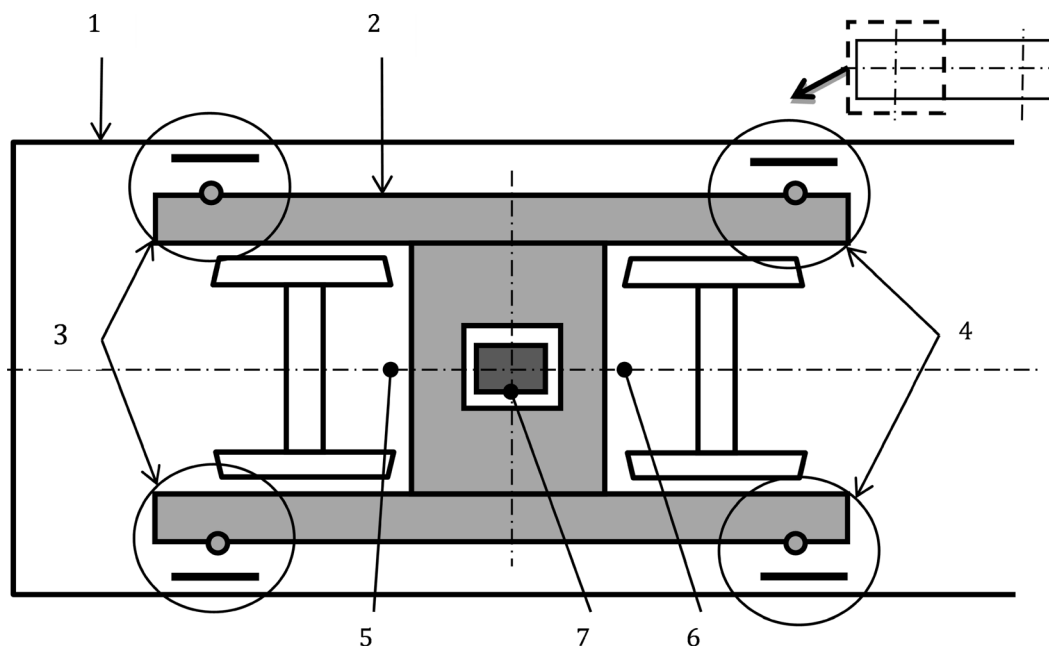
- 1 carbody
- 2 bogie pivot
- 3 lateral bump stop with elastic element

Figure 9 — Bump stops on the bogie pivot

7.1.1.5.2.2 Curve dependent lateral bump stops

Where present, their purpose is to limit the lateral displacement of the carbody relative to the bogies " w " in small radii curves, so as to obtain a wider vehicle.

Figure 10 gives an example of a simple design with which the lateral clearance “w” is dependent of the bogie rotation in function of the radius of the curve:

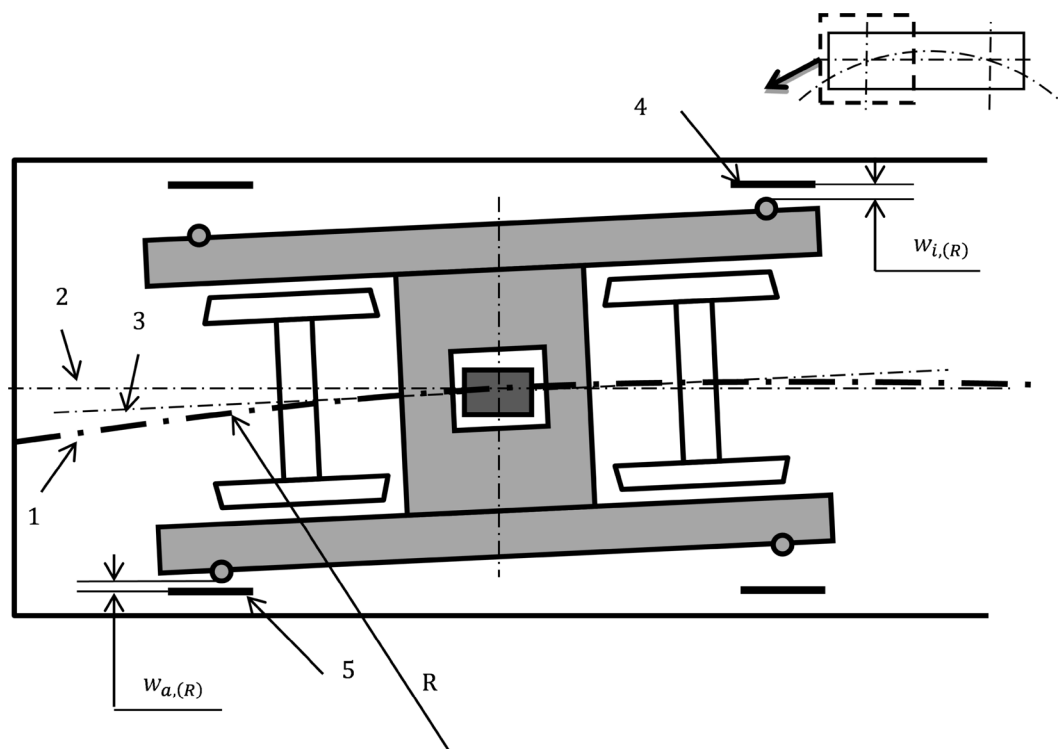


Key

- 1 carbody
- 2 bogie
- 3 bump stops beyond the pivots (clearance $w_{a,(R)}$)
- 4 bump stops between the pivots (clearance $w_{i,(R)}$)
- 5 bogie centreline
- 6 carbody centreline
- 7 bogie pivot

Figure 10 — Example of lateral bump stops

The bump stops located beyond bogie pivots limit the displacement outside the curve (w_a), those between pivots limit the displacement inside the curve (w_i).



Key

- 1 centreline of the track
- 2 centreline of the carbody
- 3 centreline of the bogie
- 4 curve dependent bump stops between bogie pivots
- 5 curve dependent bump stops beyond bogie pivots

Figure 11 — Displacements of the carbody w_i and w_a

Depending on their design, the contact surfaces of these bump stops could be simple (flat bump stops) or more complex.

Figure 12 gives an example of a vehicle with progressive bump stops.

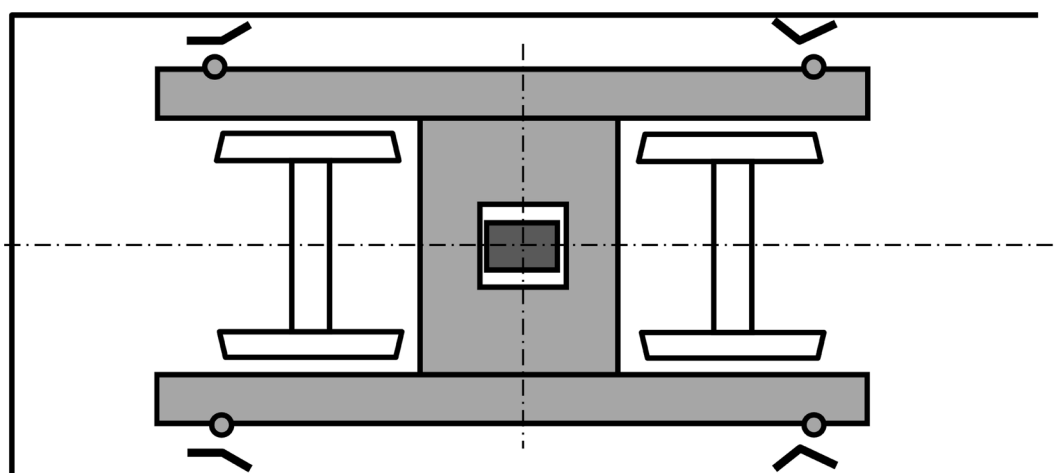
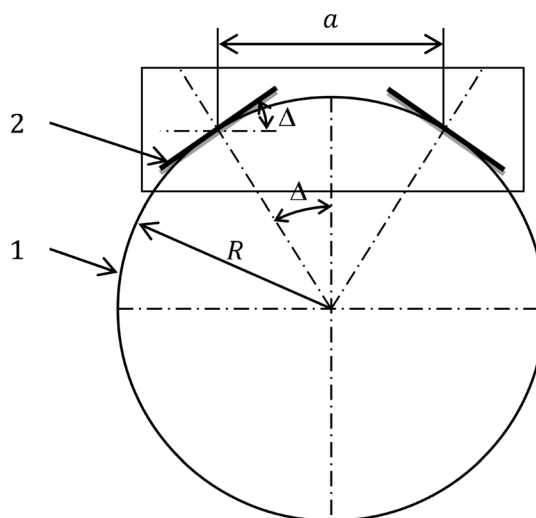


Figure 12 — Example of a vehicle with progressive bump stops

7.1.1.5.3 Calculation principle

As mentioned in EN 15273-2:2025, A.3.3 the value of lateral clearance between the carbody and the bogies is determined for a position of the longitudinal axis of the bogie centred in the track. In order to simplify the process, only the geometrical rotation Δ of the bogie is taken into account, but not the skew of the bogie and the carbody.



Key

- 1 centreline of the track
- 2 centreline of the bogie

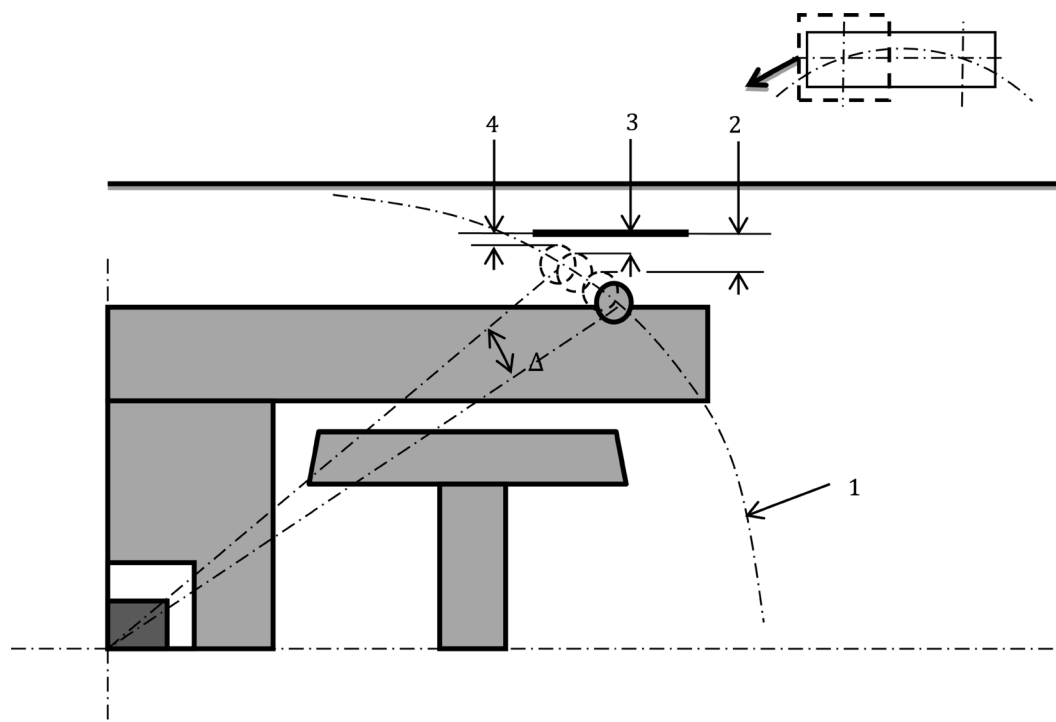
Figure 13 — Rotation angle of the axis of the bogie according to the track radius

The value of the angle Δ can be calculated using the following simplified formula:

$$\sin \Delta = \frac{a}{2R}$$

NOTE In this calculation, the effect due to geometric overthrow of the bogie does not affect the angle Δ value.

Figure 14 illustrates the evolution of the lateral clearance between the stops and bogies frame depending on the variation of the angle Δ :

**Key**

- 1 path of the bogie frame
- 2 lateral clearance w_i in a large curve
- 3 lateral clearance w_i in a medium curve
- 4 lateral clearance w_i in a tight curve

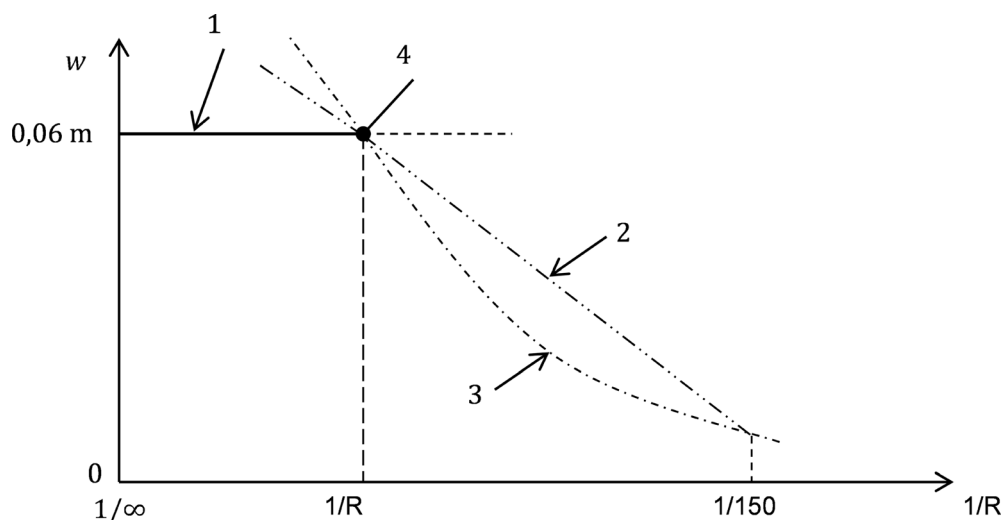
Figure 14 — Lateral clearance w_i in a curved track

When analysing the lateral displacement of the carbody as a function of the curvature of the track ($1/R$), the contribution of each bump stop is determined.

For a given curve radius, only the maximum value of w applies for the determination of static and kinematic gauges.

This approach determines the radii at which a "discontinuity point" appears (point 4 in Figure 15). This discontinuity point shows the change of lateral bump stop behaviour at which the bump stop on the bogie pivot limits the lateral displacement for smaller curve radii.

Figure 15 gives an example of this variation law of w_i or w_a as a function of $1/R$.



Key

- 1 bump stops at bogie pivot
- 2 curve dependent bump stops between bogie and carbody for a linear form
- 3 curve dependent bump stops between bogie and carbody for a progressive form
- 4 discontinuity point (change in the bump stop to be taken into account)

Figure 15 — Lateral clearance "w" according to the curve radius

The discontinuity points give the supplementary critical radii R for the calculation of the gauge.

7.1.1.6 The quasi-static roll defined by the kinematic gauges (justification)

The full quasi-static roll is $Q = s \cdot \frac{D}{L} \cdot |h - h_c|$ for inside the curve or $Q = s \cdot \frac{I}{L} \cdot |h - h_c|$ for outside the curve.

The Railway Undertaking takes into account a value z_{cin} inside the reference profile and the Infrastructure Manager takes into account qs outside the reference profile. $Q = z_{cin} + qs$.

For $D \leq D_0$ and $I \leq I_0$, no quasi-static roll is taken into account by infrastructure.

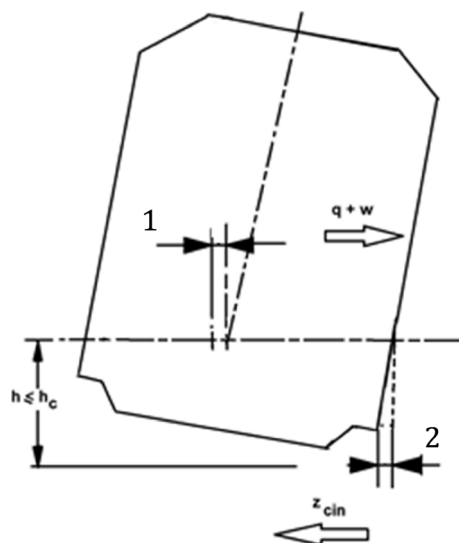
For $D > D_0$ or $I > I_0$, the value qs taken into account by the infrastructure depends on the height $h > h_{c0}$ for the value s_0 . No quasi-static roll is taken into account by infrastructure for $h \leq h_{c0}$.

The value z_{cin} depends on s and h_c of the vehicle under consideration, the height h and the fixed values of D_0 or I_0 .

For $h \geq h_{c0}$ the entire quasi-static roll is taken into account by the Railway Undertaking with D_0 or I_0 and D_{max} or I_{max} .

For the lower parts of a non-tilting vehicle, the roll effect z_{cin} in direction opposite to the clearances $q + w$ is not taken into account by the rolling stock for $h \leq h_c$, because $q + w$ is considered to be bigger.

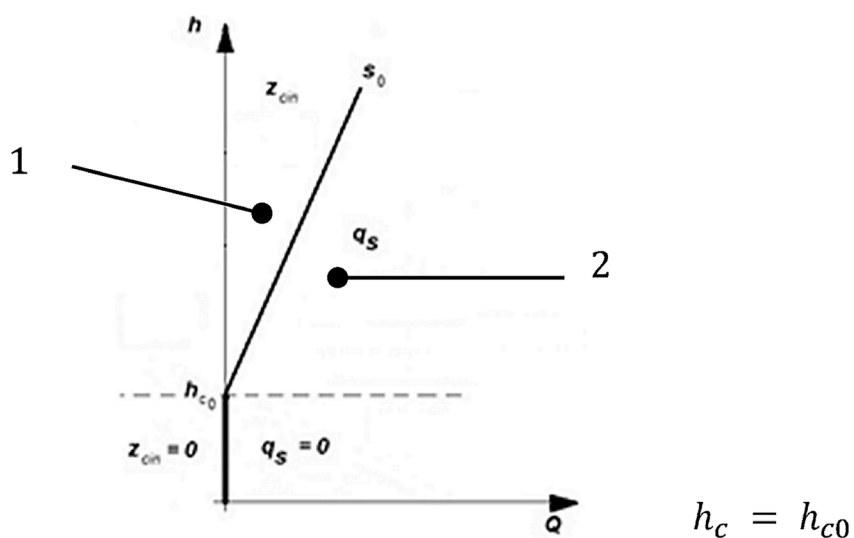
NOTE Nevertheless in lower parts, for vehicle with $s > s_0$, it is verified and the possibility to have z_{cin} higher than $q + w$ is taken into account. See A.3.2.4 in EN 15273-2:2025.

**Key**

- 1 clearance $q + w$
- 2 value z_{cin} in the opposite direction

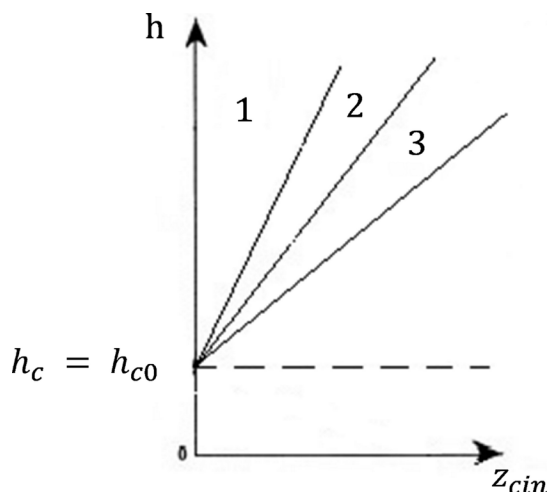
Figure 16 — Taking into account the roll effect in the lower parts of non-tilting rolling stock

The division of the roll effect between the infrastructure and non-tilting rolling stock for different conditions is illustrated in Figure 17, Figure 18 and Figure 19.

**Key**

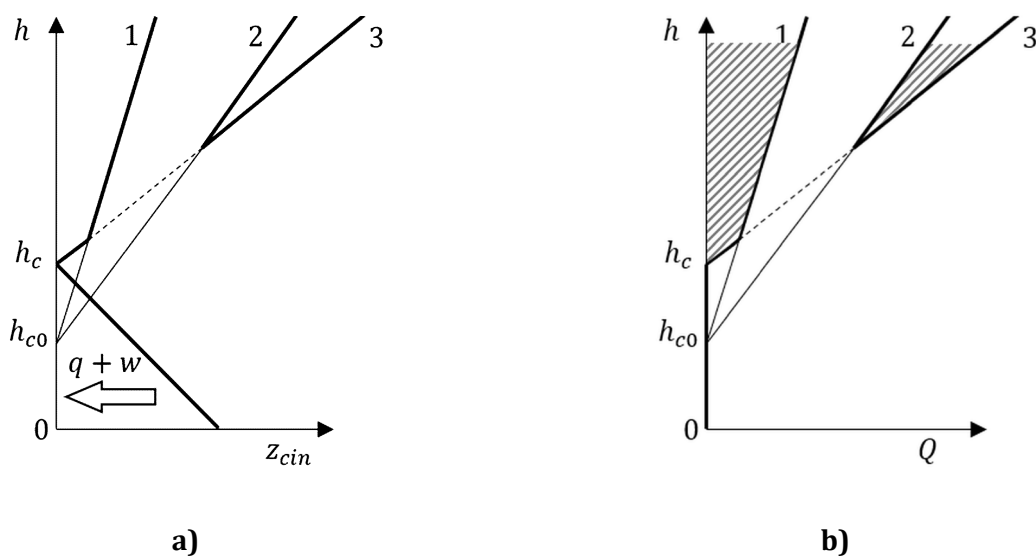
- 1 value z_{cin} taken into account by the rolling stock
- 2 value q_s taken into account by the Infrastructure Manager

Figure 17 — Agreement in the division of the roll effect between infrastructure and non-tilting rolling stock

**Key**

- 1 z_{cin} calculated with the value s of the candidate vehicle and D_0 or I_0 , taken into account by the rolling stock
- 2 qs calculated with the value s_0 and $(D - D_0)_{>0}$ or $(I - I_0)_{>0}$, taken into account by the infrastructure
- 3 supplementary z_{cin} calculated with the value $(s - s_0)_{>0}$ and $D_{max} - D_0$ or $I_{max} - I_0$, taken into account by the rolling stock

Figure 18 — Agreement between infrastructure and non-tilting rolling stock when $s > s_0$ and $h_c = h_{c0}$

**Key**

- 1 z_{cin} calculated with the value s of the candidate vehicle and D_0 or I_0 (hatched area taken into account by the rolling stock)
- 2 qs calculated with the value s_0 and $(D - D_0)_{>0}$ or $(I - I_0)_{>0}$ (taken into account by the infrastructure)
- 3 supplementary z_{cin} calculated with the value $(s - s_0)_{>0}$ and $D_{max} - D_0$ or $I_{max} - I_0$ (hatched area taken into account by the rolling stock)

Figure 19 — Agreement between infrastructure and non-tilting rolling stock when $h_c > h_{c0}$ and $s > s_0$

General case if $q + w > z_{cin}$ in the opposite direction for Figure 19:

The z_{cin} roll effect in the lower parts acts in the opposite direction to the upper parts.

Rolling stock usually only takes into account $(z_{cin} - (q + w)) > 0$.

In the most classic case of non-tilting trains, the value is < 0 and can be neglected.

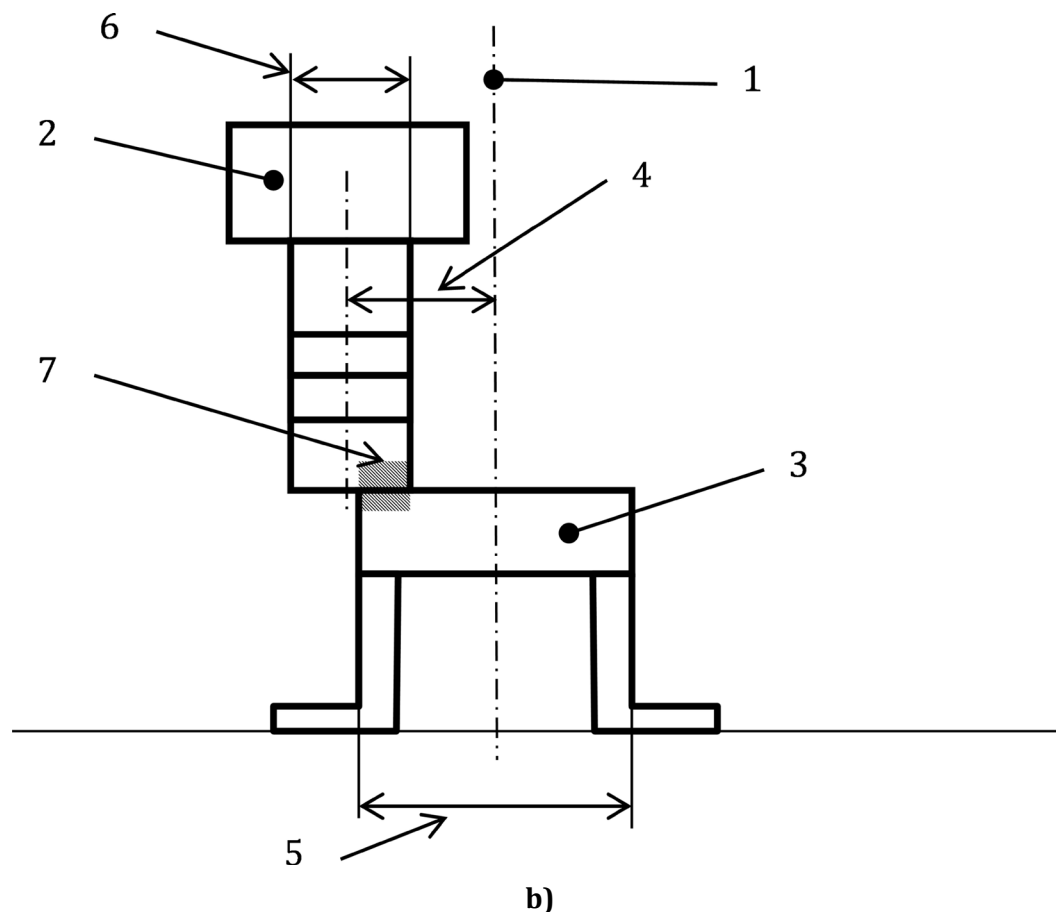
This gives the illustration in Figure 19 where the hatched area is taken into account by the rolling stock and the non-hatched area is taken into account by the infrastructure.

7.1.1.7 Contact ramps

In EN 15273-2:2025, A.3.4.2 «Contact ramps» a lateral distance of 0,065 m has been introduced in Formula (A.25) and Formula (A.26). This distance is chosen to give an acceptable limit to give a good electrical contact between the brush and the contact ramp.



a)

**Key**

- 1 track centreline
- 2 brush
- 3 contact ramp "crocodile"
- 4 maximum value of displacement (65 mm)
- 5 contact ramp width (100 mm)
- 6 brush width (90 mm)
- 7 minimum contact width (30 mm)

Figure 20 — Contact between ramp and brush

This value of 65 mm is obtained as follows:

$$\left(\frac{\text{Contact ramp width (5)} + \text{Brush width (6)}}{2} \right) - \text{Minimum contact width (7)} \leq 65 \text{ mm (4)}$$

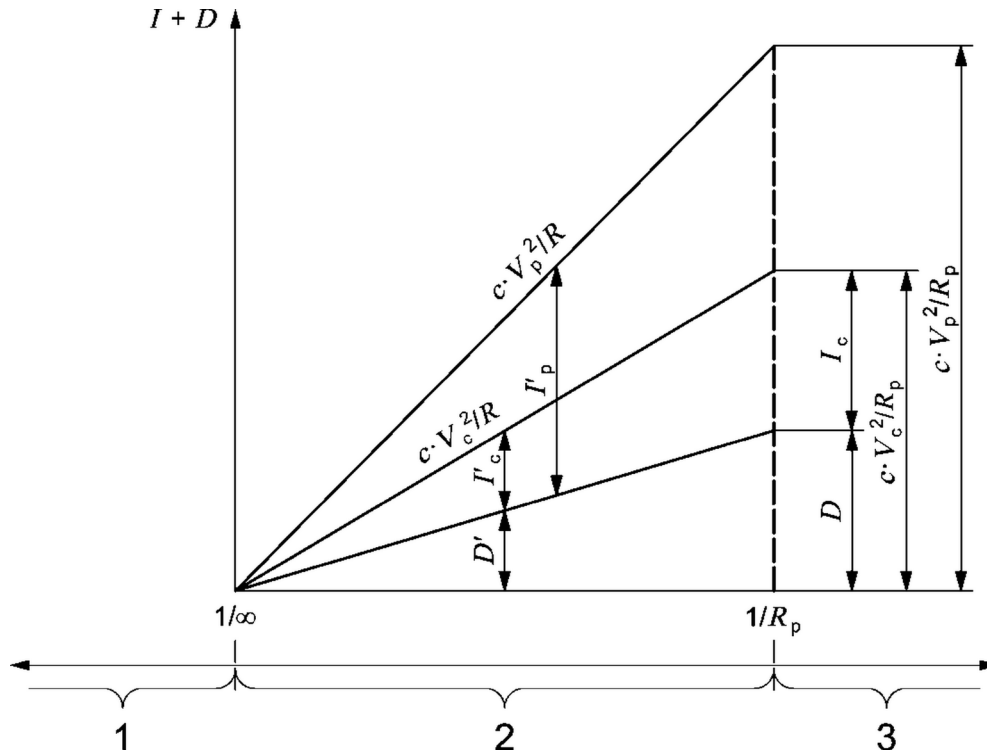
7.1.1.8 Tilting trains

7.1.1.8.1 Cant and cant deficiency

Gauge compliance is checked individually for each line.

The operation of tilting trains is dependent on a series of infrastructure parameters, a risk analysis of the behaviour of the vehicle in degraded mode and an examination of the behaviour during operation on transition curves.

The basic principle of tilting vehicles and vehicles subjected to $I_p > I_c$ is shown in Figure 21.



Key

- 1 straight track
- 2 transition zone
- 3 radius considered constant

Figure 21 — Cant and cant deficiency

The cant deficiency I_p corresponds to the maximum allowable value for tilting body trains.

The values D' , I'_c and I'_p are intermediate values generally attained in large radii.

Radius R_p is the radius for which the maximum values of D' , I'_c and I'_p are obtained, in the knowledge that they remain constant if the radius continues to decrease.

The Infrastructures Manager to be covered impose the value D , I_p maximum for the track stability and the minimum limit value $\frac{I_c}{I_p}$ to be met by the rolling stock in the curve so that:

$$\frac{I'_c}{I_p} \geq \left(\frac{I_c}{I_p} \right)_{\min} \quad (1)$$

With for example $\left(\frac{I_c}{I_p} \right)_{\min} = 0,6$ whereas this value = 1 for non-tilting vehicles.

This is justified by the fact that:

— for a non-tilting train:

$$V'_c = \sqrt{\left(I'_c + D' \right) \frac{R}{c}} \quad (2)$$

where

$$c = \frac{L^2}{3,6^2 g} \text{ and } I + D = \frac{cV^2}{R} \quad (3)$$

— for a tilting train:

$$V_p' = \sqrt{(I_p' + D') \frac{R}{c}} \quad (4)$$

hence

$$\frac{V_p'}{V_c'} = \sqrt{\frac{I_p' + D'}{I_c' + D'}} \quad (5)$$

and

$$V_p' = V_c' \cdot \sqrt{\frac{I_p' + D'}{I_c' + D'}} \quad (6)$$

It is generally considered that:

$$\frac{I_p'}{I_p} = \frac{I_c'}{I_c} \approx \frac{D'}{D} \quad (7)$$

The first part of the formula translates the rolling stock behaviour with constant $\frac{I_p}{I_c}$.

The second part of the formula holds true in wide radius curves and for parabolic connections.

In large radii and special connections, the proportionality is no longer ensured.

It is stated that:

$$V_p' = V_c' \cdot \sqrt{\frac{I_p \frac{D'}{D} + D'}{I_c \frac{D'}{D} + D'}} \quad (8)$$

From which is deduced that:

$$V_p' = V_c' \cdot \sqrt{\frac{I_p + D}{I_c + D}} \quad (9)$$

and that $\sqrt{\frac{I_p + D}{I_c + D}}$ is a fixed value for each network.

EXAMPLE If $D = 0,160$ m $I_c = 0,153$ m $I_p = 0,275$ m.

$$\sqrt{\frac{I_p + D}{I_c + D}} = 1,18 \text{ therefore, } V_p' = 1,18 \cdot V_c' \quad (10)$$

and

$$\left(\frac{I_c}{I_p}\right)_{min} = 0,556$$

7.1.1.8.2 Asymmetry for passive tilting vehicles

Due to the relative position between centre of gravity and roll centre of passive tilting vehicles their rotation will be performed toward the opposite side to conventional vehicles.

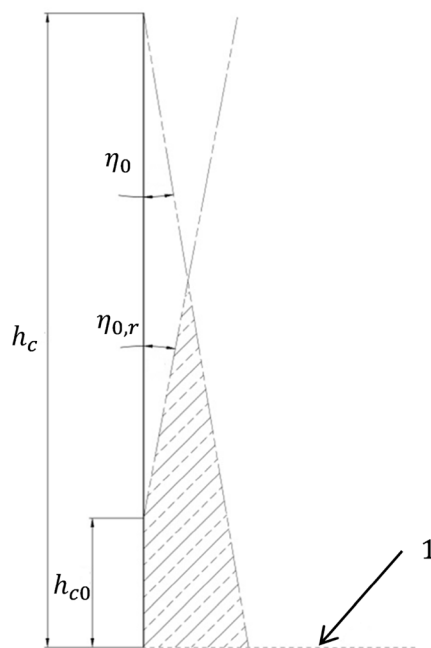
Infrastructure takes into account an asymmetry equal to $\eta_{0,r}$ considering a lateral displacement:

$$\tan \eta_{0,r} \times (h - h_{c0})_{>0}$$

Passive tilting vehicles asymmetry produces the following lateral displacement:

$$\tan \eta_0 \times |h_c - h|$$

Figure 22 represents the lateral displacement due to the asymmetry taken into account by infrastructure and a passive tilting vehicle:



Key

1 running plane

Figure 22 — Asymmetry for passive tilting vehicles

The hatched area corresponds to the lateral displacements to be considered from rolling stock side by means of the following formula:

$$[|h_c - h| \times \tan \eta_0 - \tan \eta_{0,r} \times (h - h_{c0})_{>0}]_{>0}$$

The above-mentioned formula will replace to that one used by conventional rolling stock:

$$\{\tan[\eta_0 - \eta_{0,r}]_{>0}\} \times |h_c - h|$$

7.1.1.9 Pantograph

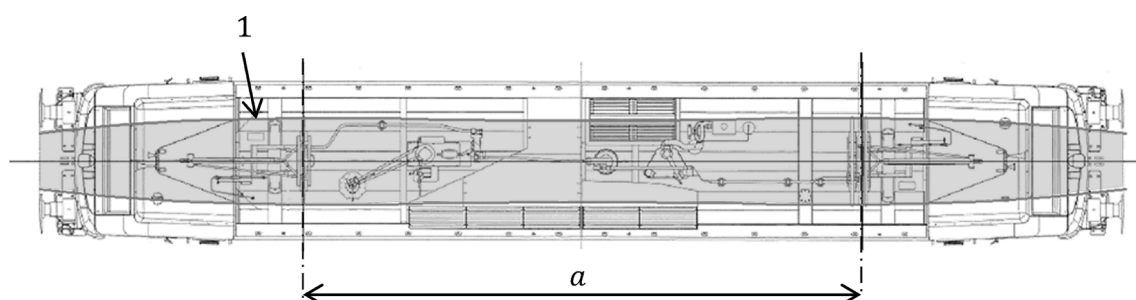
7.1.1.9.1 General

For the Railway Undertaking, the pantograph gauge is used to:

- check that the pantographs collecting position remains within the space cleared by the infrastructure;
- check the live parts on train roofs.

When this pantograph gauge is used for the implementation of live parts, it has the same progressive form that the maximum construction gauge for the carbody, except for dimension curve radius values of 150 m and lateral projection.

Figure 23 shows an example of the maximum construction gauge for the live parts:



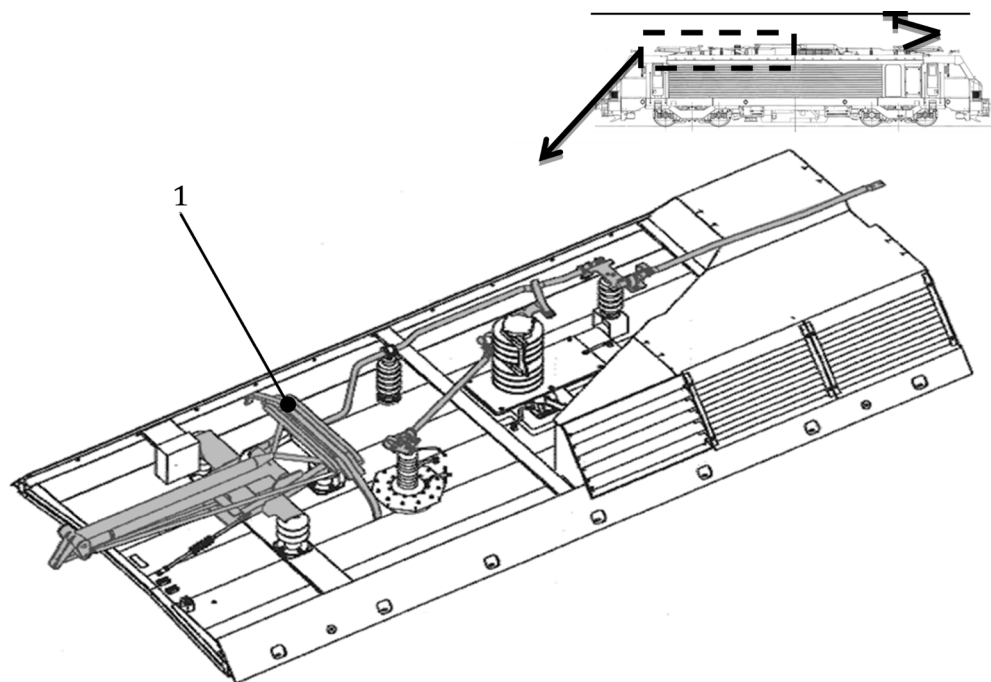
Key

- 1 maximum construction gauge for live parts

Figure 23 — Representation of the maximum construction gauge for live parts

7.1.1.9.2 Interconnected pantographs

When a pantograph is in the collecting position, it can feed different devices, including a second pantograph, by means of roof lines:

**Key**

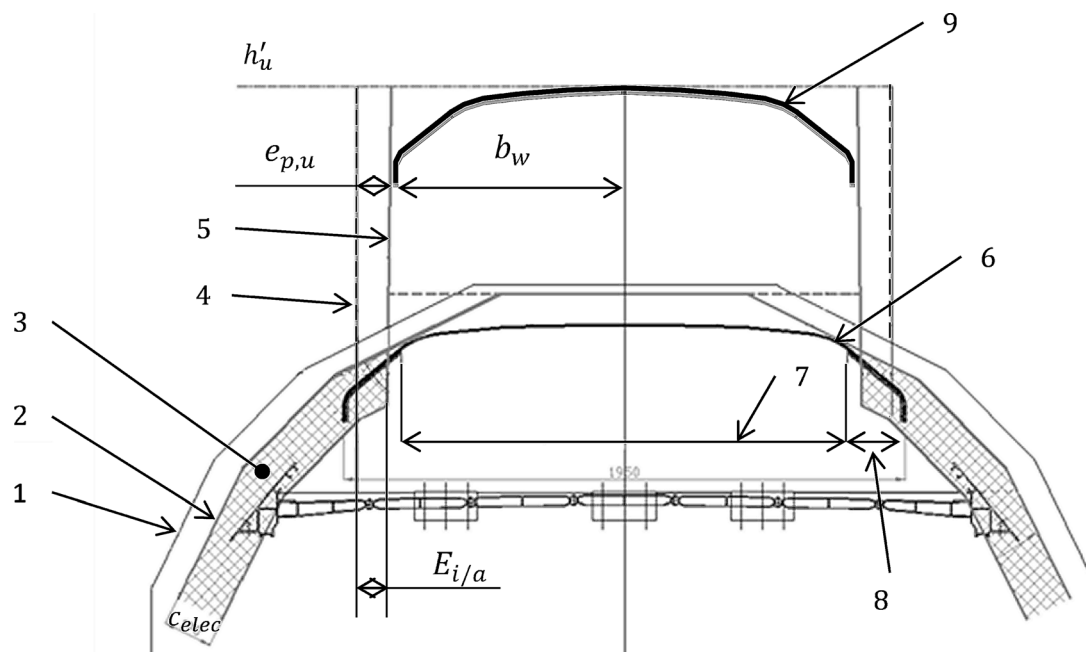
1 live part

Figure 24 — Example of live parts on the vehicle roof

All the live parts, including the pantograph in the stowed position, are checked with necessary insulation distance from the maximum construction gauge according to the voltage of the power supply system and using the width of the pantograph in the collecting position.

Figure 25 shows the maximum construction gauge obtained by applying the rules in EN 15273-2:2025, A.3.3 and A.4.2 in the section of the pantograph (width 1,950 m) in the stowed position which takes into account a pantograph in the collecting position fitted with non-insulating horns (see EN 15273-1:2025, B.4). In this case the maximum construction gauge for the pantograph area is given by:

$$b'_u = b_w + e_{p,u} - E_{i/a}$$



Key

- 1 reference profile of gauge G1
- 2 maximum construction gauge
- 3 electrical insulating clearance for rolling stock (c_{elec})
- 4 pantograph reference profile
- 5 maximum construction gauge for live part b'_u
- 6 1 950 mm pantograph with insulating horns in stowed position
- 7 live parts of the stowed pantograph (1 950 mm)
- 8 insulating horns of width c_w
- 9 1 600 mm pantograph in collecting position without insulating horns

Figure 25 — Verification of a stowed pantograph into the maximum construction gauge of a pantograph without insulated horns

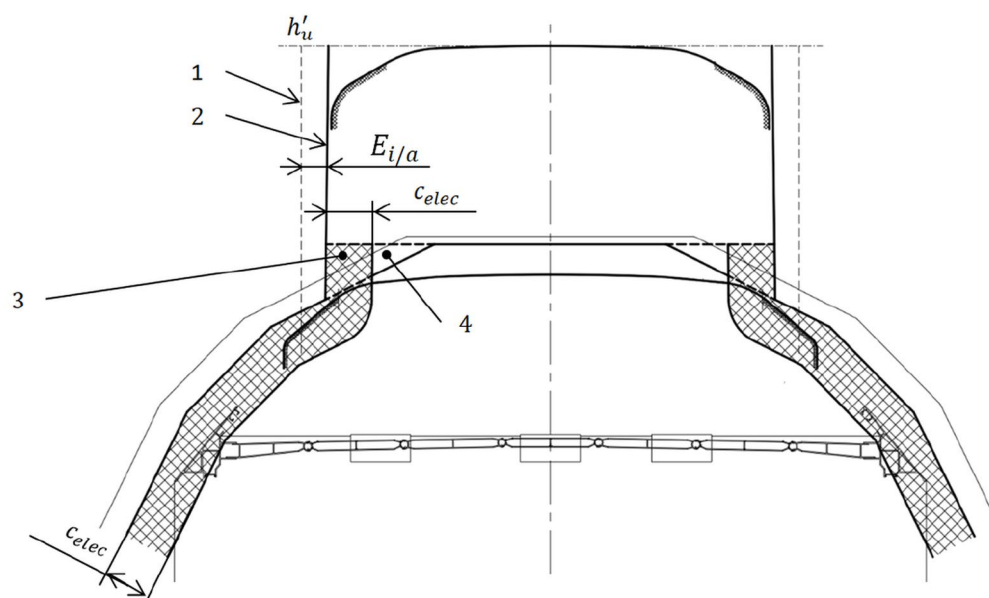
Attention: when using graphical methods, the cant or cant deficiency value used to define the z_{cin} is 0,066 m for the pantograph and 0,05 m for the carbody.

Figure 26 shows the maximum construction gauge obtained when the pantograph gauge take into account a pantograph fitted with insulating horns.

In this case the maximum construction gauge for the pantograph area is given by:

$$b'_u = b_w + e_{p,u} - E_{i/a} - c_{elec}$$

For c_{elec} see EN 15273-2:2025, Table A.7.



Key

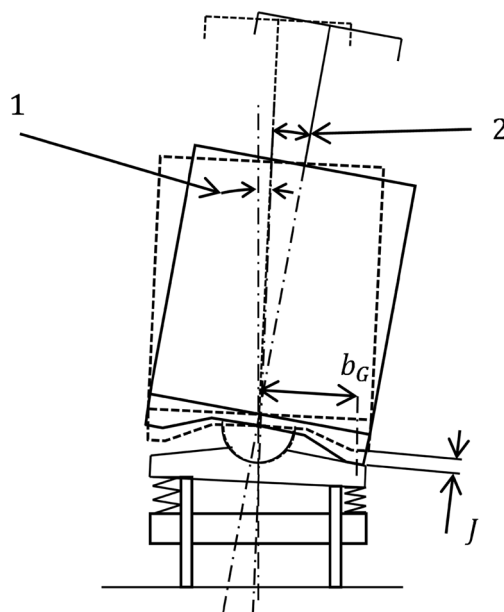
- 1 pantograph reference profile
- 2 pantograph mechanical gauge
- 3 insulation distance C_{elec} to be taken into account for the maximum construction gauge and the pantograph mechanical gauge for live parts
- 4 this area is used by rolling stock only on electrified tracks (see EN 15273-2:2025, A.4.2.3)

Figure 26 — Verification of a stowed pantograph into the maximum construction gauge of a pantograph with insulated horns

7.1.1.9.3 Pantograph fixing on vehicle with side bearers

To perform maintenance, for example of the overhead contact line, it is sometimes necessary to mount the pantographs on a vehicle with side bearers. In this case, to check the compatibility of the pantograph, it is necessary to use adapted formulae because the influence of the side bearer clearances is not considered in the quasi-static displacement z_{cin} given in EN 15273-2:2025.

Figure 27 shows the additional rotation to be considered in this case.



Key

- 1 rotation angle of the primary suspension adjustment tolerances ($\theta_{primary}$)
- 2 rotation angle due to the clearance at the side bearer

Figure 27 — Pantograph fixing on vehicle with side bearers

The value of θ is adapted as follows and used in EN 15273-2:2025 in the formulae in A.4.1.2 and A.4.1.3 for $P'_{o,i}$, $P'_{o,a}$, $P'_{u,i}$ and $P'_{u,a}$:

$$\theta = \theta_{primary} + \frac{J}{b_G}$$

7.1.1.10 Explanation for electrical clearance

The electrical insulation distances used in this series of standards for rolling stock are derived historically from UIC leaflet 505-1, UIC leaflet 606-1, 1st edition 1987 (see Table 1) and UIC leaflet 606-2, 4th edition 1986 (see Table 2). The values used in this standard series correspond to dynamic values without pollution.

Table 1 — Electrical distances for the various voltages (provided by UIC Leaflet 606-1)

	1,5 kV DC	3 kV DC	15 kV AC	25 kV AC	50 kV AC
b_1	0,010	0,010	0,020	0,030	0,050
b_2	0,010	0,010	0,030	0,040	0,060
b_3	0,010	0,010	0,020	0,050	0,070
b_4	0,020	0,020	0,030	0,030	0,080
b_5	0,050	0,050	0,100	0,100	0,180
Normal distances dynamically without pollution ^a					
	0,100	0,100	0,150	0,170	0,350
^a Catenary set in motion (passage of pantograph, wind ...) and vehicle in movement					

Table 2 — Electrical distances for the various voltages provided by UIC Leaflet 606-2

Zone	Dynamic situation ^a		Static situation ^b	
	Normal	Minimum	Normal	Minimum
Non-Polluted	$b_1+b_2=70$ $b_4=30$ $b_6=70$	$b_1+b_2=70$	$b_1+b_2=70$ $b_4=30$ $b_5=100$ $b_6=70$	$b_1+b_2=70$ $b_4=30$ $b_5=100$
	$b=170$ mm	$b=70$ mm	$b=270$ mm	$b=200$ mm
Polluted	$b_1+b_2=70$ $b_3=50$ $b_4=30$ $b_6=70$	$b_1+b_2=70$ $b_3=50$	$b_1+b_2=70$ $b_3=50$ $b_4=30$ $b_5=100$ $b_6=70$	$b_1+b_2=70$ $b_3=50$ $b_4=30$ $b_6=100$
	$b=220$ mm	$b=120$ mm	$b=320$ mm	$b=250$ mm
^a Overhead line set in motion (passage of pantograph, wind ...) with moving vehicle.				
^b Overhead line stationary, vehicle at standstill.				

The calculation of the normal dynamic distance of 170 mm takes into account the following elements:

- the sum ($b_1 + b_2 = 70$ mm) represents the variations in atmospheric pressure, temperature and humidity;
- $b_4 = 30$ mm represents the uneven distribution of the electric field;
- $b_6 = 70$ mm represents a safety margin.

By comparison, standard EN 50119:2020 gives the following values:

Table 3 — Typical insulation distances

Nominal voltage	Typical insulation distances mm	
	Static (EC_s)	Dynamic (EC_d)
DC 600 V (720 V) ^a	100	50
DC 750 V (900 V)	100	50
DC 1.5 kV (1.8 kV)	100	50
DC 3.0 kV (3.6 kV)	150	50
AC 15 kV (17.25 kV)	150	100
AC 25 kV (25.7 kV)	270	150
^a For existing systems only. Values in brackets correspond to maximum continuous voltage according to EN 50163.		

Different insulation distances for the 'static' and 'dynamic' cases are justified by probabilistic considerations taking time into account. For example, it is unlikely that a power surge could occur at exactly the same time as a pantograph passes through the narrow part of a tunnel. For this 'dynamic' or temporary case, the dynamic insulation distance is justified.

In each case, the values used in our standard are more conservative than those given in the European standard EN 50119:2020.

7.1.1.11 Explanation about value 0,035 m for open doors

Before the publication of EN 15273 in 2009, there were no specific international rules on the gauge commitments allowed for open doors and extended movable steps located between bogie pivots. The only existing international rules were contained in UIC Leaflet 560 and only concerned doors located beyond the bogie pivots. However, to cover this gap, national rules existed, notably at French level. The French standard NF F 31-051 authorised, under certain conditions, gauge commitments for mobile steps located between bogie pivots.

It is on the basis of these elements that the experts of CEN/TC 256/WG 32 have established rules of engagement for open doors and deployed movable steps located between bogie pivots. These rules are contained in EN 15273-2:2025, A.6.

Thus, for open doors and movable steps, the rule limits the maximum gauge engagement of these devices solely on the basis of the consumption of the clearance between the carbody and the bogies towards the inside of the curve – w_i without exceeding 35 mm.

The limitation of this commitment to the value of the bogie and carbody clearance is partly explained by the fact that the lateral displacement of the equipment body linked to this clearance when the vehicle is at a standstill or travelling at low speed is generally negligible and remains less than the existing margin between the kinematic defined gauge of the equipment and the limiting gauge of the platform. Therefore, this value of clearance w_i has been taken as a reference to limit the maximum penetration value in the construction gauge.

In the majority of cases, the engagement at open doors and deployed steps is achieved in a small radius curve. This value of 35 mm was determined from:

- the existing margin between the reference contour plus the projection and the minimum theoretical transverse position of the platforms. This constant margin is 30 mm and is based on platforms with a height greater than or equal to 400 mm, installed in accordance with UIC Leaflet 741 and therefore installed transversely at a distance of 1,650 mm from the track centreline;
- the difference between the geometrical inscriptions of the equipment in a 250 m curve taken into account to determine its maximum construction gauge and a 300 m curve corresponding to the minimum radius in which these platforms can be installed - this difference is estimated to be 5 mm.

7.1.1.12 Formulae demonstration explanation

7.1.1.12.1 Overthrow

For radii $R \leq 150$ m the following non approximated formulae is applied.

7.1.1.12.2 Overthrow in a curve - between bogies

Figure 28 shows:

- the centreline of the track, radius R ;
- the bogie axles (wheelbase p) are centred in the track;
- values between brackets are the square (power 2) of the represented length.

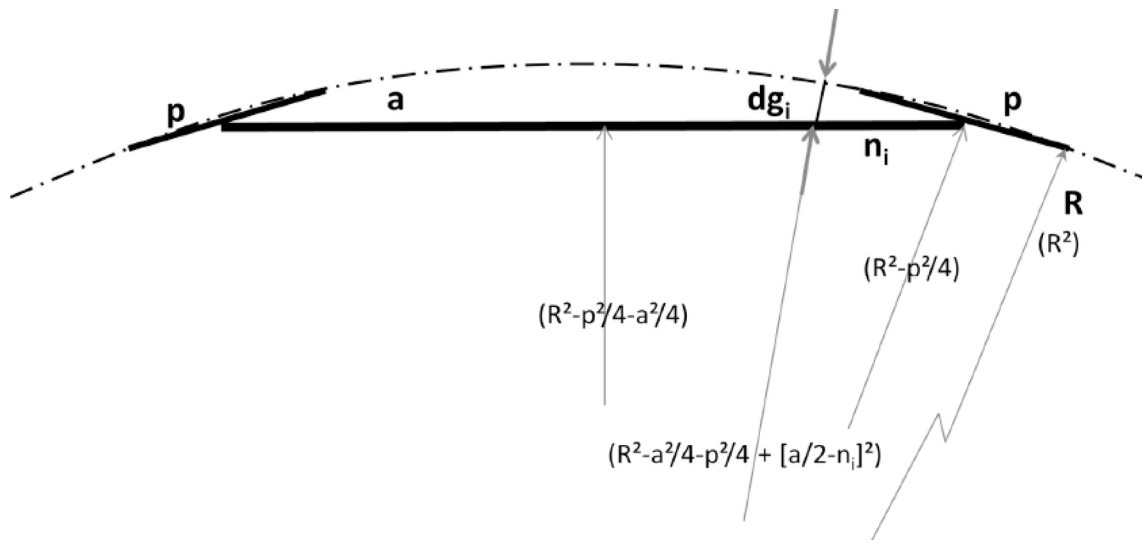


Figure 28 — dg_i Overthrow between bogies

Exact value of $dg_i = R - \sqrt{R^2 - \frac{a^2}{4} - \frac{p^2}{4} + \left[\frac{a}{2} - n_i\right]^2}$

$$dg_i = R - R \sqrt{1 + \frac{n_i^2 - an_i - \frac{p^2}{4}}{R^2}}$$

As in the square root the second term is very low compared to 1:

$$\sqrt{1+x} = 1 + \frac{x}{2} - \frac{x^2}{8} + \frac{x^3}{16} - \frac{5x^4}{128} + \dots$$

$$dg_i \approx R - R \left(1 + \frac{n_i^2 - an_i - \frac{p^2}{4}}{2R^2} \right) = \frac{an_i - n_i^2 + \frac{p^2}{4}}{2R}$$

EXAMPLE Calculated values are given for dg_i in Table 4 for $R = 150$ m and 50 m, $p = 2,5$ m, $a = 15$ m, $n_i = 3$ m and $7,5$ m.

Table 4 — dg_i calculated values

	$R = 150$ m		$R = 50$ m	
	$n_i = 3$ m	$n_i = 7,5$ m	$n_i = 3$ m	$n_i = 7,5$ m
Exact value	0,125 3 m	0,192 8 m	0,377 1 m	0,581 5 m
Approximation	0,125 2 m	0,192 7 m	0,375 6 m	0,578 1 m
Difference	0,000 1 m	0,000 1 m	0,001 5 m	0,003 4 m

7.1.1.12.3 Overthrow in a curve – out of the bogies

Figure 29 shows the centreline of the track, with a radius R .

The bogies (wheelbase p) are centred in the track.

Values between brackets are the square (power 2) of the represented length.

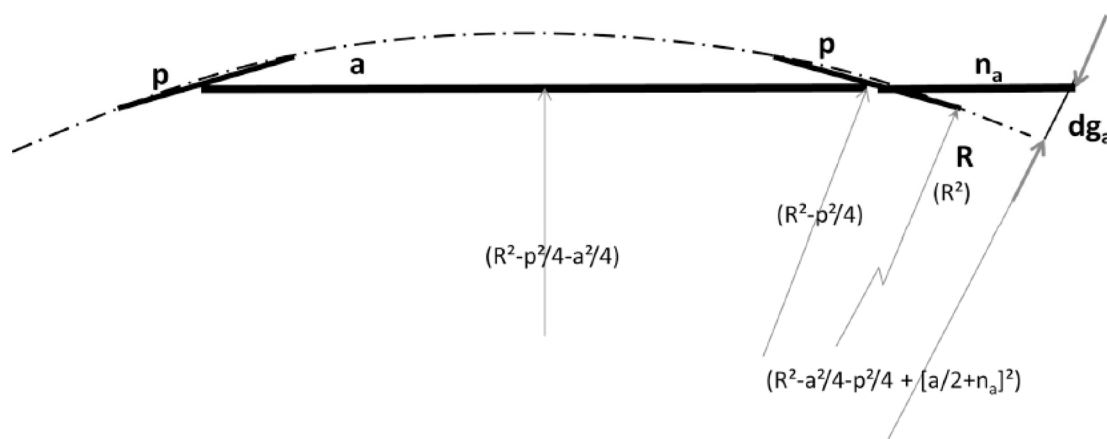


Figure 29 — dg_a Overthrow of the bogies

$$\text{Exact value of } dg_a = \sqrt{R^2 - \frac{a^2}{4} - \frac{p^2}{4} + \left[\frac{a}{2} + n_a\right]^2} - R$$

$$dg_a = -R + R \sqrt{1 + \frac{n_a^2 + an_a - \frac{p^2}{4}}{R^2}}$$

As in the square root the second term is very low compared to 1.

$$dg_a \approx -R + R \left(1 + \frac{n_a^2 + an_a - \frac{p^2}{4}}{2R^2} \right) = \frac{an_a + n_a^2 - \frac{p^2}{4}}{2R}$$

EXAMPLE Calculated values for dg_a in Table 5 for a vehicle with the following parameters: $a = 15$ m, $n_a = 3$ m, $p = 2,5$ m on curved track with the following radii $R = 150$ m and 50 m.

Table 5 — dg_a calculated values

	$R=150$ m	$R=50$ m
Exact value	0,174 7 m	0,521 6 m
Approximation	0,174 8 m	0,524 4 m
Difference	-0,000 1 m	-0,002 8 m

7.1.1.12.4 Overthrow in a transition between straight and curved track

7.1.1.12.4.1 General equation with a circle

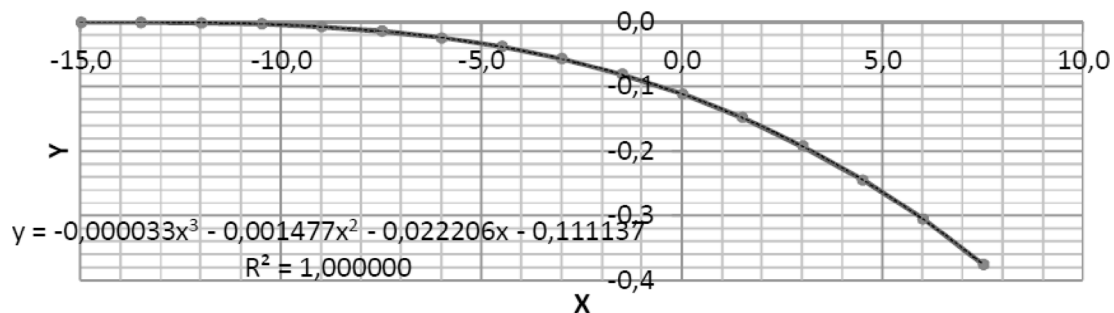


Figure 30 — Circle: general equation

Ω is the centre of the circle, radius R .

Whatever A, B and C: $AB \times AC = (d \times \cos\phi + b)(d \times \cos\phi - b)$

$$AB \cdot AC = (d \times \cos\phi)^2 - b^2 = (d^2 - c^2) - b^2 = d^2 - (R^2 - b^2) - b^2 = d^2 - R^2$$

The same demonstration when A is inside the circle gives: $AB \times AC = R^2 - d^2$.

where

d is the distance between A and Ω .

These results are independent from the position of A, B and C and from the angle ϕ .

7.1.1.12.4.2 Overthrow in such a connection

In Figure 31:

- X and Y are the reference axes used for the demonstration;
- O is the connection point between the straight part and the curved part of the track;
- Ω is the centre of the curved track, radius R ;
- M is the centre (pivot) of a bogie at a distance z of point O, in the straight part;

- N is the centre of the other bogie of the vehicle, in the curved part;
- d is the distance from M to Ω ;
- Q is the virtual intersection between the vehicle axis and the curved track;
- φ is the angle between the straight track axis and the vehicle axis.

Other parameters: see list of symbols.

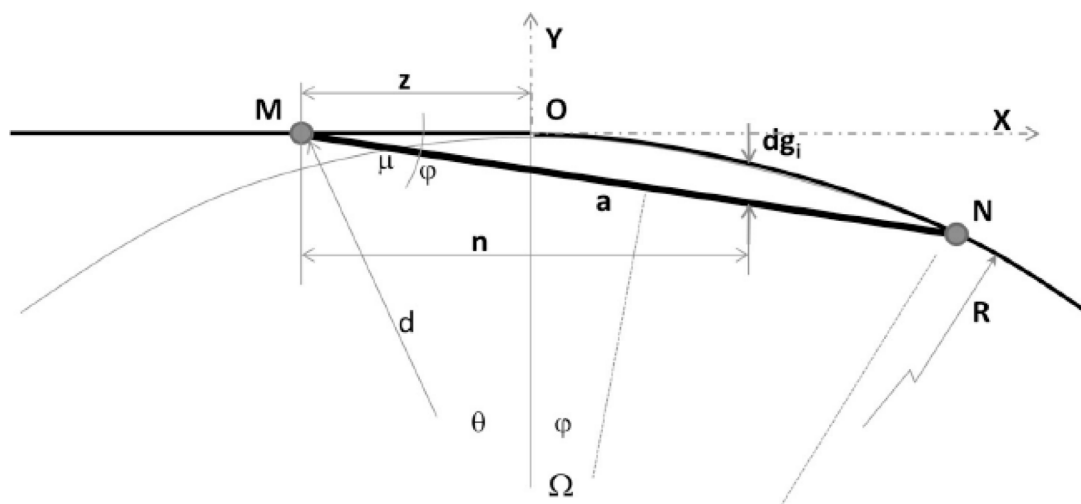


Figure 31 — Overthrow in a transition between straight and curved track

Writing $MQ = u$, we have $MQ \times MN = u \times a = d^2 - R^2$ (as from 7.1.1.12.4.1) $= z^2$.

$$— u = \frac{z^2}{a};$$

$$— d^2 = R^2 + z^2.$$

As we have

$$\frac{\left[\frac{(a-u)}{2} + u\right]}{d} = \sin(\theta + \varphi) = \frac{(a+u)}{2d} = \frac{(a^2+z^2)}{2ad} \text{ and as } \frac{z}{d} = \sin(\theta)$$

Angle φ is defined by

$$\varphi = \arcsin\left[\frac{(a^2 + z^2)}{2ad}\right] - \arcsin\left[\frac{z}{d}\right]$$

Consequently, for

$$n < z \quad dg_i = n \times \tan(\varphi)$$

And for

$$n = z \text{ or } > z \quad dg_i = n \times \tan(\varphi) - \left(R - \sqrt{R^2 - (n - z)^2}\right)$$

NOTE 1 For $z > a$ the vehicle is the straight part of the track ($dg = 0$).

NOTE 2 For $z \leq 0$, M is in the curve, see 7.1.1.12.2 above.

As

$$\arcsin(x) = x + \frac{x^3}{6} + \frac{3x^5}{40} + \frac{5x^7}{112} + \frac{35x^9}{1152} + \dots$$

When both $\arcsin$ in the φ formula are very low such as it can be considered that:

$$\arcsin(x) = x \text{ then } \varphi \approx \frac{(a^2+z^2)}{2ad} - \frac{z}{d} = \frac{(a-z)^2}{2ad}$$

and with

$$\frac{1}{d} = \frac{1}{R\sqrt{1+\frac{z^2}{R^2}}} \approx \frac{1}{R\left(1+\frac{z^2}{2R^2}\right)} \approx \frac{\left(1-\frac{z^2}{2R^2}\right)}{R}$$

It can be written

$$\varphi \approx \frac{(a-z)^2(2R^2-z^2)}{4aR^3}.$$

Table 6 gives an example with exact value of φ , approx. value, and resulting error.

For $R = 150$ m and $a = 15$ m:

Table 6 — Example of angle between vehicle axle and straight part of the track

z m	d m	φ rd	approximate rd	absolute error rd	relative error
15	150,748 1	0,000 0	0,000 0	0,000 000	0,00 %
14	150,651 9	0,000 2	0,000 2	0,000 001	0,44 %
13	150,562 3	0,000 9	0,000 9	0,000 003	0,38 %
12	150,479 2	0,002 0	0,002 0	0,000 007	0,33 %
11	150,402 8	0,003 6	0,003 5	0,000 010	0,28 %
10	150,333 0	0,005 6	0,005 5	0,000 013	0,24 %
9	150,269 8	0,008 0	0,008 0	0,000 016	0,21 %
8	150,213 2	0,010 9	0,010 9	0,000 019	0,17 %
7	150,163 2	0,014 2	0,014 2	0,000 021	0,15 %
6	150,120 0	0,018 0	0,018 0	0,000 022	0,12 %
5	150,083 3	0,022 2	0,022 2	0,000 022	0,10 %
4	150,053 3	0,026 9	0,026 9	0,000 022	0,08 %
3	150,030 0	0,032 0	0,032 0	0,000 022	0,07 %
2	150,013 3	0,037 6	0,037 6	0,000 022	0,06 %
1	150,003 3	0,043 6	0,043 6	0,000 021	0,05 %
0	150,000 0	0,050 0	0,050 0	0,000 021	0,04 %

Figure 32, with the same parameters ($R = 150$ m and $a = 15$ m), gives the calculated values of dg_i (m) versus z and:

The first column for each “ n ” contains the exact value of φ , the second column contains the “approx. value” of φ from Table 4.

$z \backslash n$	14	14	12	12	10	10	8	8	6	6	4	4	2	2	1	1
15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
14	0,0031	0,0031	0,0027	0,0027	0,0022	0,0022	0,0018	0,0018	0,0013	0,0013	0,0009	0,0009	0,0004	0,0004	0,0002	0,0002
13	0,0091	0,0091	0,0107	0,0106	0,0089	0,0089	0,0071	0,0071	0,0053	0,0053	0,0036	0,0035	0,0018	0,0018	0,0009	0,0009
12	0,0147	0,0146	0,0240	0,0239	0,0200	0,0199	0,0160	0,0159	0,0120	0,0120	0,0080	0,0080	0,0040	0,0040	0,0020	0,0020
11	0,0198	0,0196	0,0393	0,0392	0,0356	0,0355	0,0284	0,0284	0,0213	0,0213	0,0142	0,0142	0,0071	0,0071	0,0036	0,0035
10	0,0245	0,0243	0,0533	0,0532	0,0556	0,0554	0,0445	0,0443	0,0333	0,0333	0,0222	0,0222	0,0111	0,0111	0,0056	0,0055
9	0,0287	0,0284	0,0660	0,0658	0,0767	0,0765	0,0640	0,0639	0,0480	0,0479	0,0320	0,0319	0,0160	0,0160	0,0080	0,0080
8	0,0324	0,0322	0,0774	0,0771	0,0956	0,0954	0,0871	0,0870	0,0654	0,0652	0,0436	0,0435	0,0218	0,0217	0,0109	0,0109
7	0,0358	0,0355	0,0874	0,0871	0,1123	0,1121	0,1105	0,1103	0,0854	0,0852	0,0569	0,0568	0,0285	0,0284	0,0142	0,0142
6	0,0386	0,0383	0,0961	0,0958	0,1268	0,1265	0,1307	0,1306	0,1081	0,1079	0,0720	0,0720	0,0360	0,0360	0,0180	0,0180
5	0,0411	0,0407	0,1034	0,1031	0,1390	0,1388	0,1479	0,1477	0,1301	0,1299	0,0889	0,0889	0,0445	0,0444	0,0222	0,0222
4	0,0430	0,0427	0,1094	0,1091	0,1490	0,1488	0,1619	0,1617	0,1481	0,1480	0,1076	0,1075	0,0538	0,0538	0,0269	0,0269
3	0,0445	0,0442	0,1141	0,1138	0,1568	0,1566	0,1729	0,1727	0,1622	0,1620	0,1248	0,1247	0,0641	0,0640	0,0320	0,0320
2	0,0455	0,0452	0,1174	0,1171	0,1624	0,1622	0,1807	0,1805	0,1722	0,1721	0,1370	0,1369	0,0752	0,0751	0,0376	0,0376
1	0,0461	0,0458	0,1194	0,1191	0,1658	0,1656	0,1854	0,1852	0,1783	0,1781	0,1444	0,1443	0,0839	0,0838	0,0436	0,0436
0	0,0461	0,0458	0,1200	0,1197	0,1669	0,1667	0,1870	0,1868	0,1803	0,1802	0,1469	0,1468	0,0868	0,0867	0,0467	0,0467

Figure 32 — Example of dg_i values (m) versus z and n , with exact and approx. angle φ

In this particular example, the maximum difference between exact value and approximation is 0,315 mm (for this example $z = 4$ m and $n = 14$ m).

It can be noted that after this first approximation level, it is possible to go further and write

$$\begin{aligned} \text{— for } n < z \quad dg_i &\approx n \times \varphi = \frac{n(a-z)^2(2R^2-z^2)}{4aR^3}, \\ \text{— for } n \geq z \quad dg_i &\approx n \times \varphi - \frac{(n-z)^2}{2R} = \frac{(an-z^2)(a-n)}{2aR} - \frac{nz^2(a-z)^2}{4aR^3}. \end{aligned}$$

7.1.1.12.4.3 Space envelope swept by the vehicle

Figure 31: bogie M of the vehicle can move from $z = a$ (limit of bogies in the straight track), to $z = 0$ (limit of bogies in the curved track).

If it is interesting to calculate dg_i at a distance n of the bogie M for a given position z of the vehicle, it is more convenient for Infrastructure Manager to define the space envelope swept by the vehicle.

7.1.1.12.4.4 Graphical method

The computer implementation of this method is possible, and is recommended in the most difficult cases, but needs an anamorphosis made by amplifying the dimensions in the lateral direction.

The segment MN is drawn in different positions from $z = a$ to 0, and a curve, tangent to all the segments, is approximated by a parabola, the equation of which can be determined in the $[X; Y]$ plane and used by the Infrastructure Manager. (The best is an equation in Y of the third degree in X .)

7.1.1.12.4.5 A mathematical method

It is possible to use a mathematical method. The demonstration below is proposed for the $[X; Y]$ plane.

Determine equation of the straight line MN, using an independent parameter (z):

$$Y = \lambda \times X + \psi$$

With λ and ψ being functions of the parameter z .

Write the derivative of each part with regard to z :

$$0 = \frac{\delta(\lambda \times X)}{\delta z} + \frac{\delta\psi}{\delta z}$$

Solve the system of the two formulae above to get X and Y (as functions of z).

The result $X = f(z)$ and $Y = g(z)$ is the envelope of the straight line MN, function of z .

The following is an example corresponding to Figure 29.

For $0 < z < a$ and in axis $[X; Y]$ Bogie M = $[-z; 0]$

(MN): $Y = -X \tan \varphi + K$ with K such as $Y = 0$ for $X = -z$

$$Y = -X \times \tan \varphi + K = -(X + z) \times \tan \left[\arcsin \left(\frac{(a^2 + z^2)}{2ad} \right) - \arcsin \left(\frac{z}{d} \right) \right]$$

where

$$d = \sqrt{(R^2 + z^2)}$$

The derivative of both parts (with respect to z):

$$0 = -1 \times \tan[\varphi] - (X + z) \frac{\delta \tan[\dots]}{\delta z}$$

To simplify writing:

$$0 = -1 \times \tan[\varphi] - (X + z) \tan'[\varphi]$$

which give

$$X = - \left(\frac{\tan[\varphi]}{\tan'[\varphi]} + z \right)$$

And replacing X in the (MN) equation gives

$$Y = \frac{\tan^2[\varphi]}{\tan'[\varphi]}$$

where

$$\tan'[\varphi] = (1 + \tan^2[\varphi]) \times [\varphi]'$$

and where

$$[\varphi]' = \left[\arcsin \left(\frac{(a^2 + z^2)}{2a\sqrt{(R^2 + z^2)}} \right) - \arcsin \left(\frac{z}{\sqrt{(R^2 + z^2)}} \right) \right]'$$

Knowing that $[\arcsin\{\xi\}]' = \frac{\xi'}{\sqrt{1-\xi^2}}$ we have $[\varphi]' = \frac{[z^3 - za^2 - 2R^2(a-z)]}{2a^3\sqrt{(R^2+z^2)}}$.

Table 7 gives an example of envelope from the same parameters as in Table 6.

$$X = -\left(\frac{\tan[\varphi]}{\tan'[\varphi]} + z\right)$$
$$Y = \frac{\tan^2[\varphi]}{\tan'[\varphi]}$$

$$\tan'[\varphi] = (1 + \tan^2[\varphi]) \cdot [\varphi]'$$
$$[\varphi]' = \frac{[z^3 - za^2 - 2R^2(a - z)]}{2a^3\sqrt{(R^2 + z^2)}}$$

Table 7 — Example of envelope with parameters as in Table 6

z m	φ rd	$\tan \varphi$	$\tan^2 \varphi$	φ'	$\tan \varphi'$	X	Y
15	0	0	0	0	0	-15,000 0	0,000 0
14	0,000 222 2	0,000 222 225	4,938 37E-08	0,000 442 66	0,000 442 66	-13,498 0	-0,000 1
13	0,000 888 9	0,000 888 923	7,901 85E-07	0,000 886 08	0,000 886 08	-11,996 8	-0,000 9
12	0,002 000 2	0,002 000 164	4,000 66E-06	0,001 330 14	0,001 330 15	-10,496 3	-0,003 0
11	0,003 556 0	0,003 556 042	1,264 54E-05	0,001 774 74	0,001 774 76	-8,996 3	-0,007 1
10	0,005 556 6	0,005 556 671	3,087 66E-05	0,002 219 75	0,002 219 82	-7,496 7	-0,013 9
9	0,008 002 0	0,008 002 177	6,403 48E-05	0,002 665 06	0,002 665 23	-5,997 4	-0,024 0
8	0,010 892 3	0,010 892 699	0,000 118 651	0,003 110 55	0,003 110 92	-4,498 1	-0,038 1
7	0,014 227 4	0,014 228 385	0,000 202 447	0,003 556 1	0,003 556 82	-2,998 9	-0,056 9
6	0,018 007 5	0,018 009 405	0,000 324 339	0,004 001 59	0,004 002 89	-1,499 4	-0,081 0
5	0,022 232 3	0,022 235 955	0,000 494 438	0,004 446 91	0,004 449 11	0,000 3	-0,111 1
4	0,026 901 8	0,026 908 274	0,000 724 055	0,004 891 93	0,004 895 47	1,500 5	-0,147 9
3	0,032 015 7	0,032 026 662	0,001 025 707	0,005 336 53	0,005 342 00	3,001 4	-0,192 0
2	0,0375 738	0,037 591 499	0,001 413 121	0,005 780 6	0,005 788 77	4,503 0	-0,244 1
1	0,043 575 7	0,043 603 275	0,001 901 246	0,006 224 02	0,006 235 85	6,005 6	-0,304 9
0	0,050 020 9	0,050 062 617	0,002 506 266	0,006 666 67	0,006 683 38	7,509 4	-0,375 0

$\frac{z}{R}$	14	14	12	12	10	10	8	8	6	6	4	4	2	2	1	1
15	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
14	0,0031	0,0031	0,0027	0,0027	0,0022	0,0022	0,0018	0,0018	0,0013	0,0013	0,0009	0,0009	0,0004	0,0004	0,0002	0,0002
13	0,0091	0,0091	0,0107	0,0106	0,0089	0,0089	0,0071	0,0071	0,0053	0,0053	0,0036	0,0035	0,0018	0,0018	0,0009	0,0009
12	0,0147	0,0146	0,0240	0,0239	0,0200	0,0199	0,0160	0,0159	0,0120	0,0120	0,0080	0,0080	0,0040	0,0040	0,0020	0,0020
11	0,0198	0,0196	0,0393	0,0392	0,0356	0,0355	0,0284	0,0284	0,0213	0,0213	0,0142	0,0142	0,0071	0,0071	0,0036	0,0035
10	0,0245	0,0243	0,0533	0,0532	0,0556	0,0554	0,0445	0,0443	0,0333	0,0333	0,0222	0,0222	0,0111	0,0111	0,0056	0,0055
9	0,0287	0,0284	0,0660	0,0658	0,0767	0,0765	0,0640	0,0639	0,0480	0,0479	0,0320	0,0319	0,0160	0,0160	0,0080	0,0080
8	0,0324	0,0322	0,0774	0,0771	0,0956	0,0954	0,0871	0,0870	0,0654	0,0652	0,0436	0,0435	0,0218	0,0217	0,0109	0,0109
7	0,0358	0,0355	0,0874	0,0871	0,1123	0,1121	0,1105	0,1103	0,0854	0,0852	0,0569	0,0568	0,0285	0,0284	0,0142	0,0142
6	0,0386	0,0383	0,0961	0,0958	0,1268	0,1265	0,1307	0,1306	0,1081	0,1079	0,0720	0,0720	0,0360	0,0360	0,0180	0,0180
5	0,0411	0,0407	0,1034	0,1031	0,1390	0,1388	0,1479	0,1477	0,1301	0,1299	0,0889	0,0889	0,0445	0,0444	0,0222	0,0222
4	0,0430	0,0427	0,1094	0,1091	0,1490	0,1488	0,1619	0,1617	0,1481	0,1480	0,1076	0,1075	0,0538	0,0538	0,0269	0,0269
3	0,0445	0,0442	0,1141	0,1138	0,1568	0,1566	0,1729	0,1727	0,1622	0,1620	0,1248	0,1247	0,0641	0,0640	0,0320	0,0320
2	0,0455	0,0452	0,1174	0,1171	0,1624	0,1622	0,1807	0,1805	0,1722	0,1721	0,1370	0,1369	0,0752	0,0751	0,0376	0,0376
1	0,0461	0,0458	0,1194	0,1191	0,1658	0,1656	0,1854	0,1852	0,1783	0,1781	0,1444	0,1443	0,0839	0,0838	0,0436	0,0436
0	0,0461	0,0458	0,1200	0,1197	0,1669	0,1667	0,1870	0,1868	0,1803	0,1802	0,1469	0,1468	0,0868	0,0867	0,0467	0,0467

Figure 33 — Example of envelope with parameters as in Table 6

On the same graph, the track is now added (straight part and curved part), the vehicle at the limit $z = 0$ (bogie M at $X = 0$) and at position $z = 5$ (bogie M at $X = -5$).

The calculated envelope is tangential to the vehicle in its various positions.

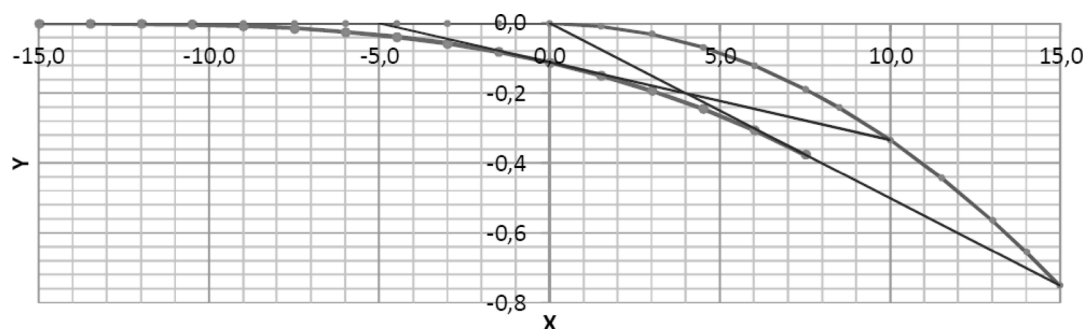


Figure 34 — Example of the calculated envelope

NOTE 1 This demonstration is done starting from the exact value of φ function of z . Approximation could be used, but only at the final step of the demonstration. To start with approximate value of φ , and develop the method, leads to absurd results.

NOTE 2 Knowing the angle φ between X axis and the vehicle axis, and after writing the equation of the straight line MN, there is no difficulty to calculate the trajectory of a point located outside of the bogies.

NOTE 3 Refer to 7.1.1.12.4.4.

7.1.1.12.5 Overthrow in a compound curve

7.1.1.12.5.1 General

Overthrows calculated above are functions of the vehicle parameters a , p and length beyond the bogie pivot.

These calculations are applicable for “classic” train configurations, as conventional vehicles equipped with two bogies (dg_i and dg_a), such as articulated vehicles equipped with intermediate Jakobs bogies (dg_i).

Nevertheless, for a “semi-articulated” configuration (see Figure 5 and Figure 6), in which the articulations are not in the same plane as the bogie pivot, need an adapted formula, such as given in the example of 7.1.1.12.5.3.

7.1.1.12.5.2 Conventional and articulated cars

Figure 35 shows conventional vehicle and articulated vehicle in a reverse curve.

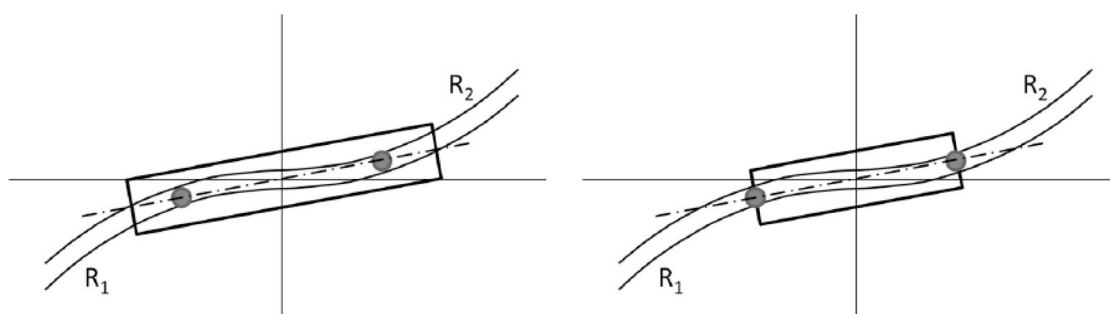


Figure 35 — Conventional and articulated vehicles in a reverse curve

The only problem for these configurations in Figure 36 is to define the angle between the axis of the vehicle and the X axis of the track when one bogie is in the “ R_1 ” curve and the other bogie in the “ R_2 ” curve. Once a bogie is located in a curve and this angle is defined, dg_i and dg_a can be easily calculated from analytical formulae.

The other cases can be calculated from the subclauses above.

Figure 36 to define this angle (φ) between the reference axis and the vehicle we can locate the bogie (M) in the curve (R_1) at a distance z from the junction between R_1 and R_2 :

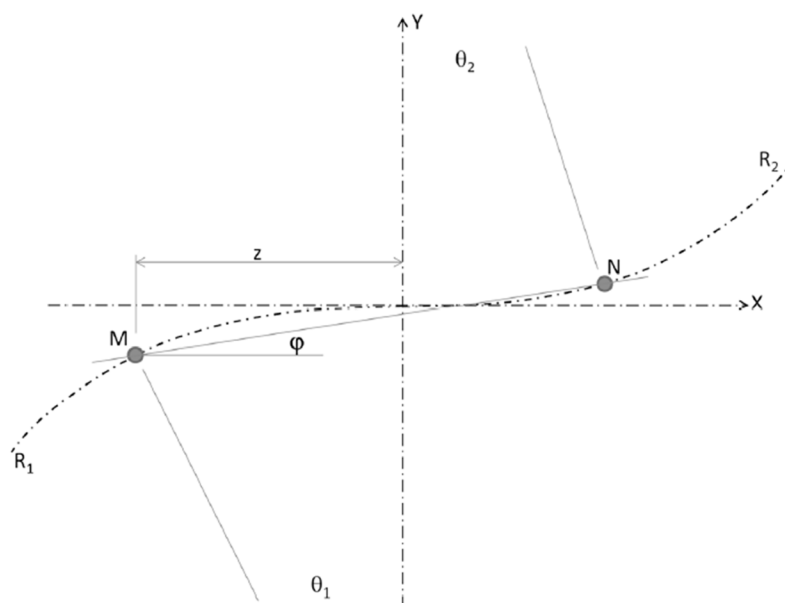


Figure 36 — Parameters for calculation in a reverse curve

If we suppose that the curves are “perfect circles”, we have $R_1 \sin(\theta_1) = z$ and, with

a = distance [MN] we get:

$$(R_1 \sin(\theta_1) + R_2 \sin(\theta_2))^2 + (R_1[1 - \cos(\theta_1)] + R_2[1 - \cos(\theta_2)])^2 = a^2$$

where the only unknown parameter is θ_2 .

Such a formula cannot be easily solved except with computer and numerical application.

When θ_2 is known, X_M, Y_M, X_N and Y_N are known and φ is defined with $\text{atan}\left(\frac{\Delta Y}{\Delta X}\right)$.

We can also suppose, with a small deviation, that curves are parabolas:

Then, curve “ R_1 ” is such as $X_M = -z$; $Y_M = \frac{-z^2}{2R_1}$ and curve “ R_2 ” is such as $X_N = x$; $Y_N = \frac{x^2}{2R_2}$.

Table 8 gives coordinates of these curves “perfect circles” and parabola, in m, with $R_1 = 150$ m in the left part of the table, and $R_2 = 250$ m in the right part.

Table 8 — Coordinates of track in a reverse curve

X	Y circles	Y parab	Δ	X	Y circles	Y parab	Δ
-20	-1,339 310 0	-1,333 330 0	-0,005 980 0	0	0,000 000 0	0,000 000 0	0,000 000 0
-18	-1,083 920 0	-1,080 000 0	-0,003 920 0	2	0,008 000 0	0,008 000 0	0,000 000 1
-16	-0,855 770 0	-0,853 330 0	-0,002 440 0	4	0,032 000 0	0,032 000 0	0,000 002 0
-14	-0,654 760 0	-0,653 330 0	-0,001 430 0	6	0,072 010 0	0,072 000 0	0,000 010 0
-12	-0,480 770 0	-0,480 000 0	-0,000 770 0	8	0,128 030 0	0,128 000 0	0,000 033 0
-10	-0,333 700 0	-0,333 330 0	-0,000 370 0	10	0,200 080 0	0,200 000 0	0,000 080 0
-8	-0,213 490 0	-0,213 330 0	-0,000 150 0	12	0,288 170 0	0,288 000 0	0,000 170 0
-6	-0,120 050 0	-0,120 000 0	-0,000 048 0	14	0,392 310 0	0,392 000 0	0,000 310 0
-4	-0,053 340 0	-0,053 330 0	-0,000 009 5	16	0,512 530 0	0,512 000 0	0,000 530 0
-2	-0,013 330 0	-0,013 330 0	-0,000 000 6	18	0,648 840 0	0,648 000 0	0,000 840 0
0	0,000 000 0	0,000 000 0	0,000 000 0	20	0,801 280 0	0,800 000 0	0,001 280 0

Absolute deviation does not exceed 1,5 mm in a curve 150 m radius when X does not exceed 14 m, and 1 mm in a curve 250 m up to $X = 19$ m.

With parabola hypothesis we have now:

$$(z + x)^2 + \left(\frac{z^2}{2R_1} + \frac{x^2}{2R_2} \right)^2 = a^2$$

and

$$\sin(\varphi) = \frac{\left(\frac{z^2}{2R_1} + \frac{x^2}{2R_2} \right)}{a}$$

The first formula has only x as an unknown parameter and can be developed to get a form as $x^4 + Px^2 + Qx + R = 0$ for which mathematical resolution is possible (refer to Ferrari equation, 4th degree, in 7.1.1.12.7.1).

It is also possible to numerically solve these equations with a computer.

Table 9 gives an example for $R_1 = 150$ m, $R_2 = 250$ m, and $a = 15$ m.

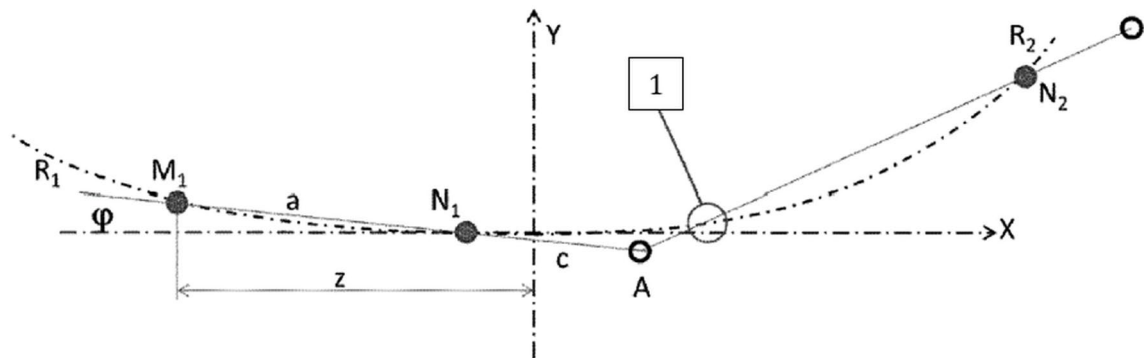
NOTE Same simulation replacing R_2 by $-R_2$ (minus R_2) leads to get results in a compound curve (opposite to S curve), R_1 = direct track, R_2 = deviated track as a complementary case of 7.1.1.12.4.

Table 9 — Coordinates of bogies (pivots) in a reverse curve

$-z (X_M)$	Y_M	X_N	x	$\sin (\varphi)$	φ
-14,981 3	-0,748 130 000	0,000 000 000	0,000 000 00	0,050	0,049 900
-14	-0,653 330 000	0,985 680 257	0,985 680 26	0,044	0,043 700
-13	-0,563 330 000	1,989 118 634	1,989 118 63	0,038	0,038 090
-12	-0,480 000 000	2,991 734 211	2,991 734 21	0,033	0,033 200
-11	-0,403 330 000	3,993 684 430	3,993 684 43	0,029	0,029 020
-10	-0,333 330 000	4,995 103 554	4,995 103 55	0,026	0,025 550
-9	-0,270 000 000	5,996 102 825	5,996 102 83	0,023	0,022 800
-8	-0,213 330 000	6,996 770 580	6,996 770 58	0,021	0,020 750
-7	-0,163 330 000	7,997 172 320	7,997 172 32	0,019	0,019 420
-6	-0,120 000 000	8,997 350 758	8,997 350 76	0,019	0,018 790
-5	-0,083 330 000	9,997 325 856	9,997 325 86	0,019	0,018 880
-4	-0,053 330 000	10,997 094 840	10,997 094 84	0,020	0,019 680
-3	-0,030 000 000	11,996 632 250	11,996 632 25	0,021	0,021 190
-2	-0,013 330 000	12,995 889 940	12,995 889 94	0,023	0,023 410
-1	-0,003 330 000	13,994 797 160	13,994 797 16	0,026	0,026 340
0	0	14,993 260 61	14,993 260 61	0,030	0,029 980

7.1.1.12.5.3 Semi-articulated cars

Figure 37 shows a semi-articulated train in a compound curve.



Key
1 fictive pivot M_2

Figure 37 — “Semi-articulated” train in a compound curve

In this example, vehicle 1 has its bogies M_1 and N_1 in the curve radius R_1 .
Taking into account the above subclauses, there is no difficulty to determine the angle φ as a function of z , and the coordinates of the articulation $A (X_A, Y_A)$.
It is clear in Figure 37 that vehicle 2 cannot be “gauge calculated” as if its distance between pivots was equal to AN_2 , but a virtual pivot M_2 is considered to define an equivalent distance “ a ” for this vehicle.

Then all the usual formulae given in this norm remain applicable.

Referring to 7.1.1.12.4.1:

$$AM_1 \cdot AN_1 = (a + c) \times c = d_1^2 - R_1^2$$

where

d_1 is the distance between the centre of circle R_1 and articulation A .

but also

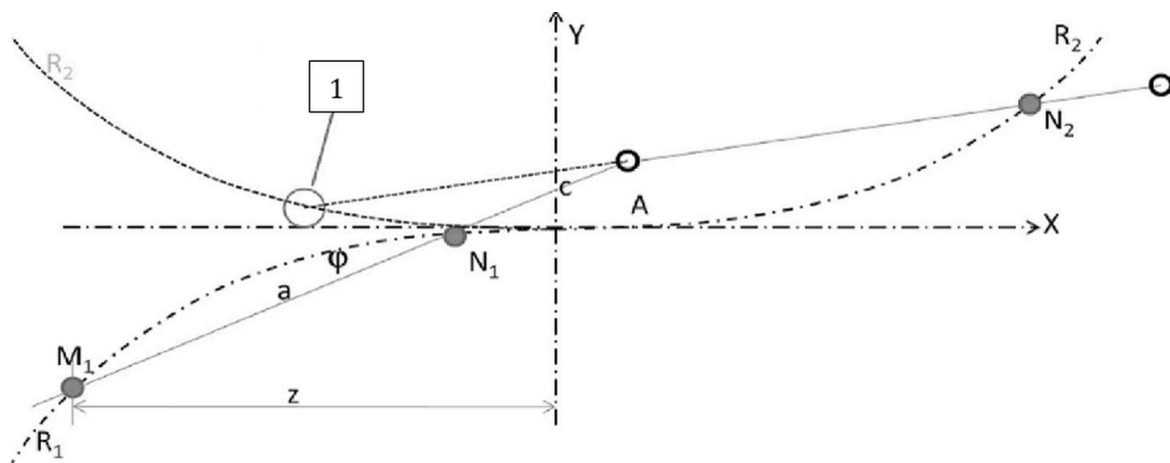
$$AM_2 \times AN_2 = d_2^2 - R_2^2 \Leftrightarrow AM_2 = \frac{(d_2^2 - R_2^2)}{AN_2}$$

where

d_2 is the distance between the centre of circle R_2 and articulation A .

As X_A and Y_A depend on R_1 , z , a , c , and thus dimensions of vehicle 1, virtual pivot of vehicle 2 will depend on dimensions of both vehicle 1 and vehicle 2.

Figure 38 shows the same semi-articulated train in an S -curve.



Key

1 fictive pivot M_2

Figure 38 — “Semi-articulated” train in a reverse curve R_1 - R_2

In this example, vehicle 1 has its bogies M_1 and N_1 in the curve radius R_1 .

It is clear in the figure that vehicle 2 cannot be “gauge calculated” as if its distance between pivots was equal to AN_2 , but a virtual pivot M_2 is considered to define an equivalent distance “ a ” for this vehicle.

Then all the usual formulae given in this document remain applicable.

But now, in S -curve, the virtual pivot is on a curve symmetric to R_2 and leads to higher value of overthrows than in a compound curve.