UIC CODE 505-1

10th edition, May 2006

Translation

O R

Railway transport stock

Rolling stock construction gauge

Matériel de transport ferroviaire - Gabarit de construction du matériel roulant
Eisenbahnfahrzeuge - Fahrzeugbegrenzungslinien

UNION INTERNATIONALE DES CHEMINS DE FER
INTERNATIONALER EISENBAHNVERBAND
INTERNATIONAL UNION OF RAILWAYS

Leaflet to be classified in Volumes:

V - Rolling stock

VI - Traction
VII - Way and Works

Application:

With effect from 1st May 2006
All members of the International Union of Railways

This leaflet applies to standard gauge lines

Record of updates

1st edition, June 1991	First issue
7th edition, May 1995	with approved modifications
8th edition, January 1997	With approved Appendix 6 (now Appendix F)
9th edition, November 2003	with approved modifications and Appendix G. Important: the articles (points) in this leaflet have been renumbered in the new edition. The first digit of each point has been increased by one (i.e. 0 becomes 1, 1 becomes 2, and so on). Please take account of this when using cross-references from other leaflets
10th edition, May 2006	amendments to points 5.4, 7.2.3, F.4 and addition of Appendix F.7 (approval by the previous study group "Rolling stock" of the SC11 UIC).

The person responsible for this leaflet is named in the UIC Code

Contents

Summary

This leaflet:

- defines the reference profile of the kinematic gauge for powered vehicles, coaches and wagons,

- fixes the rules associated with the reference profile of the kinematic gauge for determining the maximum construction gauge,

- specifies the position of the various gauges in relation to each other and gives a definition of each,

- enables the maximum construction gauges to be determined:

  - by calculation, point 7
  - by the graphic method, Appendix B.

Comments and explanations concerning the preparation of the provisions and the formulae are given in *UIC Leaflet 505-5*.

1 - General

A gauge comprises two fundamental elements:

- a reference profile,

- rules associated with this profile.

The latter comprise a set of formulae and application conditions which, on the basis of the reference profile, make it possible to determine:

- for the Rolling Stock Departments, the maximum construction gauge,

- for the Way and Works Departments, the minimum gauge for lineside structures.

2 - Scope of application

The provisions in this Leaflet, except for Appendices A - page 50, C - page 74, D - page 79 and G - page 107, are obligatory for all types of rolling stock to be built (powered vehicles, coaches, vans, wagons) for use in international service.

For tilting body vehicles (TBV), Appendix F - page 83 is applicable.

These provisions do not apply to loading. The "loading gauges" are shown in the RIV (see List of abbreviations - page 113). However, they may be applied for certain wagon and load combinations (containers and swap-bodies) (see *UIC Leaflet 506* (see Bibliography - page 114).

For vehicles carrying exceptional loads, Appendix B - page 70 may be used.

For vehicles with fixed parameters, Appendix G - page 107 may be used.

This leaflet does not apply:

- to continental wagons for running in Great Britain, for which *UIC Leaflet 503* (see Bibliography - page 114) shall apply.

3 - Definitions

3.1 - Normal coordinates

The expression "normal coordinates" is used for orthogonal axes defined in a plane normal to the longitudinal centreline of the rails in nominal position; one of these axes, sometimes called horizontal, is the intersection of the specified plane and the running surface; the other is the perpendicular to this intersection at equal distance from the rails.

For calculation purposes, this centreline and the vehicle centreline must be considered as coincident in order to be able to compare the vehicle construction gauges and the lineside structure limit gauges, both calculated on the basis of the kinematic gauge reference profile which is common to both.

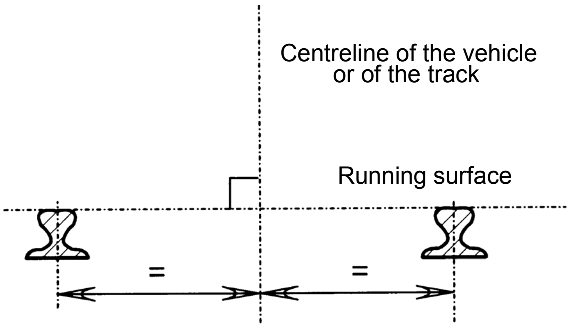


Fig. 1 - Centreline of the track in nominal position

3.2 - Reference profile

(see point 5 - page 11)

Profile related to the normal coordinates (see point 3.1), always accompanied by associated rules (see point 6 - page 17) used, for rolling stock, to define the vehicle maximum construction gauge.

3.3 - Geometric overthrow

(see point 7.1.1 - page 32)

The expression geometric overthrow means, for an element of a vehicle located on a radius R curve, the difference between the distance from this element to the track centreline and that which would exist on straight track, the axles being, in both cases, placed in a median position on the track, the play also being evenly distributed, the vehicle symmetrical and not tilted on its suspensions; in other words, it is that part of the vehicle element offset which is due to the track curve.

On the same side of the track centreline, all the points in the same vehicle body cross-section have the same geometric overthrow.

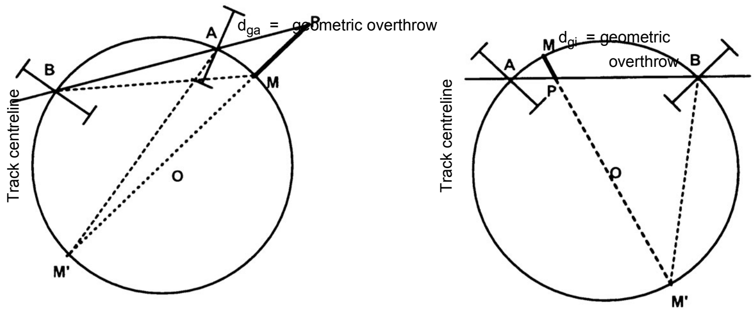


Fig. 2 -

3.4 - Roll centre C

(see point 7.1.3 - page 33 and Fig. 3 - page 6)

When the vehicle body is subjected to a lateral force parallel to the running surface (gravity component, see figure 3a, or centrifugal force, see figure 3b), it tilts on its suspensions.

If the vehicle lateral play and the effect on its dampers have reached their limits in this condition, the XX' centreline of a lateral section takes up a $X_1X'_1$ position.

In routine cases of vehicle lateral movements, the position of point C is independent of the lateral force involved.

Point C is known as the roll centre of the vehicle and its distance h_c from the running surface is known as the height of the roll centre.

In the case of extreme vehicle/bogie positions, this h_c height must be taken into account with regard to one of the vehicle body/bogie bump stops:

- rotational movement stop,
- central movement stop.

(See note, point 7.1.3).

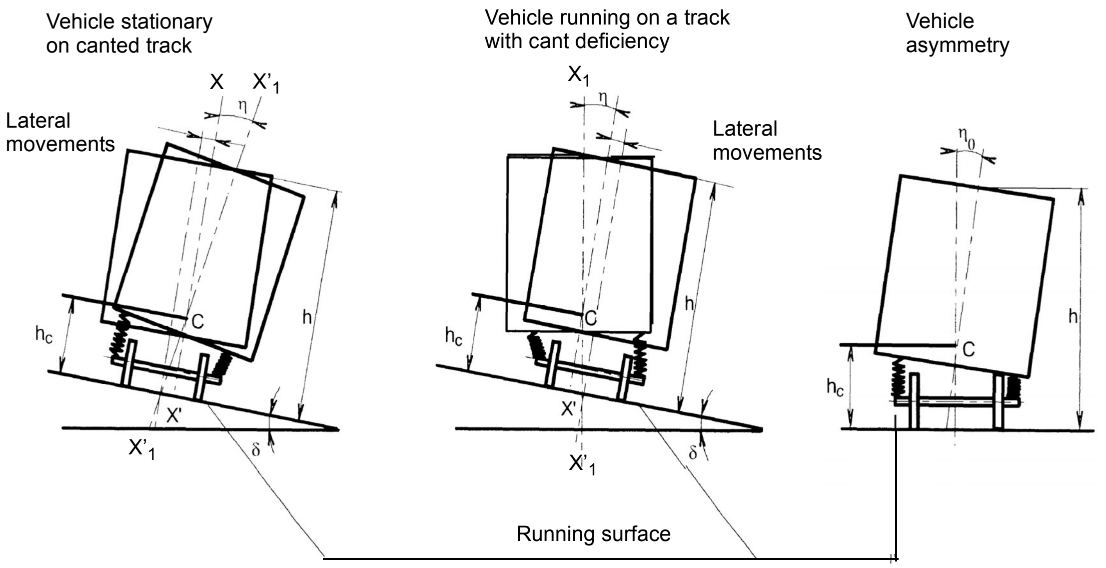


Fig. 3 -

3.5 - Asymmetry

The asymmetry of a vehicle is defined as the angle η_0 that would be formed between the vertical and the centreline of the body of a stationary vehicle on level track in the absence of friction (see figure 3c).

Asymmetry may result from constructional defects, unevenly adjusted suspension (scotching, transoms, pneumatic levelling valves, etc.) and from an off-centre load.

3.6 - Coefficient of flexibility s

(see Fig. 3)

Whenever a stationary vehicle is placed on a canted track whose running surface lies at an angle δ to the horizontal, its body leans on its suspensions and forms an angle η with the perpendicular to the rail level. The vehicle flexibility coefficient s is defined by the ratio:

$$s = \frac{\eta}{\delta}$$

This ratio may be calculated or measured (see *UIC Leaflet 505-5* (see Bibliography - page 114)). It depends in particular on the load state of the vehicle.

Powered units of constant weight	Vehicles with non-constant weight	
Locomotives, etc.	Multiple units, coaches, vans, coaches with driving cab, etc.	Wagons
Unladen state in running order	Unladen state in running order and exceptional load state (maximum load state)	Unladen state in running order and maximum load state

3.7 - Maximum construction gauge for rolling stock

(see point 4 - page 9).

The maximum construction gauge is the maximum profile, obtained by applying the rules giving reductions in relation to the reference profile, which the various parts of the rolling stock must respect. These reductions depend on the geometric characteristics of the rolling stock in question, the position of the cross-section in relation to the bogie pivot or to the axles, the height of the point considered in relation to the running surface, constructional play, the maximum wear allowance and the elastic characteristics of the suspension.

In general, the effective construction gauge uses only partially the non-hatched areas within the maximum construction gauge for the installation of foot-steps, hand-rails, etc.

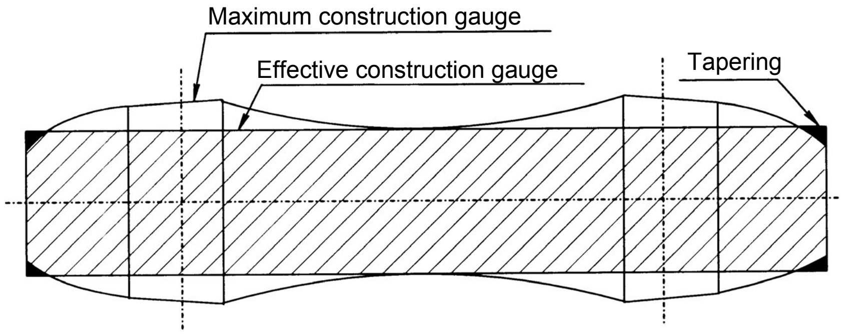


Fig. 4 -

3.8 - Kinematic gauge

This covers the furthest positions in relation to the centres of the normal coordinates likely to be taken by various parts of rolling stock, taking into account the most unfavourable positions of the axles on the track, the lateral play and semi-static movements attributable to the rolling stock and to the track.

The kinematic gauge does not take account of certain random factors (oscillations, asymmetry, if $\eta_0 \leq 1°$): the suspended parts of the vehicles may therefore exceed the kinematic gauge in the course of oscillation. Such movements are taken into account by the Way and Works Department.

3.9 - Quasi-static movements z

The part of lateral movements attributable to the rolling stock and resulting from the technology applied, suspension flexibility (s flexibility coefficient) under the effect of centrifugal force not compensated for by cant or of excessive cant (see figure 3a or 3b) and under the effect of asymmetry η_0 (see figure 3c). This value depends on the height h of the point in question.

The parameters due to cant deficiency or excess involved in the calculation of these movements are explained in point 7.1.3 - page 33.

3.10 - S projections

(see point 6.2.1 - page 26 and Fig. 5 - page 10)

Exceeding the reference profile when the vehicle is on a curve and/or on track with a gauge wider than 1,435 m.

The half-width of the vehicle, plus the D movements, minus the half-width of the reference profile at the same level, is equivalent to the actual projection S in relation to the reference profile.

Justification for the projections is given in *UIC Leaflet 505-5*.

3.11 - Vehicle limit position

The vehicle position which is obtained by giving to projection S the maximum value S_0 defined in point 6.2.1 - page 26. The reduction formulae take this value into account (see also points 3.8 - page 7 and 3.10).

3.12 - E_i or E_a reductions

To ensure that a vehicle when on the track does not exceed the "vehicle limit position" in view of its D movements, the half-width dimensions must be subject to an E_i or E_a reduction, in relation to the reference profile, such that:

E_i or E_a D - S_0.

The following distinction is made:

- E_i: reduction value for the reference profile half-width dimensions for the sections located between the end axles of vehicles not mounted on bogies or between the pivots of vehicles mounted on bogies.

- E_a: reduction value for the reference profile half-width dimensions for the sections beyond the end axles of vehicles not mounted on bogies or the pivots of vehicles mounted on bogies.

3.13 - Lineside structure gauge

Profile in relation to the axes of coordinates normal to the track, inside which no structure must penetrate despite elastic or non-elastic track movements.

4 - General comments on the method for obtaining the maximum rolling stock construction gauge

This leaflet gives the necessary elements and the methods used for determining the maximum construction gauge for rolling stock to be used in international service.

It should be noted that, in order to meet in particular the requirements of international combined traffic, height-enhanced gauges have been defined. These are covered in *UIC Leaflet 506*.

The study of the maximum construction gauge takes into account both the lateral and vertical movements of the rolling stock, drawn up on the basis of the geometrical and suspension characteristics of the vehicle under various loading conditions.

In general, the maximum construction gauge of a vehicle is determined for the n_i or n_a values which correspond to the middle of the vehicle and the headstocks. It is of course necessary to check all the projecting points, as well as those which, in view of their location, are likely to be in close proximity to the maximum vehicle construction gauge within the section under consideration.

Transversally, taking into account the vehicle body movements obtained for a point located on an n_i or n_a section at height h in relation to the running surface, the half-widths of the maximum vehicle construction gauge shall be at the most equal to the corresponding half-widths of the reference profile, specific to each type of vehicle, decreased by the E_i or E_a reductions.

These reductions must satisfy the relationship E_i or E_a D - S_0 in which:

- D represents the movements, it being understood that the quasi-static movements have been taken into account for a cant excess or deficiency, the values of which are specified in point 6 - page 17.

  The D values may be determined:

  - by calculation (see point 7 - page 32),
  - by the graphic method (see Appendix B - page 70);

- S_0 represents the maximum projections, the values of which are shown in point 6.2.1 - page 26.

Examples of the application of this leaflet by calculation or by the graphic method are given in Appendices A - page 52 and C - page 77.

Relative positions of the various gauges

Figure 5 - page 10 shows the position of the various gauges in relation to each other, as well as the main elements involved in determining the rolling stock maximum construction gauge.

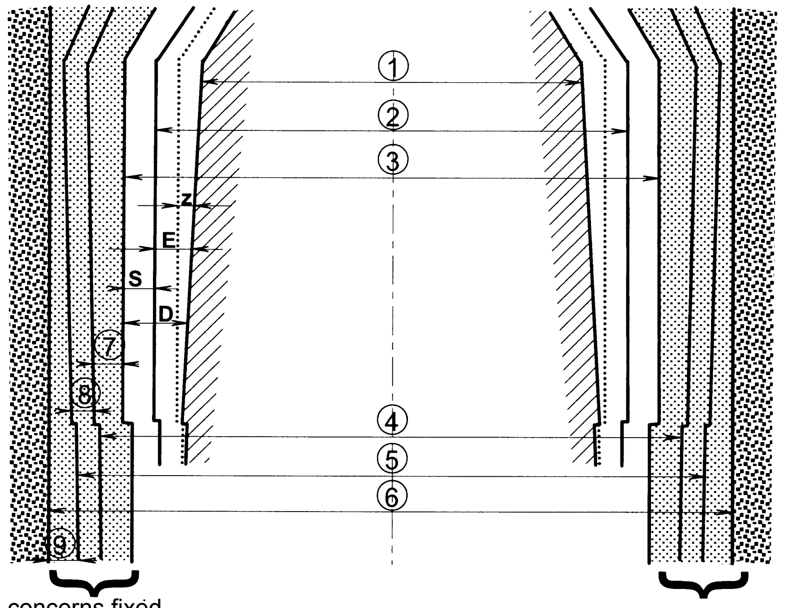


Fig. 5 -

1 Rolling stock maximum construction gauge

2 Kinematic gauge reference profile

3 Limit position of rolling stock considered in the reduction formulae

4 Rolling stock kinematic gauge

5 Lineside structure limit gauge

6 Lineside structure installation gauge

z = quasi-static movement obtained in point 6.2.3 - page 30 and taken into account in the reduction formulae:
- for a cant excess or deficiency of 0,05 m,
- for that part of the asymmetry exceeding 1°
- for cant excess or deficiency between 0,05 m and 0,2 m maximum which is not taken into account by the Way and Works Department if s > 0,4 and/or h_c < 0,5 m.

E = Reduction (E_i or E_a)

S = Lateral projection (for the rolling stock S_0 = maximum projection)

D = Lateral movement

7 Semi-static movement due to cant excess or deficiency exceeding 0,05 m (for s = 0,4, h_c = 0,5 m)

8 Value added by the Way and Works Department in order to take into account track defects in service, oscillations and asymmetries of ≤ 1° and resulting movements.

9 Margin specific to each Railway in order to take into account special situations (transport of exceptional loads, margins for increasing the speed, high prevailing cross-winds).

5 - Reference profile for the kinematic gauge

The reference profile takes into account the position of the lineside structures and the most restrictive track centre distances at UIC level.

It is:

- always accompanied by associated regulations (see points 6 - page 17 and 7 - page 32),
- divided in 2 parts as below:
  - upper part defined as being located above a level of 400 mm above the running surface, common to all vehicles (see point 5.1 - page 12),
  - lower part defined as being located at or below a level of 400 mm above the running surface and different for vehicles:

    . which must not pass over rail brakes and other activated shunting and stopping devices (see point 5.2 - page 13),
    . which must pass over such devices (part lower than 130 mm) (see point 5.3 - page 14).

The part below 130 mm differs according to the vehicles.

NB : The value "400 mm" also serves as a limit for the calculation of projections (see point 6.2.1).

NB : Loaded coaches must respect the provisions of point 5.2 when on a track without vertical curvature.

Vans and wagons, whether empty or loaded, must satisfy point 5.3 - page 14, except for well wagons and certain combined transport wagons.

In the case of wagons scheduled to run in transit on the Finnish network, the elements of the lower parts must respect the gauge given in *UIC Leaflet 430-3, Appendix 1*.

Wagons which must not pass over:

- shunting humps with a 250 m radius curvature,
- track brakes and other shunting and stopping devices
  - may not carry the RIV sign, unless explicitely authorised under the UIC Code (e.g. *UIC Leaflet 597* for bimodal wagons),
  - must carry the corresponding markings as defined in the RIV.

5.1 - Part common to all vehicles

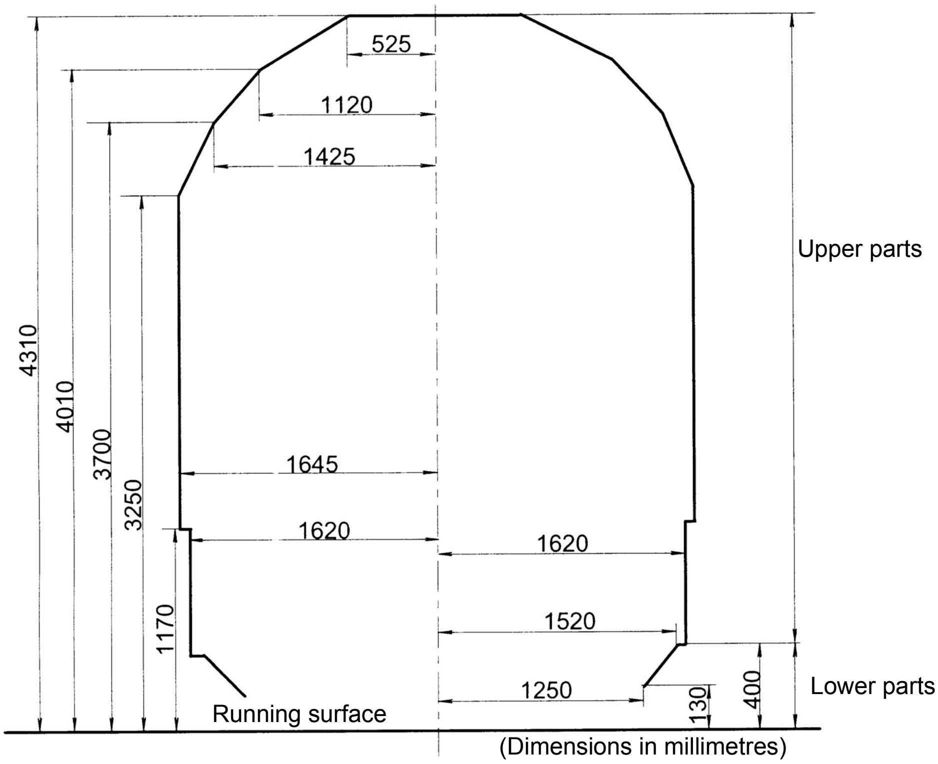


Fig. 6 -

An example is given in Appendix D - page 79 for application of superelevated gauges.

5.2 - Part below 130 mm on vehicles which must not run over rail brakes or other activated shunting and stopping devices

Certain gauge restrictions must be observed at the level of the axles when vehicles are placed on an under-floor wheel lathe for wheel reprofiling.

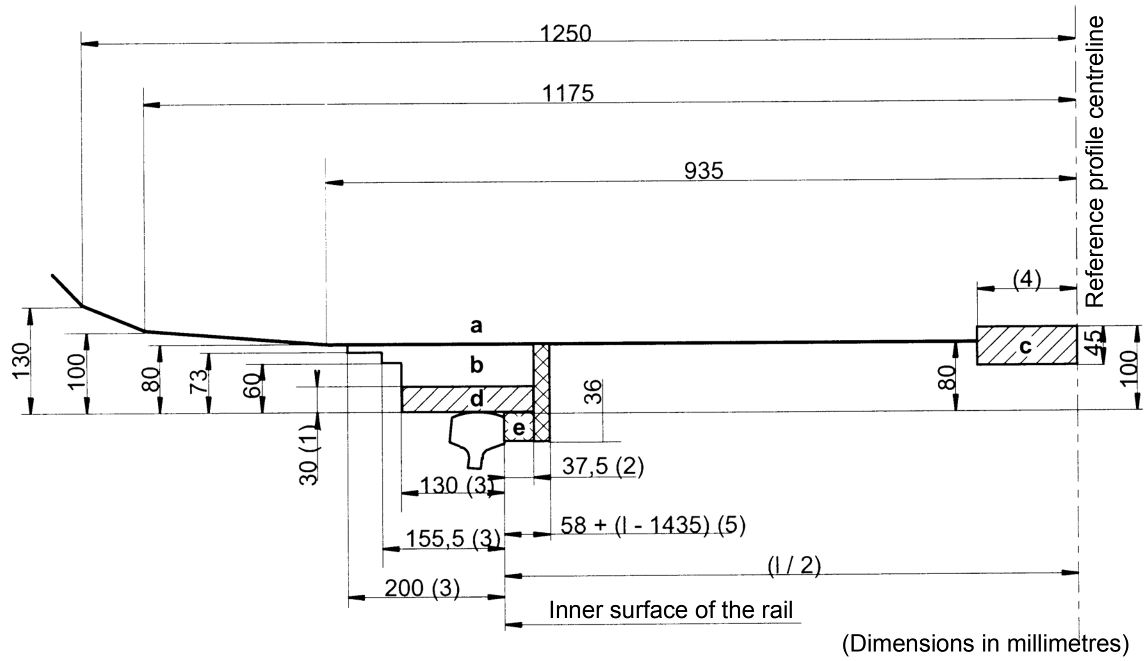


Fig. 7 -

a zone for equipment away from wheels

b zone for equipment in immediate proximity of wheels

c zone for contact ramp brushes

d zone for wheels and other parts coming into contact with the rails

e zone occupied exclusively by the wheels

(1) Limit for parts located outside the axle ends (guard irons, sanders, etc.) not to be exceeded for running over detonators.
This limit may however be disregarded for parts located between the wheels, provided these parts remain within the wheel track.

(2) Maximum theoretical width of the flange profile in the case of check-rails (*UIC Leaflet 505-5*).

(3) Effective limit position of the outside surface of the wheel and of the parts associated with this wheel. Lower parts: see *UIC Leaflet 505-5*.

(4) When the vehicle is in any position whatsoever on a curve of radius R = 250 m (minimum radius for contact ramp installation) and a track width of 1 465 mm, no part of the vehicle likely to descend to less than 100 mm from the running surface, except for the contact brush, should be less than 125 mm from the track centre. For parts located inside the bogies, this dimension is 150 mm.

(5) Effective limit position of the internal surface of the wheel when the axle is against the opposite rail. This dimension varies with gauge widening.

NB : Account should also be taken of point 6.1.1.3.2.

5.3 - Part below 130 mm for vehicles able to negotiate rail brakes and other activated shunting and stopping devices

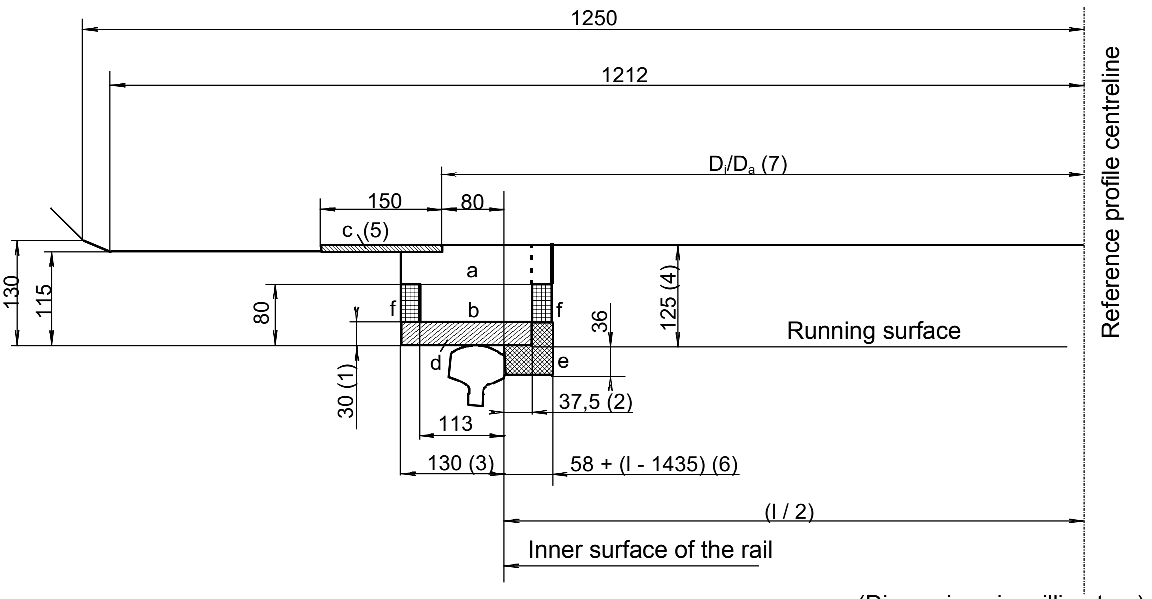


Fig. 8 -

a zone for equipment away from wheels

b zone for equipment in immediate proximity of wheels

c zone for ejection of standardised drag shoes (see *UIC Leaflet 505-5*)

d zone for wheels and other equipment coming into contact with the rails

e zone occupied exclusively by the wheels

f zone for rail brakes in released position

(1) Limit for parts located outside the axle ends (guard-irons, sanders, etc) not to be exceeded for running over detonators.

(2) Maximum fictional width of the flange profiles in the case of check rails.

(3) Effective limit position of the wheel external surface and of the parts associated with the wheel. (Lower parts: see *UIC Leaflet 505-5*).

(4) This dimension also shows the maximum height of standard drag shoes used for scotching or slowing down the rolling stock.

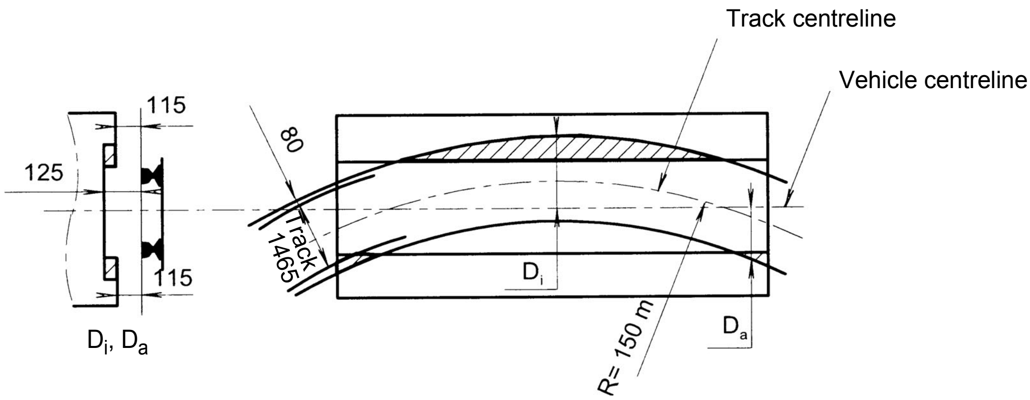
(5) No rolling stock equipment should penetrate into this area.

(6) Effective limit position of the wheel internal surface when the axle is against the opposite rail. This dimension varies with gauge widening.

(7) See following paragraph

Use of shunting devices in curved track sections

Rail brakes and other shunting and stopping devices which, when activated, can reach the dimensions 115 or 125 mm, in particular drag shoes 125 mm high, may be placed on curves of radius R 150 m.



(unless otherwise indicated, dimensions are in millimetres)

Fig. 9 -

It follows that the application limit for the 115 or 125 mm dimensions, which is at a constant distance from the inner edge of the rail (80 mm), is at a variable distance D from the centreline of the vehicle, as shown in figure 9 above.

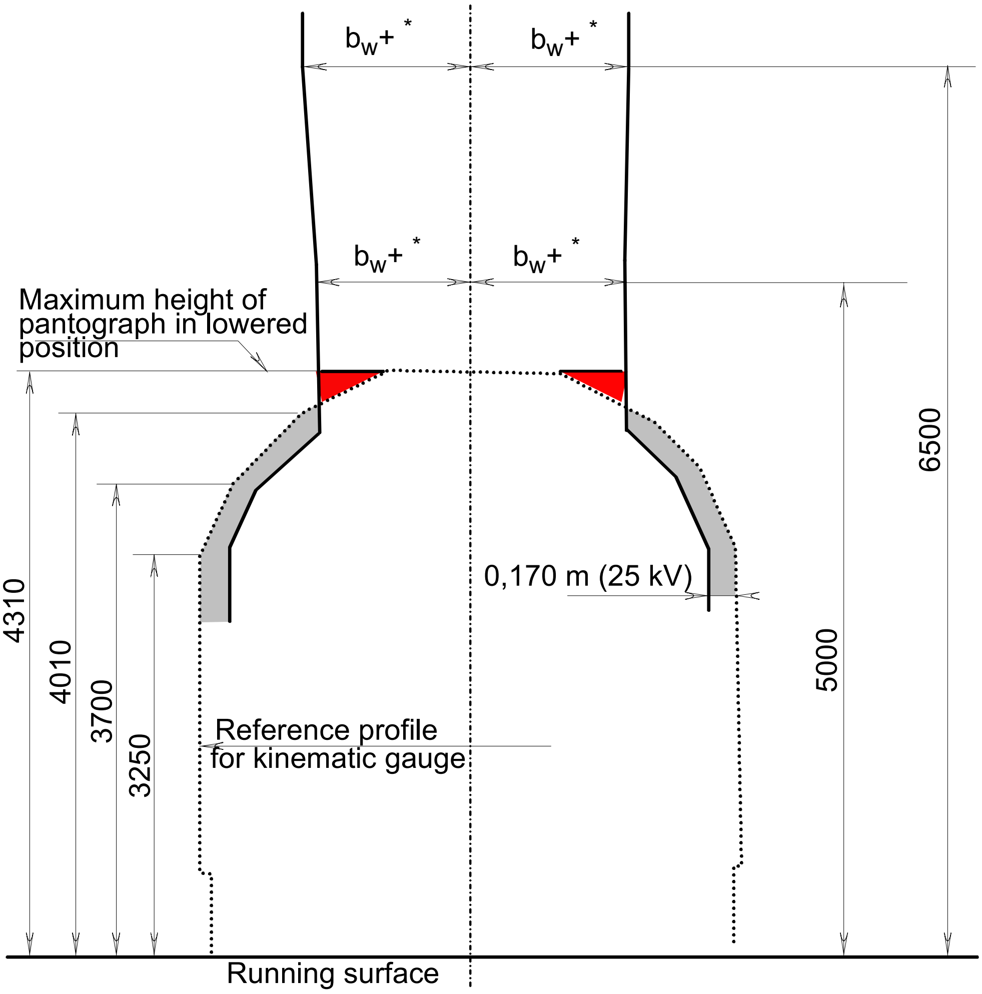
Take the following (values given in metres):

$$D_i = 0,080 + 1,465 - \frac{1,410}{2} + \frac{an - n^2 + \frac{p^2}{4}}{300} = 0,840 + \frac{an - n^2 + \frac{p^2}{4}}{300}$$

$$D_a = 0,080 + 1,465 - \frac{1,410}{2} + \frac{an + n^2 - \frac{p^2}{4}}{300} = 0,840 + \frac{an + n^2 - \frac{p^2}{4}}{300}$$

NB : In the particular case involving the use of shunting devices, the influence of plays q + w may be considered negligible.

5.4 - Reference contour for pantographs and non-insulated live parts on vehicle roof



bw	=	bow half-width
*	=	permitted movements. These movements are respected when the conditions of formulae (111) (112) (113) or (114) for h = 6,5 m and (115) (116) (117) or (118) for h = 5 m, are met
(grey)		Areas where non-insulated parts likely to remain live must not penetrate
(red)		Areas that can be used for lowered bow insulated parts or other non live parts over electrified lines. When lines are not electrified, those areas can be used only under acceptance of the infrastructure manager.

Fig. 10 -

NB : For vehicles worked on electrified lines, the shaded areas may be used for gauging pantograph bows in the down position.

On non-electrified lines, the same possibilities are allowable subject to specific studies by the railways.

6 - Rules associated with the reference profile for determining the maximum rolling stock construction gauge

In order to determine the maximum construction gauge of a vehicle, the rules associated with the reference profiles in point 5 - page 11 must take account of:

- vertical movements,
- transverse movements.

Construction tolerances are taken into account in the asymmetry calculation (see point 7.1.3 - page 33).

The nominal width value of a vehicle is obtained from the dimensions of the maximum constructional profile.

Tolerance values must not be used systematically to increase vehicle dimensions.

6.1 - Vertical movements

For the vehicle or for a given part, these movements make it possible to determine a minimum height (see point 6.1.1) and a maximum height (see point 6.1.2 - page 24) above the running surface; this is particularly the case for:

- parts located towards the lower section of the gauge (low parts);
- the step at 1 170 mm from the running surface on the reference profile;
- parts located at the upper part of the vehicles.

It should be noted that for all parts located at a height greater than 400 mm above the running surface, the vertical component of the quasi-static movements is not taken into account.

6.1.1 - Determination of minimum heights above the running surface

The minimum heights above the running surface for parts located towards the lower part of the gauge (1 170 mm and below) are determined with account being taken of the vertical movements described in the following paragraphs.

When studying the state of deflection of the vehicle bodies (see points 6.1.1.1 to 6.1.1.3 - page 19 and Appendix E - page 81), the division shown in the diagram below shall be considered.

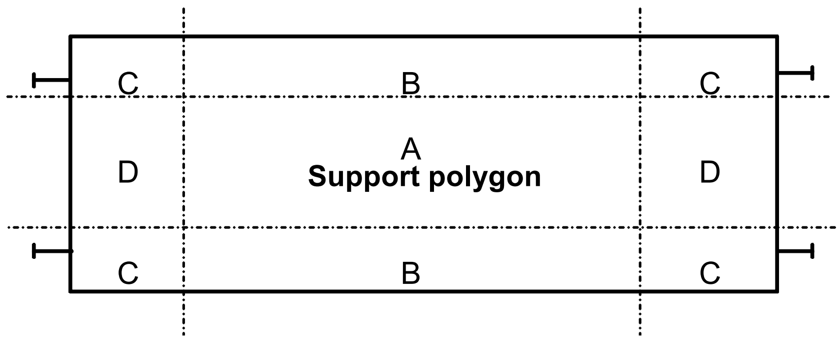


Fig. 11 -

6.1.1.1 - Deflections independent of the load state and of the suspension state

These deflections shall be considered for all vehicle body zones A, B, C and D, and concern the following parts:

-	Wheels	Maximum wear for all types of vehicles
-	Various parts	Maximum wear - examples: transoms, brake rigging, etc, for all vehicles and for each special assembly
-	Axle boxes	Wear ignored
-	Bogie frame	Manufacturing tolerances giving rise to deflection in relation to the nominal dimensions: ignored
-	Body structures	Manufacturing tolerances giving rise to deflection in relation to the nominal dimensions: ignored for all vehicles including all conventional and special wagons.

6.1.1.2 - Deflection dependent on the load state of the vehicles and on the state of their suspension

6.1.1.2.1 - Structural distortions: sag for all the vehicle body zones A, B, C, and D

-	Axles	Deflection	ignored
-	Bogie frame	Deflection	ignored
-	Body	Transverse deflection	ignored
		Twist	ignored
		Longitudinal deflection	ignored for all vehicles except wagons, for which the longitudinal sag must be taken into account under the effect of a maximum load increased by 30%, in order to take dynamic stresses into consideration.

6.1.1.2.2 - Deflection of the suspensions

1. *Types of springs*

   The primary and secondary suspensions are formed of various types of springs for which the deflections must be taken into account:

-	Steel spring	Deflection under static load, Additional deflection under dynamic stress, Deflection due to flexibility tolerances (see *UIC Leaflet 822*).
-	Rubber spring	Same deflections as for steel springs
-	Pneumatic spring	Total deflection with cushions deflated (including back-up suspension when it exists).

2. *Suspension deflection conditions*

- Equal and simultaneous deflections on the suspensions (zones A, B, C and D are concerned)

- Locomotives	Deflection of the suspensions with an overload of 30% of their sprung weight
- Coaches (empty in running order)	30 mm overall deflection
- Coaches and vans	Deflection with a 30% overload on the sprung weight (maximum load) or total deflection
- "Conventional" wagons	Total deflection (bottoming)
- Special wagons	Deflection under the effect of a 30% overload on the sprung weight (in order to make maximum use of the gauge, especially in the case of combined transport or of bulky loads) or total deflection (bottoming)
- Multiple units	Deflection under the effect of a 30% overload of their sprung weight (maximum load) or total deflection.
- Other deflections	See Appendix E - page 81.

6.1.1.3 - Passing over vertical transition curves (including marshalling yard humps) and over braking, shunting or stopping devices

6.1.1.3.1 - Vehicles with a reference profile in accordance with point 5.3 - page 14

1. *Normal values for the e_i or e_a vertical reductions to be taken into account for empty coaches, empty or loaded vans and wagons.*

   These vehicles, when they can be gravity shunted, must be capable of passing over activated rail brakes and other shunting or stopping devices located on non-vertically curved track and reaching the 115 and 125 mm dimensions above the running surface, up to 3 m from the end of convex transition curves of radius R_v 250 m (dimension d).

   They must also be able to pass over such devices located inside or near concave transition curves of radius R_v 300 m.

   In applying these conditions, the lower dimensions of these vehicles, taking into account vertical movements assessed as state d in point 6.1 - page 17, must in relation to the running centre be at least equal to 115 or 125 mm increased by the following e_i or e_a quantities:

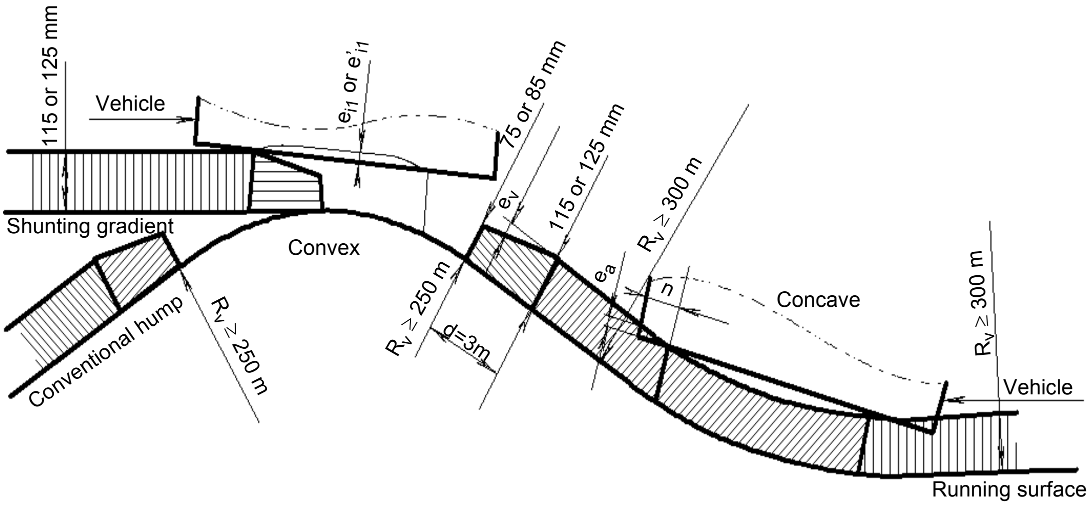


Fig. 12 -

e_i or e_a : vertical reduction at the lower part of the rolling stock equipment in relation to the 115 and 125 mm dimensions.

e_v : lowering of the rail brakes in relation to the 115 or 125 mm dimensions.

a. For sections between the end axles or bogie pivots (normal values expressed in metres)

The purpose of the numerical index applied to the e_i and e'_i values is to distinguish the normal values from the reduced values:

$$e_{i1} = \frac{n}{a}\frac{(a-n-3)^2}{500} \text{ when } a \le 17,80 \text{ m and } n < \frac{a-3}{3}$$

$$e_{i1} = \frac{(a-3)^3}{3375\,a} \text{ when } a \le 17,80 \text{ m and } n \ge \frac{a-3}{3} \quad (1)$$

$$e'_{i1} = \left[\frac{27}{4}\frac{n}{a-3}\right]\left[1-\frac{n}{a-3}\right]^2\left[\frac{a^2}{3375}-0,04\right] \text{ when } a > 17,80 \text{ m and } n < \frac{a-3}{3}$$

$$e'_{i1} = \frac{a^2}{3375} - 0,04 \text{ when } a > 17,80 \text{ m and } n \ge \frac{a-3}{3} \quad (1)$$

(1) This formula for $n \ge \frac{a-3}{3}$ gives reductions greater than or equal to those resulting from the formula $n < \frac{a-3}{3}$.

When empty coaches and empty or loaded wagons and vans can be gravity shunted, they must also be able to pass over convex transition curves of radius 250 m, without any part other than the wheel flange descending below the running surface.

This condition, which concerns the central part of the vehicles, is in addition to those resulting from the e_i formulae for long vehicles.

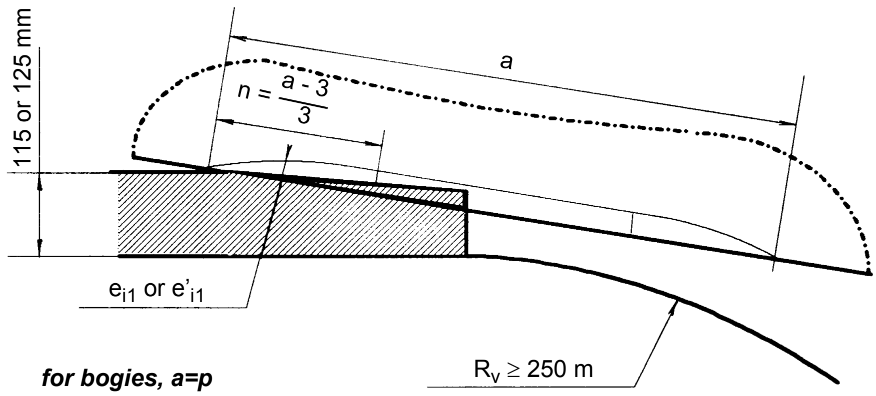


Fig. 13 -

b. For sections located beyond the end axles or bogie pivots (values in metres)

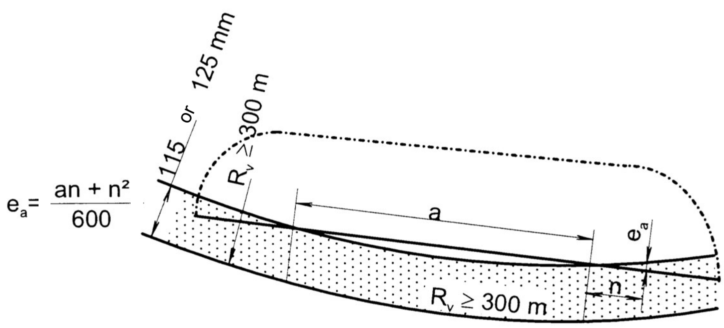


Fig. 14 -

2. *Reduced values for the e_i increase (sections between the end axles or bogie pivots) to be considered for certain vehicles for passing over gradient transition curves including shunting humps.*

   These reduced values are only tolerated for certain types of wagon, insofar as they require a larger space than that determined using the normal values given in point 6.1.1.3 - page 19. These are, for example, the recess wagons used in rail/road combined traffic, and other identical or similar designs.

   Use of these reduced values may require special precautions to be taken in certain marshalling yards with hump retarders at the base of a shunting gradient.

   For these vehicles, the value of dimension d becomes 5 m.

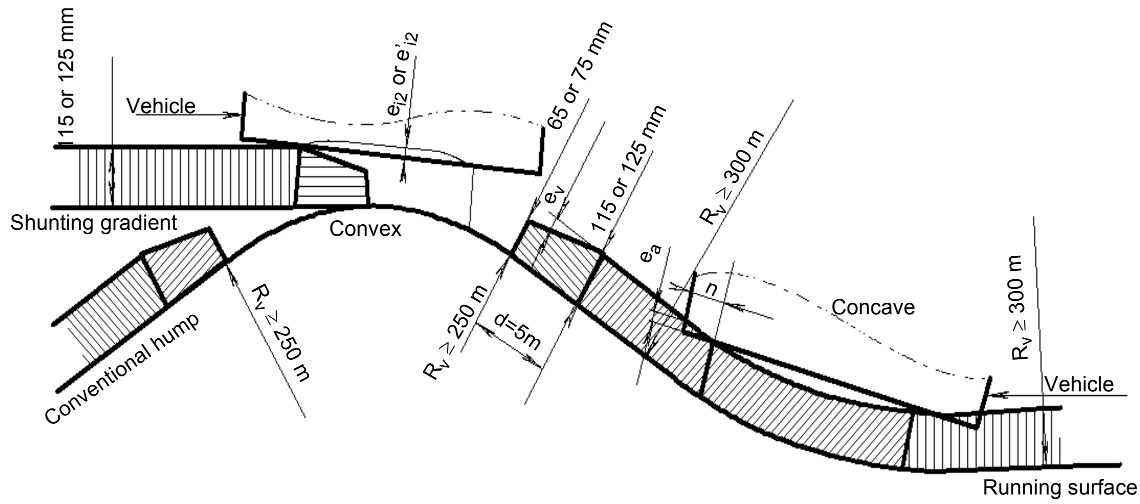


Fig. 15 -

$$e_{i2} = \frac{n}{a}\frac{(a-n-5)^2}{500} \text{ when } a \leq 15,80 \text{ m and } n < \frac{a-5}{3}$$

$$e_{i2} = \frac{(a-5)^3}{3375\,a} \text{ when } a \leq 15,80 \text{ m and } n \geq \frac{a-5}{3} \quad (1)$$

$$e'_{i2} = \left[\frac{27}{4}\frac{n}{a-5}\right]\left[1-\frac{n}{a-5}\right]^2\left[\frac{a^2}{3375}-0,05\right] \text{ when } a > 15,80 \text{ m and } n < \frac{a-5}{3}$$

$$e'_{i2} = \frac{a^2}{3375} - 0,05 \text{ when } a > 15,80 \text{ m and } n \geq \frac{a-5}{3} \quad (1)$$

(1) This formula for $n \geq \frac{a-5}{3}$ gives reductions greater than or equal to those obtained using the formula for $n < \frac{a-5}{3}$.

When they can be gravity shunted, the wagons must also be able to pass over convex transition curves with a radius greater than or equal to 250 m, without any part other than the wheel flange descending below the running surface. This condition, which concerns the central part of the wagons, is in addition to those resulting from the e_i formulae for long wagons

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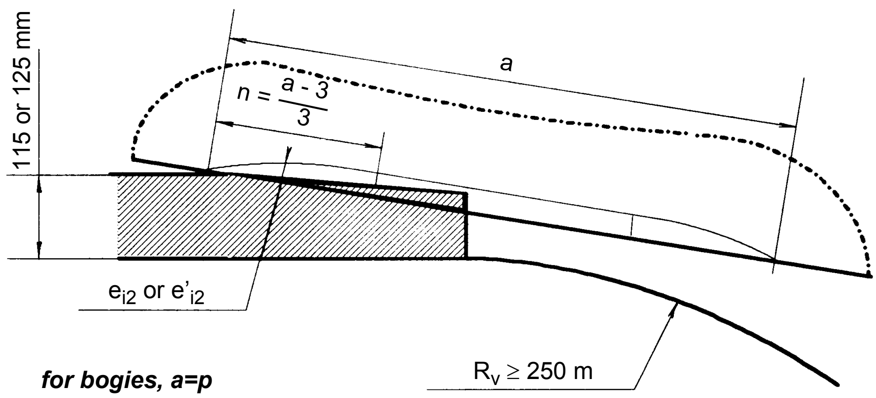
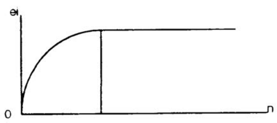


Fig. 16 -

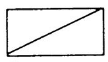
3. *Table showing the values of e_i and e'_i expressed in mm with a and n expressed in m.*

a \ n	> 6	5,5	5	4,5	4	3,5	3	2,5	2	1,5	1	0,5	0
20	79 / 69	78 / 69	78 / 69	76 / 68	73 / 66	69 / 63	63 / 59	57 / 54	49 / 46	39 / 37	28 / 27	15 / 14	0 / 0
19.5	73 / 63	73 / 63	72 / 63	71 / 62	68 / 61	65 / 59	60 / 55	54 / 50	46 / 43	37 / 35	26 / 25	14 / 14	0 / 0
19	67 / 57	67 / 57	67 / 57	66 / 57	64 / 56	60 / 54	56 / 51	50 / 46	43 / 40	35 / 33	25 / 24	13 / 13	0 / 0
18.5	61 / 51	61 / 51	61 / 51	61 / 51	59 / 51	56 / 49	52 / 47	47 / 43	41 / 37	33 / 30	23 / 22	13 / 12	0 / 0
18	56 / 46	56 / 46	56 / 46	56 / 46	54 / 46	52 / 45	48 / 42	44 / 39	38 / 34	31 / 28	22 / 20	12 / 11	0 / 0
17.5	52 / 41	52 / 41	52 / 41	51 / 41	50 / 41	48 / 40	45 / 38	41 / 35	36 / 31	29 / 26	21 / 19	11 / 10	0 / 0
17	48 / 36	48 / 36	48 / 36	48 / 36	47 / 36	45 / 35	43 / 34	39 / 31	34 / 28	28 / 23	20 / 17	11 / 9	0 / 0
16.5	44 / 31	44 / 31	44 / 31	44 / 31	44 / 31	42 / 30	40 / 30	37 / 28	32 / 25	26 / 20	19 / 15	10 / 8	0 / 0
16	41 / 26	41 / 26	41 / 26	41 / 26	41 / 26	40 / 26	38 / 25	34 / 24	30 / 21	25 / 18	18 / 13	10 / 7	0 / 0
15.5	37 / 22	37 / 22	37 / 22	37 / 22	37 / 22	37 / 22	35 / 22	32 / 21	28 / 19	23 / 16	17 / 12	9 / 6	0 / 0
15	34 / 20	34 / 20	34 / 20	34 / 20	34 / 20	34 / 20	32 / 20	30 / 19	27 / 17	22 / 14	16 / 11	9 / 6	0 / 0
14.5	31 / 18	31 / 18	31 / 18	31 / 18	31 / 18	31 / 18	30 / 17	28 / 17	25 / 16	21 / 13	15 / 10	8 / 6	0 / 0
14	28 / 15	28 / 15	28 / 15	28 / 15	28 / 15	28 / 15	27 / 15	26 / 15	23 / 14	19 / 12	14 / 9	8 / 5	0 / 0
13.5	25 / 13	25 / 13	25 / 13	25 / 13	25 / 13	25 / 13	25 / 13	24 / 13	21 / 13	18 / 11	13 / 8	7 / 5	0 / 0
13	23 / 12	23 / 12	23 / 12	23 / 12	23 / 12	23 / 12	23 / 12	22 / 12	20 / 11	17 / 10	12 / 8	7 / 4	0 / 0
12.5	20 / 10	20 / 10	20 / 10	20 / 10	20 / 10	20 / 10	20 / 10	20 / 10	18 / 10	15 / 9	12 / 7	7 / 4	0 / 0
12	18 / 8	18 / 8	18 / 8	18 / 8	18 / 8	18 / 8	18 / 8	18 / 8	16 / 8	14 / 8	11 / 6	6 / 4	0 / 0
11.5		16 / 7	16 / 7	16 / 7	16 / 7	16 / 7	16 / 7	16 / 7	15 / 7	13 / 7	10 / 5	6 / 3	0 / 0
11		14 / 6	14 / 6	14 / 6	14 / 6	14 / 6	14 / 6	14 / 6	13 / 6	12 / 6	9 / 5	5 / 3	0 / 0
10.5			12 / 5	12 / 5	12 / 5	12 / 5	12 / 5	12 / 5	12 / 5	10 / 5	8 / 4	5 / 2	0 / 0
10			10 / 4	10 / 4	10 / 4	10 / 4	10 / 4	10 / 4	10 / 4	9 / 4	7 / 3	4 / 2	0 / 0
9.5				9 / 3	9 / 3	9 / 3	9 / 3	9 / 3	9 / 3	8 / 3	6 / 3	4 / 2	0 / 0
9				7 / 2	7 / 2	7 / 2	7 / 2	7 / 2	7 / 2	7 / 2	6 / 2	3 / 1	0 / 0
8.5					6 / 1	6 / 1	6 / 1	6 / 1	6 / 1	6 / 1	5 / 1	3 / 1	0 / 0
8					5 / 1	5 / 1	5 / 1	5 / 1	5 / 1	5 / 1	4 / 1	3 / 1	0 / 0
7.5						4 / 1	4 / 1	4 / 1	4 / 1	4 / 1	3 / 1	2 / 1	0 / 0
7						3 / 0	3 / 0	3 / 0	3 / 0	3 / 0	3 / 0	2 / 0	0 / 0
6.5							2 / 0	2 / 0	2 / 0	2 / 0	2 / 0	1 / 0	0 / 0
6										1 / 0	1 / 0	1 / 0	0 / 0
5.5										1 / 0	1 / 0	1 / 0	0 / 0
5										0 / 0	0 / 0	0 / 0	0 / 0
4.5										0 / 0	0 / 0	0 / 0	0 / 0



(a-3)/3 or (a-5)/3

Key
Normal values



Reduced values

4. *Vehicles not allowed on shunting humps by reason of their length*

When empty coaches, wagons suitable for international traffic and empty or loaded vans are not allowed over marshalling yard humps on account of their length, they must nonetheless respect the profile in point 5.3 - page 14 when placed on a non-vertically curved track, so as to allow for the use of shunting or stopping devices.

6.1.1.3.2 - All vehicles

All vehicles must be able to pass over convex or concave transition curves of radius R_V 500 m, without any part other than the wheel flange descending below the running surface.

This may concern mainline vehicles whose:

- wheelbase is greater than 17,8 m,
- overhang is greater than 3,4 m.

6.1.1.3.3 - Special cases

Vertical transition curves for vehicles fitted with the automatic coupler (see *UIC Leaflet 522* (see Bibliography - page 114)).

Angle of inclination for vehicles used on ferries, see:

- *UIC Leaflet 507* (see Bibliography - page 114) for wagons,
- *UIC Leaflet 569* (see Bibliography - page 114) for coaches and vans.

6.1.2 - Determination of maximum heights above the running surface

The value of vertical movements to be taken into consideration, as regards the upper parts of rolling stock where h 3 250 mm, is determined with account being taken of the upward dynamic movements for empty rolling stock in running order without wear.

In this part, the vehicles come close to the reference profile under the influence of:

1. upward oscillations,
2. the vertical component of the quasi-static inclination,
3. transverse movements.

Consequently, the vertical dimensions of the reference profile must be reduced by the values generated by these movements ξ, if they can be calculated, or otherwise by a fixed value of 15 mm per suspension stage. Nevertheless, it must be noted that when the vehicle is subject to quasi-static inclination, the side opposite the inclination rises but at the same time moves away from the reference profile in such a way that no interference is to be feared. Conversely, on the side of the inclination, the vehicle lowers, thus compensating part of the upward movements.

As an approximation, for cant excess or deficiency of 50 mm, this vertical reduction $\Delta V(h)$ of the reference profile for nominal heights greater than h = 3,25 m is expressed as:

$$\Delta V(h) = \zeta - \left\{ \frac{\left[\frac{1}{2}LCR(h) - E_i \text{ oder } a\right] s}{30} \right\}$$

where: $\frac{1}{2}LCR(h)$ represents the half-width of the reference profile,

E_i or E_a, the transverse reductions,

s the vehicle's coefficient of flexibility,

ξ the vehicle resilience (fixed or calculated term).

Example: for a vehicle with a reduction E_i or E_a of 217 mm based on h = 3,25 m, we obtain:

Reductions for cut-away sides on the upper part of the reference profile.

s = 0,3 ; ξ = 30 mm

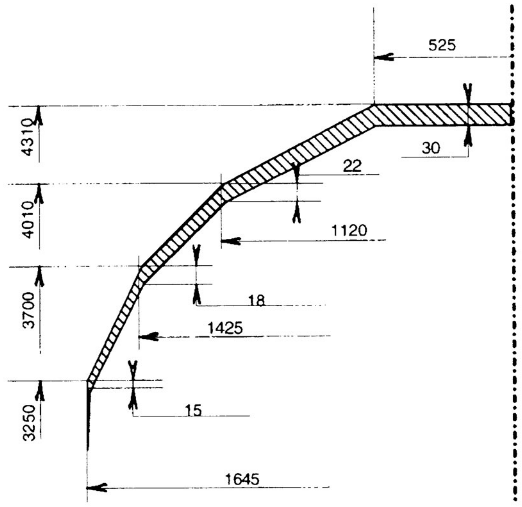


Fig. 17 - Vehicle with 2 suspension stages (dimensions in millimetres)

s = 0,1 ; ξ = 15 mm

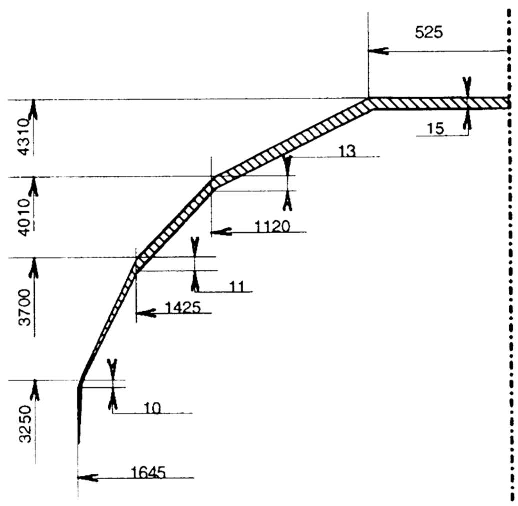


Fig. 18 - Vehicle with 1 suspension stage (dimensions in millimetres)

6.2 - Lateral movements (D)

These movements are the sum of the following movements:

- geometric movements resulting from the vehicle running through curves and straight track (projections, lateral play, etc.), where the vehicle centreline is considered to be perpendicular to the running surface;

- quasi-static movements resulting from the inclination of the suspended parts under the influence of gravity (canted track) and/or centrifugal acceleration (curved track);

- lateral sag of the vehicle body is generally disregarded except for those special types of wagon or heavily-laden wagons for which these values are particularly high.

6.2.1 - Authorised projections S_0 (S)

The S effective projections must not exceed the S_0 values in the table below.

S_0 projection values

Dimensions given in metres

Vehicle types	**Track**	**E_i calculation**		**E_a calculation**	
		Sections between the end axles of vehicles not fitted with bogies or between the pivots of bogie vehicles		**Sections beyond the end axles of vehicles not fitted with bogies or beyond the pivots of bogie vehicle**	
		$h \leq 0{,}400$	$h > 0{,}400$	$h \leq 0{,}400$	$h > 0{,}400$
All powered or trailing vehicles	straight	0,015	0,015	0,015	0,015
Powered vehicles Trailing axle vehicles	on 250 curve	0,025	0,030	0,025	0,030
Bogies taken individually and their associated parts	on 150 curve	$0,025 + \frac{100}{750}$ $= 0,158$	$0,030 + \frac{100}{750}$ $= 0,1633$	$0,025 + \frac{120}{750}$ $= 0,185$	$0,030 + \frac{120}{750}$ $= 0,190$
Trailing bogie stock or equivalent	on 250 curve	0,010	0,015	0,025	0,030
	on 150 curve	$0,010 + \frac{100}{750}$ $= 0,1433$	$0,015 + \frac{100}{750}$ $= 0,1483$	$0,025 + \frac{120}{750}$ $= 0,185$	$0,030 + \frac{120}{750}$ $= 0,190$

NB : On 150 curve, term xi or xa in the reduction formulae (see point 7.1.4 - page 35).

NB : These values have been calculated with the l track gauge which leads to the most restrictive E reduction. This value is L = l max. = 1,465 m in all cases except for the E_i internal reduction for trailing bogie stock or equivalent vehicles for which it is necessary to take l min = 1,435 m. Furthermore, for powered units and railcars with one designated "motor" bogie and one trailer bogie or bogie considered as a "trailer" (see point 7.2.2.1 - page 39), the width of the track considered in the internal reduction E_i formulae is 1,435 m for the trailer bogie and 1,465 m for the motor bogie. However, for the sake of simplicity in calculating reductions graphically the following values may be taken for both bogies: l = 1,435 m on straight track and 1,465 m on a 250 m curve. In this latter case, the width of the vehicle body is penalised at the level of the trailer bogie.

NB : These values do not apply to the reference profile for parts on the roof.

6.2.2 - Vehicle running position on the track and displacement factor (A)

The various vehicle running positions on the track depend on the transverse play of the various parts connecting the vehicle body to the track and on the configuration of the running gear (independent axles, powered bogies, trailer bogies, etc).

It is therefore necessary to consider the various positions which the vehicle may take up on the track so as to take into account any displacement factor A to be applied to certain terms in the fundamental formulae used for calculating the E_i internal and E_a external reductions (see point 7 - page 32).

The displacement factor and the vehicle running position on the track are given in the table below. For the cases of axle configuration not represented in the table, the running position conditions to be taken into account must be the least favourable.

For articulated vehicles, it is recommended to take the running position for conventional 2-bogie vehicles.

Special cases of multiple units and coaches fitted with a reversing cab

For this rolling stock, the bogies are classified according to their μ adhesion factor on starting.

If μ 0,2	the bogie is designated	"motor"
If $0 < \mu < 0,2$	the bogie is considered	"trailer"
If $\mu = 0$	the bogie is	"trailer".

The reduction formulae applicable as a result are given in point 7.2.2 - page 39.

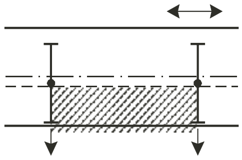
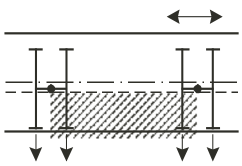
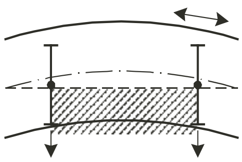
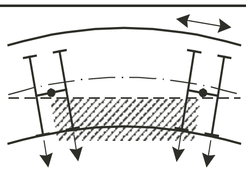
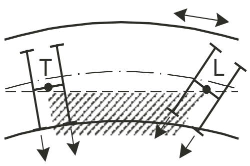
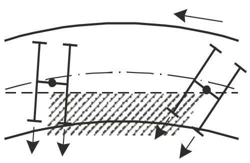
Calculation of international reductions E_i						
	Rolling stock type	Terms to which A factor applies / Running position on the track	$\frac{1{,}465 - d}{2}$	W: On straight track W_∞	W: Depending on curve radius $W_{i(R)}$	$\frac{p^2}{4}$ (on curve)
On straight track			Displacement factor A			
1	2-axle vehicles or bogies taken individually and associated parts		1			
2	2-bogie vehicles except those below		1	1		
3	Vehicles with one designated "motor" bogie leading and one trailer bogie leading or considered as such		1	W_∞: $\frac{a - n_\mu}{a}$; W'_∞: $\frac{n_\mu}{a}$		
On curve			Displacement factor A			
4	2-axle vehicles or bogies taken individually and associated parts		The running positions and displacement factors for curves are the same as for straight track			
5	Vehicles with 2 motor bogies or designated as such		1		1	1
6	Vehicles with one designated "motor" bogie and one trailer bogie or considered as such		$\frac{a - n_\mu}{a}$		$W_{i(R)}$: $\frac{a - n_\mu}{a}$; $W'_{i(R)}$: $\frac{n_\mu}{a}$	$\frac{p^2}{4}$: $\frac{a - n_\mu}{a}$; $\frac{p'^2}{4}$: $\frac{n_\mu}{a}$
7	Vehicles with 2 trailer bogies or considered as such (1) special case for wagons		0 0 (1)		1 1 (1)	1 1 (1)

Fig. 19 - Displacement factor and vehicle position on the track

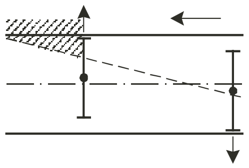
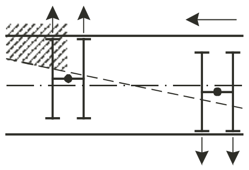
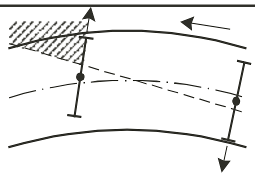
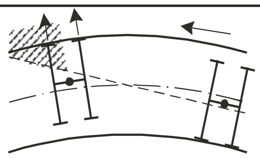
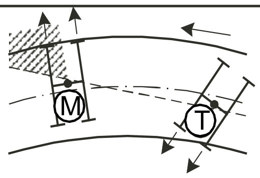
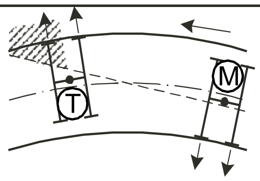
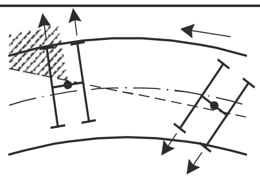
	Calculation of international reductions E_a						
	Terms to which A factor applies / Running position on the track	$\frac{1{,}465 - d}{2}$	q	W: On straight track W_∞	W: Depending on curve radius $W_{i\,(R)}$	W: Depending on curve radius $W_{a\,(R)}$	$\frac{p^2}{4}$ (on curve)
	On straight track	Displacement factor A					
1		$\frac{2n+a}{a}$	$\frac{2n+a}{a}$				
2		$\frac{2n+a}{a}$	$\frac{2n+a}{a}$	$\frac{2n+a}{a}$			
3		$\frac{2n+a}{a}$	$\frac{2n+a}{a}$	W_∞ | W'_∞ *Leading motor bogie* $\frac{n+a}{a}$ | $\frac{n}{a}$ *Leading trailer bogie* $\frac{n}{a}$ | $\frac{n+a}{a}$			
	On curve	Displacement factor A					
4		The running positions and displacement factors for curves are the same as for straight track					
5		$\frac{2n+a}{a}$	$\frac{2n+a}{a}$		$\frac{n}{a}$	$\frac{n+a}{a}$	1
6		$\frac{n+a}{a}$	$\frac{2n+a}{a}$		$W_{i\,(R)}$ | $W'_{i\,(R)}$ | $\frac{n}{a}$	$W_{a\,(R)}$ | $W'_{a\,(R)}$ $\frac{n+a}{a}$ |	$\frac{p^2}{4}$ | $\frac{p'^2}{4}$ $\frac{n+a}{a}$ | $\frac{n}{a}$
		$\frac{2n+a}{a}$	$\frac{2n+a}{a}$		$\frac{n}{a}$ |	| $\frac{n+a}{a}$	$\frac{n}{a}$ | $\frac{n+a}{a}$
7		$\frac{n+a}{a}$ $\frac{n+a}{a}$ (1)	$\frac{2n+a}{a}$ $\frac{2n+a}{a}$ (1)	 $\frac{2n+a}{a}$ (1)	$\frac{n}{a}$	$\frac{n+a}{a}$	1 1 (1)

Fig. 19 - Displacement factor and vehicle position on the track (cont'd)

6.2.3 - Quasi-static movement (z)

These movements are taken into account when calculating E_i or E_a, depending on the flexibility coefficient s, the height h above the running surface of the point under consideration and the height of the roll centre h_c. Remarks on these movements are given in *UIC Leaflet 505-5*.

The Way and Works Department shall define the lineside clearance gauge for h > 0,5 m, when the effective cant excess or deficiency of the track is greater than 0,05 m calculating in conventional manner the extra quasi-static inclination for rolling stock with a coefficient of flexibility of 0,4 and a roll centre height of 0,5 m.

The Rolling Stock Department shall determine E_i and E_a taking into account:

- a cant excess or deficiency of 0,05 m,
- where appropriate a cant excess or deficiency of 0,2 m, when the respective values of s and h_c lead to the gauge defined by the Way and Works Department being exceeded (see figure below and point 7.1.3 - page 33).

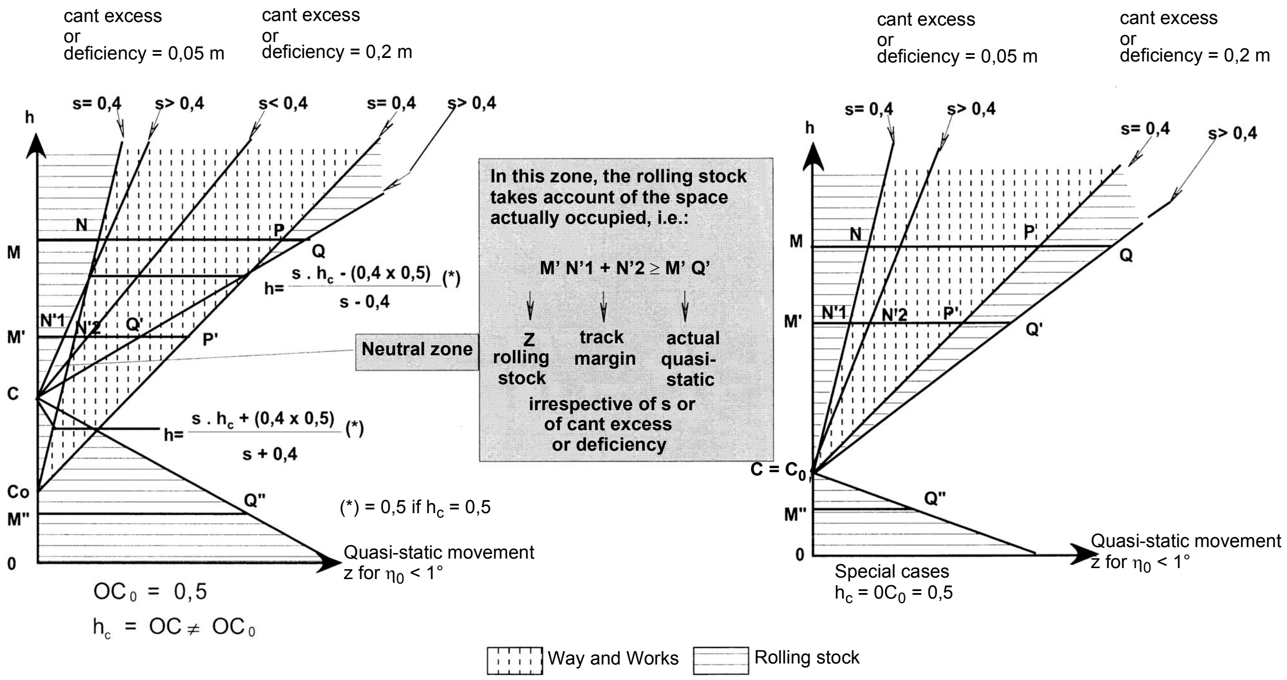


Fig. 20 -

Straight line	Equation	From the equations opposite, infer the lengths of the segments below, the values of which also appear in the "special cases" in point 7.1.3 - page 33 :
CoN	$z = s \cdot 0,05 \left\lvert \frac{h - h_c}{1,5} \right\rvert$	Cant excess or deficiency = 0,05 m $\overline{M'N'_1} = s \cdot 0,05 \frac{h - h_c}{1,5} = \frac{s}{30} \lvert h - h_c \rvert$ Cant excess or deficiency = 0,2 m
CN'1	$z = s \cdot 0,05 \left\lvert \frac{h - h_c}{1,5} \right\rvert$	$\overline{MQ}$ or $\overline{M''Q''} = \left(\frac{s}{30} + \frac{s}{10}\right) \lvert h - h_c \rvert = \frac{4s}{30} \lvert h - h_c \rvert$
CoP	$z = 0,4 \cdot 0,2 \left\lvert \frac{h - 0,5}{1,5} \right\rvert$	$\overline{NP} = 0,4(0,2 - 0,05) \frac{h - 0,5}{1,5} = 0,04(h - 0,5)$
CQ CQ'' }	$z = s \cdot 0,2 \left\lvert \frac{h - h_c}{1,5} \right\rvert = \frac{4s}{30} \lvert h - h_c \rvert$	

(in the above formulae, dimensions are given in metres).

- the influence, beyond 1°, of the asymmetry resulting from design and adjustment (see influence of transom play for wagons fitted with bogies in point 7.1.3.2 - page 34) and from any unevenness in the distribution of the normal load. The influence of asymmetry less than 1° is taken into account in the lineside clearance gauge, as are the lateral oscillations created randomly by causes inherent both to the rolling stock and track (for resonance phenomena in particular).

7 - Determination of reductions by calculation

Reductions E_i and E_a are determined on the basis of the following fundamental relation:

Reduction E_i or E_a = Movement D_i or D_a - Projection S_0

Internal reductions

$$E_i = \frac{an_i - n_i^2 + \frac{p^2}{4}(A)}{2R} + \frac{1,465 - d}{2}(A) + q + w(A) + z + x_i - S_0$$

and external reductions

$$E_a = \frac{an_a + n_a^2 - \frac{p^2}{4}(A)}{2R} + \frac{1,465 - d}{2}(A) + q(A) + w(A) + z + x_a - S_0$$

In these formulae:

- A, displacement factor, describes the position of the axles on the track. Values for A are given in point 6.2.2 - page 27;
- D_i or D_a is the sum of the movements defined in point 7.1;
- S_0 is the maximum projection defined in point 6.2.1 - page 26;
- x_i and x_a are special terms for the calculation for vehicles with very large wheelbase, defined in point 7.1.4 - page 35.

7.1 - Terms taken into account in calculating movements (D)

In view of the particular features of each type of vehicle, additional terms are necessary and some parameters may alter the following terms:

7.1.1 - Terms concerning the running position of the vehicle on a curve (geometric overthrow)

$\frac{1}{2R}\left(an_i - n_i^2 + \frac{p^2}{4}\right) =$ Geometric overthrow of a given section towards the inside of a curve of radius R (problem of vehicle body sections located on inside of bogie pivots or of axles).

$\frac{1}{2R}\left(an_a + n_a^2 - \frac{p^2}{4}\right) =$ Geometric overthrow of a given section towards the outside of a curve of radius R (problem of vehicle body sections located on outside of bogie pivots or of axles).

NB : For special vehicles with particular bogie configurations, these formulae do not apply and the graphic method is recommended (Appendix B).

7.1.2 - Group of terms concerning lateral play

The value of all these plays is measured level with the axles or pivots, with all parts at wear limit.

(The vehicle running positions on the track, as shown in point 6.2.2 - page 27, enable the play to be taken into account in the formulae and the value of the displacement coefficient applicable to be determined, in order to calculate their effect on the section considered).

$\boxed{\frac{1,465 - d}{2}}$ = play of the axle in the track

$\boxed{q}$ = play between axles and underframe and/or between axle and vehicle body

In other words, the lateral movement between axle-boxes and journals, plus that between the underframe and axle-boxes from the central position and on each side.

$\boxed{w}$ = play of bogie pivots or bolsters

This is the possible lateral movement of the bogie pivots or bolsters, from the central position and on each side, or, for vehicles without a pivot, the possible lateral movement of the vehicle body in relation to the bogie frame, from the central position and depending on the curve radius and the direction of movement.

If the value of w varies with the curve radius:

- $w_{i(R)}$ means that w is considered for radius R and the inside of the curve;
- $w_{a(R)}$ means that w is considered for radius R and the outside of the curve;
- w_{∞} means that w is considered for straight track.

According to the specific features of each type of vehicle, this term may be notated as shown in point 6.2.2: w', w_i, w'_i, etc. It can also be equal to the sum of some of these notations: $w_i + w_a$, etc., each of these terms being potentially influenced by the corresponding displacement factor.

7.1.3 - Term concerning vehicle inclination on its suspension and its asymmetry when this is greater than 1° (quasi-static movements)

Point 6.2.3 - page 30 gives a diagram showing the different terms going to make up z.

z = deviation from the track central position.

This deviation is equal to the sum of 2 terms:

$\frac{s}{30}\lvert h - h_c \rvert$	term concerning the inclination due to the suspension (lateral movement due to the flexibility of the suspension, under the influence of cant excess or deficiency of 0,05 m);
$\tan[\eta_0 - 1°]_{>0} \lvert h - h_c \rvert$	term concerning the asymmetry (lateral movement due to that part of the asymmetry exceeding 1°).

This sum may be increased by:

$\left[\frac{s}{10}|h - h_c| - 0,04[h - 0,5]_{>0}\right]_{>0}$ term integrating cant excess or deficiency of 0,2 m and applicable under the conditions defined in point 6.2.3 - page 30.

For sprung parts located at height h, the above terms give, in the formulae, a value of:

$$z = \left[\frac{s}{30} + \tan[\eta_0 - 1°]_{>0}\right]|h - h_c| + \left[\frac{s}{10}|h - h_c| - 0,04[h - 0,5]_{>0}\right]_{>0}$$

NB : h_c may be measured or calculated. In the case of the extreme vehicle body/bogie position for calculating the maximum construction gauge, this height h_c must be taken level with one of the vehicle body/bogie stops concerned (central or rotational stop); when this parameter cannot be measured or calculated, the fixed value h_c = 0,5 m should be used.

7.1.3.1 - Special cases

- when	$h > h_c$ and 0,5 m $s \leq 0,4$ $\eta_0 \leq 1°$	$z = \frac{s}{30}(h - h_c)$
- when	h < 0,5 m $\eta_0 \leq 1°$ and for any value of h_c and s	$z = \frac{4s}{30}\|h_c - h\|$
- when $h = h_c$		z = 0

For unsprung parts, z = 0.

7.1.3.2 - Influence of transom play for wagons fitted with bogies

- For wagons fitted with bogies whose transom play is less than or equal to 5 mm, the 1° angle of asymmetry is considered to cover this play and the formula η_0 = 1° is conventionally used.

  The term "z" taking into account transom play less than or equal to 5 mm is given as:

  $$z = \left[\frac{s}{30}\right]|h - h_c| + \left[\frac{s}{10}|h - h_c| - 0,04[h - 0,5]_{>0}\right]_{>0}$$

  where the special cases under point 7.1.3.1 - page 34 must be taken into consideration.

- For wagons fitted with bogies whose transom play is greater than 5 mm, account should be taken of the additional inclination α of the vehicle body, expressed as follows:

  $$\alpha = \arctan\frac{J - 0,005}{b_G}$$

This additional inclination α leads to depression of the suspension which, when multiplied by the coefficient of flexibility s, is given as a rotation of the vehicle body: αs

where s : coefficient of flexibility

The total additional inclination may be expressed as:
$\alpha\,(1 + s)$

Term z taking account of transom play greater than 5 mm becomes:

$$z = \left\{\frac{s}{30} + \tan\left[\eta'_0 + \left(\arctan\frac{(J - 0,005) > 0}{b_G}\right)(1 + s) - 1°\right]_{>0}\right\}|h - h_c| + \left[\frac{s}{10}|h - h_c| - 0,04[h - 0,5]_{>0}\right]_{>0}$$

NB : $[]_{>0}$ means that the expression between the square brackets should be taken as its own value if that value is positive or as 0 if that value is negative. η'_0 = asymmetry in the case of 5 mm transom play.

7.1.4 - Special terms

Terms representing the correction to be made to certain formulae in point 7.2 - page 35 for the parts distant from the pivots of vehicles with a very large wheelbase and/or very large overhang in order to limit space requirement in curves of radius between 250 m and 150 m: x_i or x_a

It will be noted that:

- x_i only enters the formulae if $\frac{a^2 + p^2}{4}$ > 100, i.e. an approximate value for a of 20 m;
- x_a only applies if $an_a + n_a^2 - \frac{p^2}{4} > 120$ (exceptional case).

Special condition for x_a

The term x_a is not used in the calculation of reductions applicable to vehicles whose overhang respects the conditions laid down for the automatic coupler (see *UIC Leaflet 522*).

7.2 - Reduction formulae

Reduction formulae applicable to:

- powered vehicles (locomotives, power cars) (see point 7.2.1 - page 36)
- multiple units (see point 7.2.2 - page 39)
- powered vehicles fitted with pantographs (see point 7.2.3 - page 41)
- coaches (see point 7.2.4 - page 44)
- wagons (see point 7.2.5 - page 48)

NB : The following formulae may also be used for the construction gauge of articulated trains of which the axles or the bogie centres coincide with the axles of the articulation. For other designs of articulated trains, the formulae may be adapted to the real geometric conditions. For tilting vehicles, see Appendix F.

7.2.1 - Reduction formulae applicable to powered vehicles (dimensions in metres)

Powered vehicles for which play w is independent of the track position or varies linearly depending on the curvature

Internal reductions E_i (where $n = n_i$)

Sections **between** the end axles of powered vehicles not fitted with bogies or between the pivots of powered bogie vehicles.

$$\text{when} \quad an - n^2 + \frac{p^2}{4} - 500(w_\infty - w_{i(250)}) \leq \begin{vmatrix} 5 & (1) \\ 7,5 & (2) \end{vmatrix}$$

position on straight track preponderant :

$$E_i = \frac{1{,}465 - d}{2} + q + w_\infty + z - 0{,}015 \qquad (101)$$

$$\text{when} \quad an - n^2 + \frac{p^2}{4} - 500(w_\infty - w_{i(250)}) > \begin{vmatrix} 5 & (1) \\ 7,5 & (2) \end{vmatrix}$$

position on curve preponderant :

$$E_i = \frac{an - n^2 + \frac{p^2}{4}}{500} + \frac{1{,}465 - d}{2} + q + w_{i(250)} + z + [x_i]_{>0} - \begin{vmatrix} 0,025 & (1) \\ 0,030 & (2) \end{vmatrix} \qquad (102)$$

$$\text{with} \quad x_i = \frac{1}{750}\left(an - n^2 + \frac{p^2}{4} - 100\right) + w_{i(150)} - w_{i(250)} \qquad (103)$$

(1) This value applies to those parts no more than 0,400 m above the running surface and those which may descend below this level as a result of wear and vertical movements assessed as per point 6.1 - page 17.

(2) This value applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

External reductions E_a (where $n = n_a$)

Sections **beyond** the end axles of powered vehicles not fitted with bogies or the pivots of powered bogie vehicles.

$$\text{when } an + n^2 - \frac{p^2}{4} - 500\left[(w_\infty - w_{i(250)})\frac{n}{a} + (w_\infty - w_{a(250)})\frac{n+a}{a}\right] \le \begin{vmatrix} 5 & (1) \\ 7,5 & (2) \end{vmatrix}$$

position on straight track preponderant :

$$E_a = \left(\frac{1{,}465 - d}{2} + q + w_\infty\right)\frac{2n+a}{a} + z - 0{,}015 \qquad (106)$$

$$\text{when } an + n^2 - \frac{p^2}{4} - 500\left[(w_\infty - w_{i(250)})\frac{n}{a} + (w_\infty - w_{a(250)})\frac{n+a}{a}\right] > \begin{vmatrix} 5 & (1) \\ 7,5 & (2) \end{vmatrix}$$

position on curve preponderant :

$$E_a = \frac{an + n^2 - \frac{p^2}{4}}{500} + \left(\frac{1{,}465 - d}{2} + q\right)\frac{2n+a}{a} + w_{i(250)}\frac{n}{a} + w_{a(250)}\frac{n+a}{a} + z + [x_a]_{>0} - \begin{vmatrix} 0,025 \\ 0,030 \end{vmatrix} \qquad (107)$$

(1)

(2)

$$\text{with } x_a = \frac{1}{750}\left(an + n^2 - \frac{p^2}{4} - 120\right) + (w_{i(150)} - w_{i(250)})\frac{n}{a} + (w_{a(150)} - w_{a(250)})\frac{n+a}{a} \qquad (108)$$

(1) This value applies to those parts no more than 0,400 m above the running surface and those which may descend below this level as a result of wear and vertical movements assessed as per point 6.1 - page 17.

(2) This value applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

Powered units for which play w varies non-linearly depending on the curvature (exceptional case)

- Other than curves of radius R 150 and 250 m for which formulae (104), (105), (109) and (110) are identical to formulae (101), (102), (106) and (107) respectively, formulae (104), (105), (109) and (110) must be applied for the value of R for which the variation of w as a function of $\frac{1}{R}$ shows a discontinuity; in other words, the value of R as from which the variable stops come into play.

- For each section of the powered unit, the reduction to be taken is the greatest of those obtained from the application of the formulae, in which the value of R to be used is that which gives the highest value for the part between square brackets.

Internal reductions E_i (where $n = n_i$)

when $\infty > R \; 250$

$$E_i = \left[\frac{an - n^2 + \frac{p^2}{4} - \begin{vmatrix} 5 & (1) \\ 7,5 & (2) \end{vmatrix}}{2R} + w_{i(R)} \right] + \frac{1,465 - d}{2} + q + z - 0,015 \qquad (104)$$

when $250 > R \; 150$

$$E_i = \left[\frac{an - n^2 + \frac{p^2}{4} - 100}{2R} + w_{i(R)} \right] + \frac{1,465 - d}{2} + q + z + \begin{vmatrix} 0,175 & (1) \\ 0,170 & (2) \end{vmatrix} \qquad (105)^{(3)}$$

External reductions E_a (where $n = n_a$)

when $\infty > R \; 250$

$$E_a = \left[\frac{an + n^2 - \frac{p^2}{4} - \begin{vmatrix} 5 & (1) \\ 7,5 & (2) \end{vmatrix}}{2R} + w_{i(R)} \frac{n}{a} + w_{a(R)} \frac{n + a}{a} \right] + \left(\frac{1,465 - d}{2} + q \right) \frac{2n + a}{a} + z - 0,015 \qquad (109)$$

when $250 > R \; 150$

$$E_a = \left[\frac{an + n^2 - \frac{p^2}{4} - 120}{2R} + w_{i(R)} \frac{n}{a} + w_{a(R)} \frac{n + a}{a} \right] + \left(\frac{1,465 - d}{2} + q \right) \frac{2n + a}{a} + z + \begin{vmatrix} 0,215 & (1) \\ 0,210 & (2) \end{vmatrix} \qquad (110)^{(3)}$$

(1) This value applies to those parts no more than 0,400 m above the running surface and those which may descend below this level as a result of wear and vertical movements assessed as per point 6.1 - page 17.

(2) This value applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

(3) In practice, formulae (105) and (110) are without effect, since the variation in play w, resulting from the variable stops taking effect, begins only when R > 250.

7.2.2 - Reduction formulae applicable to multiple units (dimensions in metres)

Multiple units fitted with:	Value of μ for each bogie	Running position (point 6.2.2 - page 27)	Reduction formulae
two motor bogies	μ 0,2	cases 2 and 5, Fig.19 - page 28	see point 7.2.1 - page 36
two bogies considered as "trailers" one bogie considered as a "trailer" bogie and one trailer bogie	$0 < \mu < 0,2$ $0 < \mu < 0,2$ $\mu = 0$	cases 2 and 7, Fig. 19	see point 7.2.4 - page 44
one motor bogie and one trailer bogie or considered as a "trailer" bogie	μ 0,2 $\mu = 0$ $0 < \mu < 0,2$	cases 3 and 6, Fig. 19	see point 7.2.2 or point 7.2.1 - page 36[a]

a. The results of the formulae in points 7.2.1 and 7.2.2 are very similar; as a result, the formulae in point 7.2.1 are generally employed, those of point 7.2.2 being reserved for cases where the increased reduction obtained on the half-width of the maximum construction gauge is particularly significant (0 to 12,5 mm according to the vehicle section considered).

7.2.2.1 - For multiple units with one motor bogie and one trailer bogie (see above table)

Internal reductions E_i

NB : The reduction to apply for the same value of n is the greatest resulting from the formulae: - (101 a) or (102 a) and (103 a); - (106 a) or (107 a) and (108 a); - (106 b) or (107 b) and (108 b).

Sections **between** bogie pivots

$$E_i = \frac{1{,}465 - d}{2} + q + w_{\infty}\frac{a - n_{\mu}}{a} + w'_{\infty}\frac{n_{\mu}}{a} + z - 0{,}015 \qquad (101a)$$

(102a)

$$E_i = \frac{an_{\mu} - n_{\mu}^2 + \frac{p^2}{4} \cdot \frac{a - n_{\mu}}{a} + \frac{p'^2}{4} \cdot \frac{n_{\mu}}{a}}{500} + \frac{1{,}465 - d}{2} \cdot \frac{a - n_{\mu}}{a} + q + w_{i(250)}\frac{a - n_{\mu}}{a} + w'_{i(250)}\frac{n_{\mu}}{a} + z + [x_i]_{>0} - \left| \begin{matrix} 0{,}010\ (1) \\ 0{,}015\ (2) \end{matrix} \right. - 0{,}015\frac{a - n_{\mu}}{a}$$

$$\text{with } x_i = \frac{1}{750}\left[an_{\mu} - n_{\mu}^2 + \frac{p^2}{4} \cdot \frac{a - n_{\mu}}{a} + \frac{p'^2}{4} \cdot \frac{n_{\mu}}{a} - 100\right] + (w_{i(150)} - w_{i(250)})\frac{a - n_{\mu}}{a} + (w'_{i(150)} - w'_{i(250)})\frac{n_{\mu}}{a} \qquad (103a)$$

(1) This value applies to those parts no more than 0,400 m above the running surface and those which may descend below this level as a result of wear and vertical movements assessed as per point 6.1 - page 17.

(2) This value applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

External reductions E_a motor bogie side (at the front in the running direction)

NB : The reduction to apply for the same value of n is the greatest resulting from the formulae: - (101 a) or (102 a) and (103 a); - (106 a) or (107 a) and (108 a); - (106 b) or (107 b) and (108 b).

Sections **beyond** the bogie pivots (where $n = n_a$)

$$E_a = \left[\frac{1{,}465 - d}{2} + q\right]\frac{2n + a}{a} + w_\infty \frac{n + a}{a} + w'_\infty \frac{n}{a} + z - 0{,}015 \qquad (106a)$$

(107a)

$$E_a = \frac{an + n^2 - \frac{p^2}{4} \cdot \frac{n + a}{a} + \frac{p'^2}{4} \cdot \frac{n}{a}}{500} + \frac{1{,}465 - d}{2} \cdot \frac{n + a}{a} + q\frac{2n + a}{a} + w'_{i(250)}\frac{n}{a} + w_{a(250)}\frac{n + a}{a} + z + [x_a]_{>0} - \begin{vmatrix} 0{,}025 \\ 0{,}030 \end{vmatrix} \begin{matrix} (1) \\ (2) \end{matrix}$$

$$\text{with} \quad x_a = \frac{1}{750}\left[an + n^2 - \frac{p^2}{4} \cdot \frac{n + a}{a} + \frac{p'^2}{4} \cdot \frac{n}{a} - 120\right] + (w'_{i(150)} - w'_{i(250)})\frac{n}{a} + (w_{a(150)} - w_{a(250)})\frac{n + a}{a} \qquad (108a)$$

(1) This value applies to those parts no more than 0,400 m above the running surface and those which may descend below this level as a result of wear and vertical movements assessed as per point 6.1 - page 17.

(2) This value applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

External reductions E_a trailer bogie side (at the front in the running direction)

NB : The reduction to apply for the same value of n is the greatest resulting from the formulae: - (101 a) or (102 a) and (103 a); - (106 a) or (107 a) and (108 a); - (106 b) or (107 b) and (108 b).

Sections **beyond** the bogie pivots (where $n = n_a$)

$$E_a = \left[\frac{1{,}465 - d}{2} + q\right]\frac{2n + a}{a} + w_\infty \frac{n}{a} + w'_\infty \frac{n + a}{a} + z - 0{,}015 \qquad (106b)$$

(107b)

$$E_a = \frac{an + n^2 + \frac{p^2}{4} \cdot \frac{n}{a} - \frac{p'^2}{4} \cdot \frac{n + a}{a}}{500} + \left(\frac{1{,}465 - d}{2} + q\right)\frac{2n + a}{a} + w_{i(250)}\frac{n}{a} + w'_{a(250)}\frac{n + a}{a} + z + [x_a]_{>0} - \begin{vmatrix} 0{,}025 \\ 0{,}030 \end{vmatrix} \begin{matrix} (1) \\ (2) \end{matrix}$$

$$\text{with} \quad x_a = \frac{1}{750}\left[an + n^2 + \frac{p^2}{4} \cdot \frac{n}{a} - \frac{p'^2}{4} \cdot \frac{n + a}{a} - 120\right] + (w_{i(150)} - w_{i(250)})\frac{n}{a} + (w'_{a(150)} - w'_{a(250)})\frac{n + a}{a} \qquad (108b)$$

(1) This value applies to those parts no more than 0,400 m above the running surface and those which may descend below this level as a result of wear and vertical movements assessed as per point 6.1 - page 17.

(2) This value applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

7.2.2.2 - Pantographs

The limit position for pantographs on a railcar with one motor bogie and one trailer bogie shall be determined as if both bogies were identical to the one above which the pantograph is placed.

7.2.3 - Pantograph gauge verification and other live parts on roof

7.2.3.1 - Pantograph in current collection position

Vehicles fitted with pantographs must respect the limit position resulting from the reference profile given in point 5.4 figure 10 - see page 16.

The movements of the pantographs must remain smaller than those accorded by reference; for that the quantities E'_i and E'_a (pantographs raised to 6.5m above the surface) and E''_i and E''_a (pantographs raised to 5m above the running surface) must be negative or nihil.

The reference values and the method are given by *UIC Leaflet 505-5* (see Bibliography - page 114).

The characteristics of pantographs for standard gauge powered units are defined by *UIC Leaflet 608*.

7.2.3.1.1 - General requirements

1. Vehicles having the transverse play linearly variable with R.
   Two cases had to be analysed: the position of a vehicle running on a curve of minimum radius R = 150m, and the position coming from straight line, R = ∞.

2. Vehicles having the transverse play non linearly variable with R.
   The vehicle must be considered in straight line and in a curve R=150m, and then it should be considered for values of R for which the variation of w as a function of $\frac{1}{R}$ presents a discontinuity (or more than one).

If the play varies according to the track radius, the value w_{iR} at pivot level (real or theoretical) shall be taken for j'_i, as for j'_a the value w_{aR} and its corresponding w_{iR}.

7.2.3.1.2 - Pantograph located between bogie pivot (or end axles): vehicle in stationary condition in canted track

Formulas for vehicles with s ≤ 0.225

$$j'_i = q + w_{iR} - 0,0375$$

$$z' = \frac{0,066.(6,5 - h_c)}{1,5} \cdot s + \sqrt{t^2 + \tau^2 + [\theta(6,5 - h_c)]^2} - 0,1175$$

$$z''= \frac{0{,}066.(5 - h_c)}{1{,}5} \cdot s + \sqrt{\left[t \cdot \frac{5 - h_t}{6{,}5 - h_t}\right]^2 + \tau^2 + [\theta.(5 - h_c)]^2} - 0{,}0925$$

(111)

$$E'_i = \left[\frac{a.n_i - n_i^2 + \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + j'_i + z'$$

If $E'_i \leq 0$ the pantograph remain inside the gauge in its upper collecting point

(112)

$$E''_i = \left[\frac{a.n_i - n_i^2 + \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + j'_i + z''$$

If $E''_i \leq 0$ the pantograph remain inside the gauge in its lower collecting point

Formulas for vehicles with s > 0,225

$j'_i = q + w_{iR} - 0{,}0375$

$$z'= \frac{0{,}2.(6{,}5 - h_c)}{1{,}5} \cdot s + \sqrt{t^2 + \tau^2 + [\theta(6,5 - h_c)]^2} - 0{,}2375$$

$$z''= \frac{0{,}2.(5 - h_c)}{1{,}5} \cdot s + \sqrt{\left[t.\frac{5 - h_t}{6{,}5 - h_t}\right]^2 + \tau^2 + [\theta.(5 - h_c)]^2} - 0{,}1825$$

(113)

$$E'_i = \left[\frac{a.n_i - n_i^2 + \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + j'_i + z'$$

If $E'_i \leq 0$ the pantograph remain inside the gauge in its upper collecting point

(114)

$$E''_i = \left[\frac{a.n_i - n_i^2 + \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + j'_i + z''$$

If $E''_i \leq 0$ the pantograph remain inside the gauge in its upper collecting point

7.2.3.1.3 - Pantograph located beyond bogie pivots (or end axles): vehicle in running conditions on tracks with can't deficiency

Formulas for vehicles with s ≤ 0,225

$$j'_a = q.\frac{2.n_a + a}{a} + w_{aR}\cdot\frac{n_a + a}{a} + w_{iR}\cdot\frac{n_a}{a} - 0{,}0375$$

$$z' = \frac{0{,}066.(6{,}5 - h_c)}{1{,}5}\cdot s + \sqrt{t^2 + \tau^2 + [\theta(6,5 - h_c)]^2} - 0{,}1175$$

$$z'' = \frac{0{,}066.(5 - h_c)}{1{,}5}\cdot s + \sqrt{\left[t.\frac{5 - h_t}{6{,}5 - h_t}\right]^2 + \tau^2 + [\theta.(5 - h_c)]^2} - 0{,}0925$$

$$E'_a = \left[\frac{a.n_a + n_a^2 - \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + \frac{1{,}465 - d}{2}.\frac{2n_a}{a} + j'_a + z' \qquad (123)$$

If $E'_a \leq 0$ the pantograph remain inside the gauge in its upper collecting point

$$E''_a = \left[\frac{a.n_a + n_a^2 - \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + \frac{1{,}465 - d}{2}.\frac{2n_a}{a} + j'_a + z'' \qquad (124)$$

If $E''_a \leq 0$ the pantograph remain inside the gauge in its lower collecting point

Formulas for vehicles having s > 0,225

$$j'_a = q.\frac{2.n_a + a}{a} + w_{aR}\cdot\frac{n_a + a}{a} + w_{iR}\cdot\frac{n}{a} - 0{,}0375$$

$$z' = \frac{0{,}2.(6{,}5 - h_c)}{1{,}5}\cdot s + \sqrt{t^2 + \tau^2 + [\theta(6,5 - h_c)]^2} - 0{,}2375$$

$$z'' = \frac{0{,}2.(5 - h_c)}{1{,}5}\cdot s + \sqrt{\left[t.\frac{5 - h_t}{6{,}5 - h_t}\right]^2 + \tau^2 + [\theta.(5 - h_c)]^2} - 0{,}1825$$

$$E'_a = \left[\frac{a.n_a + n_a^2 - \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + \frac{1{,}465 - d}{2}.\frac{2n_a}{a} + j'_a + z' \qquad (125)$$

If $E'_a \leq 0$ the pantograph remain inside the gauge in its upper collecting point

$$E''_a = \left[\frac{a.n_a + n_a^2 - \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + \frac{1{,}465 - d}{2} \cdot \frac{2n_a}{a} + j'_a + z'' \qquad (126)$$

If $E''_a \leq 0$ the pantograph remain inside the gauge in its lower collecting point

7.2.3.2 - Pantograph in lowered position

Subject, if necessary, to the conditions laid down in point 7.2.3.3 - page 44 below, the lowered pantograph must fall entirely within the gauge defined in points 5.4 - page 16 (taking insulation margins into account) and 7.2.3 - page 41.

7.2.3.3 - Other roof-mounted equipment

On vehicles which may use a 25 kV power supply, all non-insulated parts likely to remain live must be arranged so as to fall well within the 0,170 m reference profile (area shown shaded on figure 10 - page 16 of point 5.4).

7.2.4 - Reduction formulae applicable to coaches and passenger vehicles (dimensions in metres)

7.2.4.1 - For bogie coaches, with the exception of the bogies themselves and their associated parts

Coaches for which the play w is independent of the track position radius or varies linearly depending on the curvature.

Internal reductions E_i

Sections **between** bogie pivots (where $n = n_i$)

$$\text{when } an - n^2 + \frac{p^2}{4} - 500(w_\infty - w_{i(250)}) \leq 250(1{,}465 - d) - \left| \begin{matrix} 2{,}5 & (1) \\ 0 & (2) \end{matrix} \right.$$

position on straight track preponderant :

$$\boxed{E_i = \frac{1{,}465 - d}{2} + q + w_\infty + z - 0{,}015} \qquad (201)$$

$$\text{when } an - n^2 + \frac{p^2}{4} - 500(w_\infty - w_{i(250)}) > 250(1{,}465 - d) - \left| \begin{matrix} 2{,}5 & (1) \\ 0 & (2) \end{matrix} \right.$$

position on curve preponderant :

$$\boxed{E_i = \frac{an - n^2 + \frac{p^2}{4}}{500} + q + w_{i(250)} + z + [x_i]_{>0} - \left| \begin{matrix} 0{,}010 \\ 0{,}015 \end{matrix} \right.} \begin{matrix} (1) \\ (2) \end{matrix} \qquad (202)$$

$$\text{with } x_i = \frac{1}{750}\left(an - n^2 + \frac{p^2}{4} - 100\right) + w_{i(150)} - w_{i(250)} \qquad (203)$$

(1) This value applies to those parts no more than 0,400 m above the running surface and to parts which, as a result of wear and vertical movements, may descend below this level, as defined in point 6.1 - page 17.

(2) This value applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

External reductions E_a

Sections **beyond** bogie pivots (where $n = n_a$)

when

$$an + n^2 - \frac{p^2}{4} - 500\left[(w_\infty - w_{i(250)})\frac{n}{a} + (w_\infty - w_{a(250)})\frac{n+a}{a}\right] \leq 250(1{,}465 - d)\frac{n}{a} + \left| \begin{matrix} 5 & (1) \\ 7{,}5 & (2) \end{matrix} \right.$$

position on straight track preponderant :

$$\boxed{E_a = \left(\frac{1{,}465 - d}{2} + q + w_\infty\right)\frac{2n+a}{a} + z - 0{,}015} \qquad (206)$$

when

$$an + n^2 - \frac{p^2}{4} - 500\left[(w_\infty - w_{i(250)})\frac{n}{a} + (w_\infty - w_{a(250)})\frac{n+a}{a}\right] > 250(1{,}465 - d)\frac{n}{a} + \left| \begin{matrix} 5 & (1) \\ 7{,}5 & (2) \end{matrix} \right.$$

position on curve preponderant :

$$\boxed{E_a = \frac{an + n^2 - \frac{p^2}{4}}{500} + \frac{1{,}465 - d}{2} \cdot \frac{n+a}{a} + q\frac{2n+a}{a} + w_{i(250)}\frac{n}{a} + w_{a(250)}\frac{n+a}{a} + z + [x_a]_{>0} - \left| \begin{matrix} 0{,}025 \\ 0{,}030 \end{matrix} \right.} \begin{matrix} (1) \\ (2) \end{matrix} \qquad (207)$$

$$\text{with } x_a = \frac{1}{750}\left(an + n^2 - \frac{p^2}{4} - 120\right) + (w_{i(150)} - w_{i(250)})\frac{n}{a} + (w_{a(150)} - w_{a(250)})\frac{n+a}{a} \qquad (208)$$

(1) This value applies to those parts no more than 0,400 m above the running surface and to parts which, as a result of wear and vertical movements, may descend below this level, as defined in point 6.1 - page 17.

(2) This value applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

Coaches for which the play w varies non-linearly in relation to the curvature

On straight track, the reductions are calculated using formulae 201 and 206.

On curves, the reductions are calculated for R = 150 m and R = 250 m using formulae (204), (205), (209) and (210).

It should be noted that, for a radius of R = 250 m, formulae (204) and (209) are identical to formulae (202) and (207) respectively.

Furthermore, formulae (204), (205) and (209), (210) must be applied for values of R for which the variation of w, as a function of $\frac{1}{R}$ presents a discontinuity, i.e. the value of R from which the variable stops come into play.

For each section of the coach, the reduction to be taken is the greatest of those resulting from the application of the above-mentioned formulae, in which the value of R to be used is that which gives the highest value for the part between square brackets.

Internal reductions E_i (where $n = n_i$)

when $\infty > R \geq 250$

$$E_i = \left[\frac{an - n^2 + \frac{p^2}{4} - \left| \begin{array}{l} 5 \quad (1) \\ 7,5 \ (2) \end{array} \right.}{2R} + w_{i(R)} \right] + q + z \qquad (204)$$

when 250 > R 150

$$E_i = \left[\frac{an - n^2 + \frac{p^2}{4} - 100}{2R} + w_{i(R)} \right] + q + z + \left| \begin{array}{l} 0,190 \ (1) \\ 0,185 \ (2) \end{array} \right. \qquad (205)\ (3)$$

External reductions E_a (where $n = n_a$)

when $\infty > R \geq 250$

$$E_a = \left[\frac{an + n^2 - \frac{p^2}{4} - \left| \begin{array}{l} 5 \quad (1) \\ 7,5 \ (2) \end{array} \right.}{2R} + w_{i(R)} \frac{n}{a} + w_{a(R)} \frac{n+a}{a} \right] + \frac{1,465 - d}{2} \cdot \frac{n+a}{a} + q \frac{2n+a}{a} + z - 0,015 \qquad (209)$$

when $250 > R \geq 150$

$$E_a = \left[\frac{an + n^2 - \frac{p^2}{4} - 120}{2R} + w_{i(R)} \frac{n}{a} + w_{a(R)} \frac{n+a}{a} \right] + \frac{1,465 - d}{2} \cdot \frac{n+a}{a} + q \frac{2n+a}{a} + z + \left| \begin{array}{l} 0,215 \ (1) \\ 0,210 \ (2) \end{array} \right.$$

(210)
(3)

(1) This value applies to those parts no more than 0,400 m above the running surface and to parts which, as a result of wear and vertical movements, may descend below this level, as defined in point 6.1 - page 17.

(2) This value applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

(3) In practice, formulae (205) and (210) are without effect, since the variation in play w, resulting from the variable stops taking effect, begins only when R > 250.

7.2.4.2 - For bogies and their associated parts

The reduction formulae applicable are those given in point 7.2.5, the reference profile remaining that shown in point 5 - page 11. Nonetheless, the distance between the end axles of the bogies is in most cases such that formulae (101) and (106) - mentioned above - are applicable.

7.2.5 - Reduction formulae applicable to wagons (dimension in metres)

7.2.5.1 - For wagons with independent axles and the bogies themselves and their associated parts (w = 0)

For 2-axle wagons, and only for those parts located below 1,17 m above the running surface, term Z in formulae (301) to (307) may be reduced by 0,005 m when (z-0,005) > 0. It shall be considered nil when (z-0,005) ≤ 0.

7.2.5.1.1 - Internal reductions E_i - Sections between the end axles (where n = n_i)

$$\text{when } an - n^2 \leq \left| \begin{array}{ll} 5 & (1) \\ 7,5 & (2) \end{array} \right.$$

position on straight track preponderant: $$E_i = \frac{1,465 - d}{2} + q + z - 0,015 \qquad (301)$$

$$\text{when } an - n^2 > \left| \begin{array}{ll} 5 & (1) \\ 7,5 & (2) \end{array} \right.$$

position on curve preponderant:

$$E_i = \frac{an - n^2}{500} + \frac{1,465 - d}{2} + q + z - \left| \begin{array}{ll} 0,025 & (1) \\ 0,030 & (2) \end{array} \right. \qquad (302)$$

7.2.5.1.2 - External reductions E_a - Sections beyond the end axles (where n = n_a)

$$\text{wenn } an + n^2 \leq \left| \begin{array}{ll} 5 & (1) \\ 7,5 & (2) \end{array} \right.$$

position on straight track preponderant: $$E_a = \left(\frac{1,465 - d}{2} + q\right)\frac{2n + a}{a} + z - 0,015 \qquad (306)$$

$$\text{wenn } an + n^2 > \left| \begin{array}{ll} 5 & (1) \\ 7,5 & (2) \end{array} \right.$$

position on curve preponderant:

$$E_a = \frac{an + n^2}{500} + \left(\frac{1,465 - d}{2} + q\right)\frac{2n + a}{a} + z - \left| \begin{array}{ll} 0,025 & (1) \\ 0,030 & (2) \end{array} \right. \qquad (307)$$

(1) This value is applicable to parts located no more than 0,400 m above the running surface and to parts which may descend below this level as a result of wear and play.

(2) This value is applicable to parts located more than 0,400 m above the running surface, except for those covered in footnote (1) above.

7.2.5.2 - For bogie wagons whose play is considered to be constant, except for the bogies themselves and their associated parts

Special remark for calculation of z

for this type of wagon, see point 7.1.3.2 - page 34

7.2.5.2.1 - Internal reductions E_i - Sections between bogie pivots (where n = n_i)

$$\text{when } an - n^2 + \frac{p^2}{4} \leq 250(1{,}465 - d) - \left| \begin{array}{ll} 2,5 & (1) \\ 0 & (2) \end{array} \right.$$

position on straight track preponderant:

$$\boxed{E_i = \frac{1{,}465 - d}{2} + q + w + z - 0{,}015} \qquad (311)$$

$$\text{when } an - n^2 + \frac{p^2}{4} > 250(1{,}465 - d) - \left| \begin{array}{ll} 2,5 & (1) \\ 0 & (2) \end{array} \right.$$

position on curve preponderant:

$$\boxed{E_i = \frac{an - n^2 + \frac{p^2}{4}}{500} + q + w + z + [x_i]_{>0} - \left| \begin{array}{l} 0{,}010 \\ 0{,}015 \end{array} \right|} \begin{array}{l} (1) \\ (2) \end{array} \qquad (312)$$

$$\text{with} \quad x_i = \frac{1}{750}\left(an - n^2 + \frac{p^2}{4} - 100\right) \qquad (313)$$

7.2.5.2.2 - External reductions E_a - Sections beyond bogie pivots (where n = n_a)

$$\text{when } an + n^2 - \frac{p^2}{4} \leq 250(1{,}465 - d)\frac{n}{a} + \left| \begin{array}{ll} 5 & (1) \\ 7,5 & (2) \end{array} \right.$$

position on straight track preponderant:

$$\boxed{E_a = \left(\frac{1{,}465 - d}{2} + q + w\right)\frac{2n + a}{a} + z - 0{,}015} \qquad (316)$$

$$\text{when } an + n^2 - \frac{p^2}{4} > 250(1{,}465 - d)\frac{n}{a} + \left| \begin{array}{ll} 5 & (1) \\ 7,5 & (2) \end{array} \right.$$

position on curve preponderant:

$$\boxed{E_a = \frac{an + n^2 - \frac{p^2}{4}}{500} + \frac{1{,}465 - d}{2} \cdot \frac{n + a}{a} + (q + w)\frac{2n + a}{a} + z + [x_a]_{>0} - \left| \begin{array}{l} 0{,}025 \\ 0{,}030 \end{array} \right|} \begin{array}{l} (1) \\ (2) \end{array} \qquad (317)$$

$$\text{with} \quad x_a = \frac{1}{750}\left(an + n^2 - \frac{p^2}{4} - 120\right) \qquad (318)$$

(1) This value is applicable to parts located no more than 0,400 m above the running surface and to parts which may descend below this level as a result of wear and play.

(2) This value is applicable to parts located more than 0,400 m above the running surface, except for those covered in footnote (1) above.

Appendix A - Examples of application of the kinematic gauge by calculation

In general terms, the maximum vehicle construction gauge is verified for values of n_i or n_a corresponding to the centre of the vehicle body and the headstocks.

However, all projecting points should be checked, as well as those which, by reason of their position, may be likely to enter the vicinity of the maximum vehicle construction gauge in the section considered.

NB : The values used in the calculations and graphic examples given below are shown as an indication only. For each study, the values given on the official drawings and documents should be taken into account.

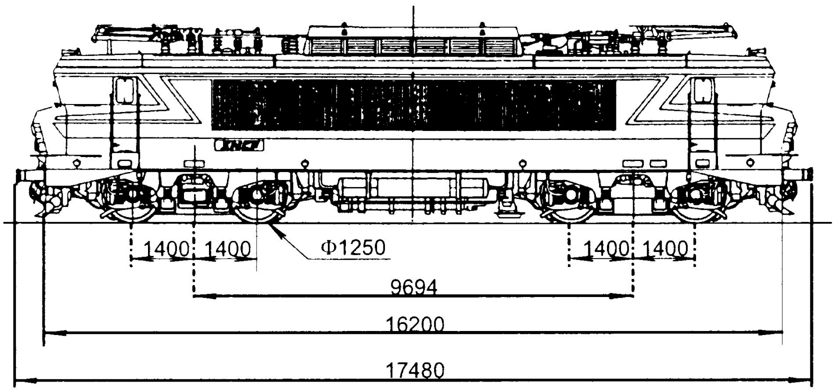
NB : The values of h shown in the tables are the characteristic heights of the reference profile. To obtain the maximum construction gauge from them, they must be corrected by the value of the vertical movements (see point 6.1).

It may be necessary to complete them using other values, taking account of the position of the most projecting parts of the vehicle under consideration.

A.1 - Determination of reductions for locomotives

A.1.1 - Reductions applicable to the vehicle body

The dimensions on the diagram are given in millimetres. Other values are in metres, unless otherwise indicated.



1. Characteristics:

$a = 9{,}694$ $d = 1{,}410$ $p = 2{,}800$ $q = 0{,}006$ $s = 0{,}1$ $h_c = 0{,}500$ $\eta_0 < 1°$ $> 0{,}2$

We take $w_{i(R)} = w_{a(R)} = 0{,}060$ for any value of R: $\frac{a^2 + p^2}{4} < 100 \Rightarrow x_i = 0$ (see point 7.1.4 - page 35).

2. Vehicle body section half-way between pivots:

$$n = \frac{a}{2} = 4,847$$

$an - n^2 + \frac{p^2}{4} = 25,453$; value greater than 7,5. The formula to apply is:

$$E_i = \frac{an - n^2 + \frac{p^2}{4}}{500} + \frac{1,465 - d}{2} + q + w_{i(250)} + z - 0,030 \text{ (for h > 0,400)}$$

$E_i = 0,1144 + z$ with $z = \frac{s}{30}(h - h_c)$

h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	**E_i**	**Available half-width**
4,310	0,0127	0,525	0,127	0,398
4,010	0,0117	1,120	0,126	0,994
3,700	0,0107	1,425	0,125	1,300
3,250	0,0092	1,645	0,124	1,521
1,170	0,0022	1,645 1,620	0,117	1,528 1,503
0,500	0	1,620	0,114	1,506

3. Vehicle body section level with the headstock: n = 3,253

$an + n^2 - \frac{p^2}{4} = 40,157$; value greater than 7,5. The formula to apply is:

$$E_a = \frac{an + n^2 - \frac{p^2}{4}}{500} + \left(\frac{1,465 - d}{2}\right)\frac{2n + a}{a} + w_{i(250)}\frac{n}{a} + w_{a(250)}\frac{n + a}{a} + z + [x_a]_{>0} - 0,030$$

formula valid for h > 0,400, with $x_a = \frac{1}{750}\left(an + n^2 - \frac{p^2}{4} - 120\right) = -0,106$

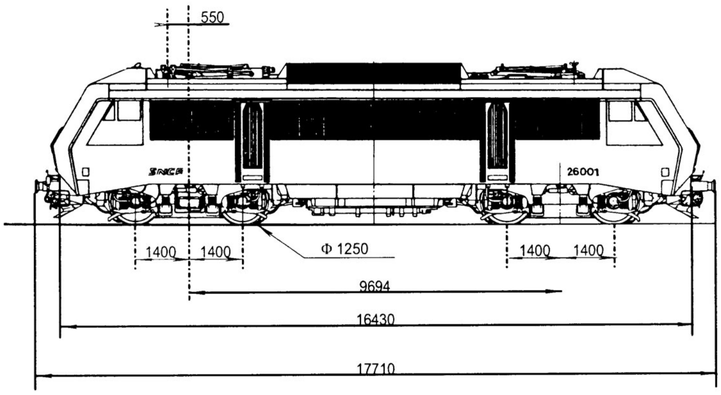
$x_a < 0$ is not considered.

$E_a = 0,2066 + z$ with $z = \frac{s}{30}(h - h_c)$

h (For the values of h, see the second note on first page of Appendix A)	z	Reference profile half-width	E_a	Available half-width
4,310	0,0127	0,525	0,219	0,306
4,010	0,0117	1,120	0,218	0,902
3,700	0,0107	1,425	0,217	1,208
3,250	0,0092	1,645	0,216	1,429
1,170	0,0022	1,645 1,620	0,209	1,436 1,411
0,500	0	1,620	0,207	1,413

A.1.2 - Reductions applicable to the pantograph

The dimensions of the diagram are expressed in millimetres. Other values are expressed in metres, unless otherwise indicated.



1. Characteristics:

$a = 9,694$ $p = 2,800$ $n = 0,550$ $d = 1,410$

$w_\infty = 0,060$ $w_{i250} = 0,060$ $w_{a250} = 0,060$ $q = 0,006$

$h_c = 0,500$ $h_t = 4,005$ $s = 0,2$

$\tau = 0,01$ $\theta = 0,0016$ $t = 0,014$

2. Section beyond bogie pivots: n = 0,550

$$an + n^2 - \frac{p^2}{4} = 3,6742 < 5$$

Position on straight track preponderant.

3. Preliminary calculations:

$$j'_a = q\frac{2n + a}{a} + w_a\frac{n + a}{a} + w_i\frac{n}{a} - 0{,}037$$

$j'_a = 0{,}036$
$s < 0{,}225$

$$z' = \frac{8}{30}(s - 0,225) + (t - 0,03) + (\tau - 0,01) + 6(\theta - 0,005)$$

$h = 6{,}5$
$z' = -0{,}04307$

$$z'' = \frac{6}{30}s + \sqrt{\left(t\frac{h - h_t}{6,5 - h_t}\right)^2 + \tau^2 + [\theta(h - h_c)]^2} - 0,0925$$

$h = 5$
$z'' = -0{,}039$

4. Pantograph raised to h = 6,5 m above running surface:

$$E'_a = j'_a + z' + \frac{1{,}465 - d}{2}\ \frac{2n}{a}$$

$E'_a = -0{,}0039$

5. Pantograph raised to h = 5 m above running surface:

$$E''_a = j'_a + z'' + \frac{1{,}465 - d}{2}\ \frac{2n}{a}$$

$E''_a = 0$

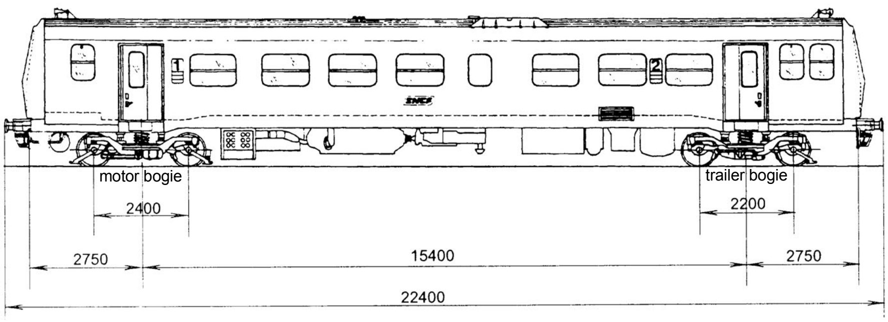
6. Conclusion:

E'_a and E''_a being negative or nil, the pantograph may be fitted 0,550 m beyond the bogie pivot centreline.

A.2 - Determination of reductions for multiple units

Reductions applicable to the vehicle body.

The dimensions on the diagram are expressed in millimetres. Other values are expressed in metres, unless otherwise indicated.



1. Characteristics:

$a = 15{,}400$ $d = 1{,}410$ $q = 0{,}002$ $s = 0{,}35$ $h_c = 0{,}500$

$\eta_0 < 1°$ $\mu > 0{,}2$ motor bogie $\mu = 0$ trailer bogie

$p = 2{,}400$ $w_\infty = 0{,}060$ $w_{i(250)} = 0{,}022$ $w_{a(250)} = 0{,}046$

$p' = 2{,}200$ $w'_\infty = 0{,}060$ $w'_{i(250)} = 0{,}020$ $w'_{a(250)} = 0{,}050$

2. Vehicle body section half-way between the bogie pivots: $n = \frac{a}{2} = 7,700$

Application of formula (101a):

$$E_i = \frac{1{,}465 - d}{2} + q + w_\infty \frac{a - n_\mu}{a} + w'_\infty \frac{n_\mu}{a} + z - 0{,}015$$

$E_i = 0{,}0745 + z$

Application of formula (102a):

$$E_i = \frac{an_\mu - n_\mu^2 + \frac{p^2}{4} \cdot \frac{a - n_\mu}{a} + \frac{p'^2}{4} \cdot \frac{n_\mu}{a}}{500} + w_{i(250)} \frac{a - n_\mu}{a} + \frac{1{,}465 - d}{2} \cdot \frac{a - n_\mu}{a} + q + z - 0{,}015$$

formula valid for $h > 0{,}400$

$E_i = 0{,}1344 + z$

The reduction to be applied is therefore that obtained from formula (102a)

with: $z = \frac{s}{30}(h - h_c)$

h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	E_i	**Available half-width**
4,310	0,045	0,525	0,180	0,345
4,010	0,041	1,120	0,176	0,944
3,700	0,037	1,425	0,173	1,252
3,250	0,032	1,645	0,168	1,477
1,170	0,008	1,645 1,620	0,143	1,502 1,477
0,500	0	1,620	0,135	1,485

3. Section at the end of the vehicle body, motor bogie side: n = 2,750 beyond the bogie pivots

Application of formula (106a):

$$E_a = \left[\frac{1{,}465 - d}{2} + q\right]\frac{2a + n}{a} + w_\infty\frac{n + a}{a} + w'_\infty\frac{n}{a} + z - 0{,}015$$

$E_a = 0{,}1064 + z$

Application of formula (107a):

$$E_a = \frac{an + n^2 - \frac{p^2}{4} \cdot \frac{n + a}{a} + \frac{p'^2}{4} \cdot \frac{n}{a}}{500} + \frac{1{,}465 - d}{2} \cdot \frac{n+a}{a} + q\frac{2a + n}{a} + w'_{i(250)}\frac{n}{a} + w_{a(250)}\frac{n + a}{a} + z - 0{,}03$$

formula valid for h > 0,400

$E_a = 0{,}1598 + z$

The reduction to apply is therefore that obtained using formula (107a)

with: $z = \frac{s}{30}(h - h_c)$

h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	E_a	**Available half-width**
4,310	0,045	0,525	0,205	0,320
4,010	0,041	1,120	0,201	0,919
3,700	0,037	1,425	0,197	1,228
3,250	0,032	1,645	0,192	1,453
1,170	0,008	1,645 1,620	0,168	1,477 1,452
0,500	0	1,620	0,160	1,460

4. Section at the end of the vehicle body, trailer bogie side: n = 2,750 beyond the bogie pivots

Application of formula (106b):

$$E_a = \left(\frac{1{,}465 - d}{2} + q\right)\frac{2a + n}{a} + w_\infty \frac{n}{a} + w'_\infty \frac{n + a}{a} + z - 0{,}015$$

$E_a = 0{,}1064 + z$

Application of formula (107b):

$$E_a = \frac{an + n^2 - \left(\frac{p^2}{4} \cdot \frac{n}{a} - \frac{p'^2}{4} \cdot \frac{n + a}{a}\right)}{500} + \left(\frac{1{,}465 - d}{2} + q\right)\frac{2a + n}{a} + w_{i(250)}\frac{n}{a} + w'_{a(250)}\frac{n + a}{a} + z - 0{,}0$$

formula valid for h > 0,400

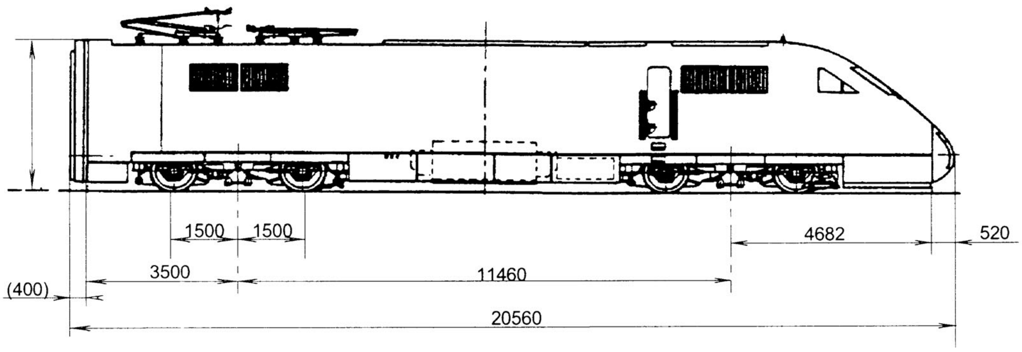
$E_a = 1704 + z$

The reduction to be applied is therefore that obtained using formula (107b) with: $z = \frac{s}{30}(h - h_c)$

h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	**E_a**	**Available half-width**
4,310	0,045	0,525	0,215	0,310
4,010	0,041	1,120	0,211	0,909
3,700	0,037	1,425	0,207	1,218
3,250	0,032	1,645	0,202	1,443
1,170	0,008	1,645 1,620	0,178	1,467 1,442
0,500	0	1,620	0,170	1,450

A.3 - Determination of reductions for powered units

Reductions applicable to the vehicle body (power car with 2 motor bogies) - Dimensions on the diagram are given in millimetres. Other values are given in metres, unless otherwise indicated.



1. Characteristics:

$a = 11,460$ $d = 1,416$ $q = 0,010$ $p = 3,000$

$s = 0,116$ $h_c = 1,106$ $\eta_0 < 1°$ $\mu > 0,2$

R (m)	150	250	500	1 000
w_i (mm)	22,5	30,0	39,0	48,0
w_a (mm)	38,0	38,0	49,0	50,0

2. Vehicle body section half-way between bogie pivots: $n = \frac{a}{2} = 5,730$

$$E_i = \frac{an - n^2 + \frac{p^2}{4} - 7,5}{500} + w_{i(250)} + \frac{1,465 - d}{2} + q + z - 0,015$$

formula valid for h > 0,400

$E_i = 0,105 + z$ where $z = \frac{s}{30}(h - h_c)$ for $h \quad h_c$

h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	**E_i**	**Available half-width**
4,310	0,0124	0,525	0,117	0,408
4,010	0,0112	1,120	0,116	1,004
3,700	0,0100	1,425	0,115	1,310
3,250	0,0083	1,645	0,113	1,532
1,800	0,0027	1,645	0,107	1,538
1,170	0	1,645 1,620	0,105	1,540 1,515
1,106	0	1,620	0,105	1,515
0,500	0,0094	1,620	0,114	1,506

3. Section at the end of the vehicle body: n = 3,500 beyond the bogie pivots

$$E_a = \frac{an + n^2 + \frac{p^2}{4} - 7,5}{500} + w_{i(250)}\frac{n}{a} + w_{a(250)}\frac{n + a}{a} + \left(\frac{1,465 - d}{2} + q\right)\frac{2n + a}{a} + z - 0,015$$

formula valid for h > 0,400

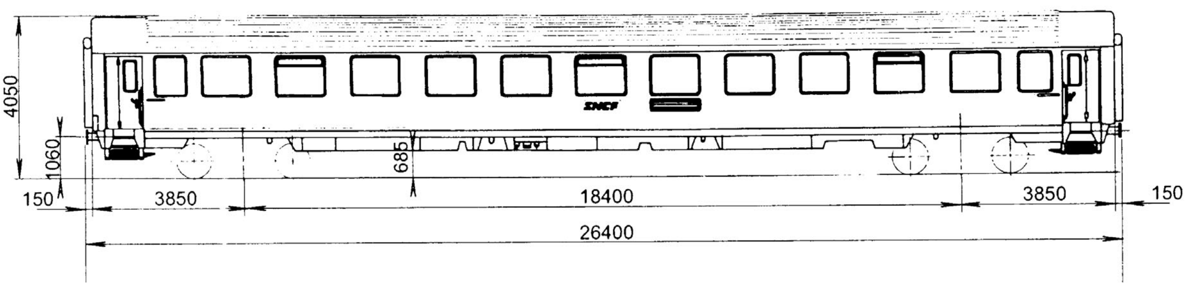
$E_a = 0,184 + z$ where $z = \frac{s}{30}(h - h_c)$ for $h \quad h_c$

h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	E_a	**Available half-width**
4,310	0,0124	0,525	0,197	0,328
4,010	0,0112	1,120	0,196	0,924
3,700	0,0100	1,425	0,195	1,230
3,250	0,0083	1,645	0,193	1,452
1,800	0,0027	1,645	0,187	1,458
1,170	0	1,645 1,620	0,185	1,460 1,435
1,106	0	1,620	0,185	1,435
0,500	0,0094	1,620	0,193	1,426

A.4 - Determination of reductions for coaches

Reductions applicable to the vehicle body

Dimensions on the diagram are given in millimetres, all other values being expressed in metres unless otherwise indicated.



1. Characteristics:

$a = 18{,}4$ $d = 1{,}410$ $p = 2{,}56$ $q = 0{,}002$ $w_\infty = 0{,}082$

$w_{i(250)} = 0{,}020$ $w_{a(250)} = 0{,}048$ $s = 0{,}3$ $h_c = 0{,}500$ $\eta_0 < 1°$

$$\frac{a^2 + p^2}{4} < 100 \quad \Rightarrow x_i = 0$$

2. Vehicle body section half-way between pivots: $n = \frac{a}{2} = 9,2$

when $an - n^2 + \frac{p^2}{4} - 500(w_\infty - w_{i(250)}) > 250(1{,}465 - 1{,}410) - 0$

the formula to apply for h > 0,400 is:

$$E_i = \frac{an - n^2 + \frac{p^2}{4}}{500} + q + w_{i(250)} + z - 0,015$$

$E_i = 0{,}1796 + z$ with: $z = \frac{s}{30}(h - h_c)$

h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	**E_i**	**Available half-width**
4,310	0,0381	0,525	0,218	0,307
4,010	0,0351	1,120	0,215	0,905
3,700	0,0320	1,425	0,212	1,213
3,250	0,0275	1,645	0,207	1,438
1,170	0,0067	1,645 1,620	0,186	1,459 1,434
0,500	0	1,620	0,180	1,440

3. Section at end of vehicle body: n = 3,850

$an + n^2 - \frac{p^2}{4} < 120 \Rightarrow x_a = 0$

when $an + n^2 - \frac{p^2}{4} - 500\left[(w_\infty - w_{i(250)})\frac{n}{a} + (w_\infty - w_{a(250)})\frac{n+a}{a}\right] > 250(1{,}465\text{-}1{,}410)\frac{n}{a} + 7,5$

giving 57,024 > 7,677

The formula to apply for h > 0,400 is:

$$E_a = \frac{an + n^2 - \frac{p^2}{4}}{500} + \frac{1,465 - d}{2} \cdot \frac{n + a}{a} + q\frac{2n + a}{a} + w_{i(250)}\frac{n}{a} + w_{a(250)}\frac{n + a}{a} + z - 0,030$$

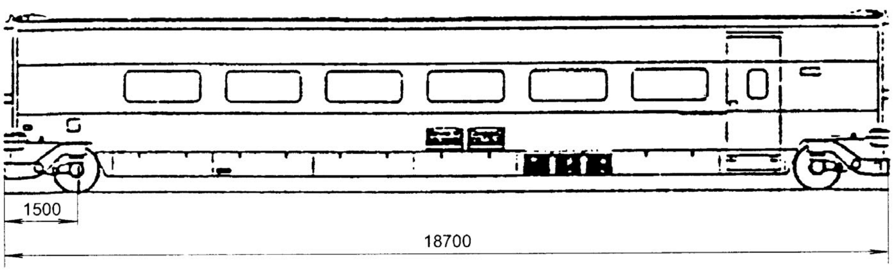
$E_a = 0,2364 + z$ with $z = \frac{s}{30}(h - h_c)$

h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	**E_a**	**Available half-width**
4,310	0,0381	0,525	0,275	0,250
4,010	0,0351	1,120	0,272	0,848
3,700	0,0320	1,425	0,268	1,157
3,250	0,0275	1,645	0,264	1,381
1,170	0,0067	1,645 1,620	0,243	1,402 1,377
0,500	0	1,620	0,236	1,384

A.5 - Determination of reductions for articulated vehicles

Reductions applicable to the vehicle body.

Dimensions on the diagram are given in millimetres, all other values being expressed in metres unless otherwise indicated.



1. Characteristics:

$a = 18,7$ $d = 1,410$ $p = 3$ $w_\infty = 0,080$

$w_{i(250)} + q = 0,021$ $s = 0,25$ $h_c = 0,800$ $\eta_0 = 1°$

$$\frac{a^2 + p^2}{4} < 100 \Rightarrow x_i = 0$$

2. Vehicle body section half-way between pivots: $n = \frac{a}{2} = 9, 35$

when $an - n^2 + \frac{p^2}{4} - 500(w_{\infty} - w_{i(250)}) > 250(1,465 - 1,410) - 0$

the formula to apply for h > 0,400 est :

$$E_i = \frac{an - n^2 + \frac{p^2}{4}}{500} + q + w_{i(250)} + z - 0, 015$$

$E_i = 0,1853 + z$ with $z = \frac{s}{30}(h - h_c)$

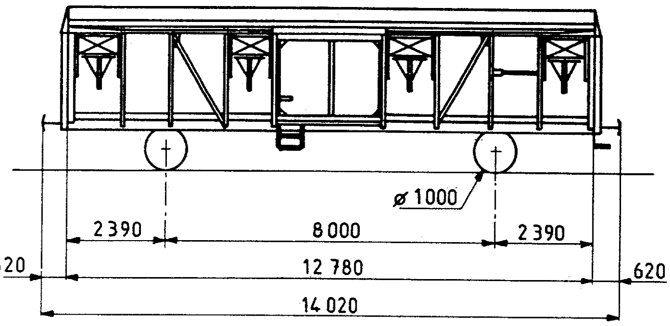
h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	E_a	**Available half-width**
4,310	0,0292	0,525	0,214	0,311
4,010	0,0267	1,120	0,212	0,908
3,700	0,0242	1,425	0,209	1,216
3,250	0,0204	1,645	0,206	1,439
1,700	0,0075	1,645	0,193	1,452
1,170	0,0031	1,645 1,620	0,188	1,457 1,432
0,800	0	1,620	0,185	1,435

A.6 - Determination of reductions for wagons

Reductions applicable to the vehicle body.

Dimensions on the diagram are given in millimetres, all other values being expressed in metres unless otherwise indicated.

A.6.1 - Covered 2-axle wagon



1. Characteristics:

$a = 8,000$ $d = 1,410$ $q = 0,023$[a] $s = 0,10$

$h_c = 0,500$ $\eta_0 < 1°$ and $w = 0$

a. q = 0,023 is the value set by the UIC's European Rail Research Institute (ERRI) for a nominal lateral play of 20 mm.

2. Vehicle body section half-way between axles: $n = \frac{a}{2} = 4,000$

an - n^2 = 16; value greater than 7,5. The formula to apply is therefore:

$$E_i = \frac{an - n^2}{500} + \frac{1,465 - d}{2} + q + z - 0,030 \quad \text{(for parts such that } h > 0,400\text{)}$$

$E_i = 0,0525 + z$

For h 0,500: $z = \frac{s}{30}(h - h_c)$

$$z = 0,00333\ (h - 0,5)$$

3. Vehicle body section at the end of the underframe: n = 2,390

an + n^2 = 24,832; value greater than 7,5. The formula to apply is therefore:

$$E_a = \frac{an + n^2}{500} + \left(\frac{1,465 - d}{2} + q\right)\frac{2n + a}{a} + z - 0,030 \quad \text{(for parts such that } h > 0,400\text{)}$$

$E_a = 0,1003 + z$

z has the same value as for the section located in the centre of the vehicle body, that is 0,00333 (h - 0,5).

4. Numerical values

To plot the construction gauge for each section, the reductions and the half-widths available must be calculated for the characteristic points of the reference profile and if necessary the points for which z = 0.

The numerical values for the 2 sections studied are drawn up in the table below:

h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	**E_i** (vehicle body centre)	**Available half-width** (vehicle body centre)	**E_a** (2,390 beyond axles)	**Available half-width** (2,390 beyond axles)
4,310	0,0127	0,525	0,066	0,459	0,113	0,412
4,010	0,0117	1,120	0,065	1,055	0,112	1,008
3,700	0,0107	1,425	0,064	1,361	0,111	1,314
3,250	0,0092	1,645	0,062	1,583	0,110	1,535
1,170	0,0022 For h < 1,170, z = 0 since (z-0,005) < 0 (see point 7.2.5.1 - page 48)	1,645 1,620	0,055	1,590 1,565	0,103	1,542 1,517

If the gauge was also to be studied for the lower parts (fairly unlikely for this type of wagon), the formula to be used would be:

- For the section located half-way between the axles:

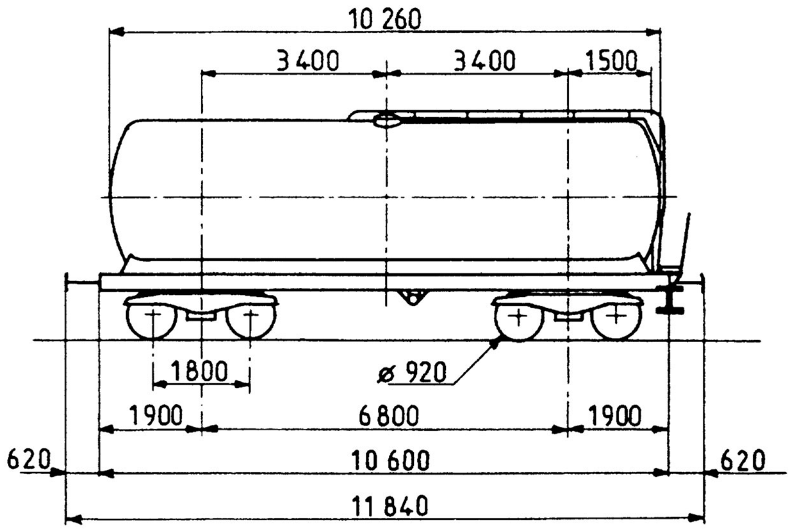
$$E_i = \frac{an - n^2}{500} + \frac{1{,}465 - d}{2} + q + z - 0{,}025 \qquad \text{since } E_i = 0{,}0575 + z$$

- For the section located at the end of the underframe:

$$E_a = \frac{an + n^2}{500} + \left(\frac{1{,}465 - d}{2} + q\right)\frac{2n + a}{a} + z - 0{,}025 \qquad \text{since } E_a = 0{,}1053 + z$$

For both sections, we would take z = 0 since for 0,125 < h < 0,400, we obtain (z - 0,005) < 0

A.6.2 - Bogie tank wagon



1. Characteristics:

$a = 6{,}800$ $d = 1{,}410$ $q = 0{,}0115$[a] $w = 0$ $p = 1{,}800$ $s = 0{,}3$

$h_c = 0{,}500$ $\eta_0 < 1°$[b]

a. Justification of the value of q:

- Play between axle boxes and bogie underframe	= 0,010
- Wear	= 0,0015
q=total	= 0,0115

b. The asymmetry caused by the 5 mm transom play and the other elements defined in point 7 - page 32 is taken conventionally to be 1°.

Fitted with bogies, fixed transoms (play = 5 mm).

2. Vehicle body section half-way between bogie pivots: $n = \frac{a}{2} = 3,400$

$an - n^2 + \frac{p^2}{4} = 12,37$ and $250(1{,}465\text{-}d) = 13{,}75$

The formula to apply is therefore:

$$E_i = \frac{1,465 - d}{2} + q + w + z - (0,015) \text{ (for parts such that } h > 0{,}400)$$

$E_i = 0{,}024 + z$

For h 0,500 : $z = \frac{s}{30}(h - h_c)$

$$z = 0{,}00433\,(h - 0{,}5)$$

3. Vehicle body section 1,500 beyond bogie pivots: n = 1,500

$$an + n^2 - \frac{p^2}{4} = 11,64 \quad \text{and} \quad 250(1,465 - d)\frac{n}{a} + 7,5 = 10,53$$

The formula to apply is therefore:

$$E_a = \frac{an + n^2 - \frac{p^2}{4}}{500} + \frac{1,465 - d}{2} \cdot \frac{n + a}{a} + (q + w)\frac{2n + a}{a} + z + [x_a]_{>0} - 0,030$$

(for parts such that h > 0,400)
x_a being negative, it shall be taken as zero.

E_a = 0,0434 + z

z has the same value as for the section located in the vehicle body centre, that is 0,00433 (h - h_c).

4. Numerical values

The numerical values for the 2 sections studied are drawn up in the table below:

			at vehicle body centre		1,500 beyond bogie pivots	
h (For the values of h, see the second note on first page of Appendix A)	**z**	**Reference profile half-width**	**E_i**	**Available half-width**	**E_a**	**Available half-width**
4,310	0,0165	0,525	0,041	0,484	0,060	0,465
4,010	0,0152	1,120	0,039	1,081	0,059	1,061
3,700	0,0139	1,425	0,038	1,387	0,057	1,368
3,250	0,0119	1,645	0,036	1,609	0,055	1,590
1,170	0,0029	1,645 1,620	0,027	1,618 1,593	0,046	1,599 1,574
0,500	0	1,620	0,024	1,596	0,043	1,577

As an example of the use of the formulae, a similar calculation could be carried out for the lower parts, although for this type of wagon this would be a rare case. This would give:

- For the section located in the middle of the wagon:

$$E_i = \frac{an - n^2 + \frac{p^2}{4}}{500} + q + w + z + [x_i]_{>0} - 0,010 \qquad \text{since } E_i = 0,0262 + z$$

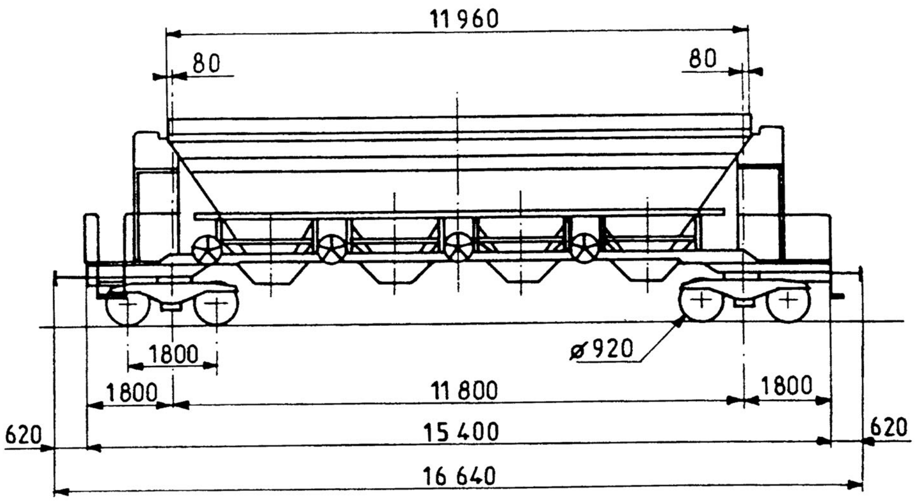
- For the section located 1,500 beyond the bogie pivots:

$$E_a = \frac{an + n^2 - \frac{p^2}{4}}{500} + \frac{1,465 - d}{2} \cdot \frac{n + a}{a} + (q + w)\frac{2n + a}{a} + z + [x_a]_{>0} - 0,025$$

since $E_a = 0,0484 + z$

For both sections, we take: $z = \frac{4s}{30}(0,5 - h)$ or: $z = 0,01733(0,5 - h)$

A.6.3 - Bogie hopper wagons



1. Characteristics:

$a = 11,800$ $d = 1,410$ $q = 0,0115$[a] $w = 0$ $p = 1,800$

$b_G = 0,850$ $s = 0,13$ $h_c = 0,500$

a. Justification of the value of q:

- Play between axle boxes and bogie underframe	= 0,010
- Wear	= 0,0015
q=total	= 0,0115

Fitted with bogies, with transoms (J = 0,013 - justification of the value of play: 0,012 0,001).

2. Vehicle body section half-way between bogie pivots: $n = \frac{a}{2} = 5,900$

$$an - n^2 + \frac{p^2}{4} = 35,62 \quad \text{and} \quad 250(1,465 - d) = 13,75$$

The formula to apply is therefore:

$$E_i = \frac{an - n^2 + \frac{p^2}{4}}{500} + q + w + z + [x_i]_{>0} - 0,015 \text{ (for parts such that h > 0,400)}$$

x_i being negative, it shall be taken as zero.

$E_i = 0,0677 + z$

For h 0,500 : $z = \left[\frac{s}{30} + tg[\alpha(1 + s)]\right](h - h_c) \quad tg\alpha = \frac{J - (0,005)}{b_G}$

$\alpha = 0,0094$ rd
$z = 0,015\ (h - h_c)$

3. Section at the end of the vehicle body: n = 0,080 beyond the bogie pivots

$$an + n^2 - \frac{p^2}{4} = 0,1404 \quad \text{and} \quad 250(1,465 - d)\frac{n}{a} + 7,5 = 7,593$$

The formula to apply is therefore:

$$E_a = \left(\frac{1,465 - d}{2} + q + w\right)\frac{2n + a}{a} + z - 0,015 \quad \text{(for parts such that h > 0,400)}$$

$E_a = 0,0245 + z$

z is the same as for the section located in the middle of the vehicle body, that is:
$z = 0,0150\ (h - h_c)$

4. Numerical values

The numerical values for the two sections studied are drawn up in the table below:

h (For the values of h, see the second note on first page of Appendix A)	z	Reference profile half-width	E_i (in the centre of the vehicle body)	Available half-width (in the centre of the vehicle body)	E_a (0,080 beyond the bogie pivots)	Available half-width (0,080 beyond the bogie pivots)
4,310	0,0570	0,525	0,125	0,400	0,081	0,444
4,010	0,0525	1,120	0,120	1,000	0,077	1,043
3,700	0,0479	1,425	0,116	1,309	0,072	1,353
3,250	0,0412	1,645	0,109	1,536	0,066	1,579
1,170	0,0100	1,645 1,620	0,078	1,567 1,542	0,034	1,611 1,586
0,500	0	1,620	0,068	1,552	0,025	1,595

As an example for use of the formulae, a similar calculation could be carried out for the lower parts of the vehicle. This would give:

- For the section located in the centre of the wagon:

$$E_i = \frac{an - n^2 + \frac{p^2}{4}}{500} + q + w + z + [x_i]_{>0} - 0,010$$

or $E_i = 0,0727 + z$

- For the section 0,080 beyond the bogie pivots:

$$E_a = \left(\frac{1,465 - d}{2} + q + w\right)\frac{2n + a}{a} + z - 0,015$$

or $E_a = 0,0245 + z$

For both these sections, we take:

$$z = \left[\frac{4s}{30} + tg[\alpha(1+s)]\right](h - h_c)$$

or $z = 0,028\ (h_c - h)$

Appendix B - Graphic method

B.1 - Determination of the maximum construction gauge by the graphic method

This method is useful for studying both conventional and special vehicles and can be used for any curve radius.

It gives the exact position of the vehicle body centreline in relation to the track centreline and so allows all the characteristic sections of the vehicle to be obtained immediately.

This method also enables the positioning of vehicle body/bogie stops on curves and on curves and reverse curves to be optimised.

B.2 - Determination of reductions by the graphic method

This method allows reductions E_i and E_a to be obtained by taking directly from diagrams the lateral movements (bogie-track, vehicle body-bogie) and those due to inclination of the vehicle body.

The running positions of the bogies and the vehicle body, both on curves and straight track, are shown in the table in point 6.2.2 - page 27.

This method requires a 2-step process to determine the reductions:

1. determination of reductions without z;
2. determination of z and the reductions taking z into account.

For vehicle whose lateral movements vary:

- **linearly** in relation to the curvature $\frac{1}{R}$, the associated rule in point 6 - page 17 should be applied for R = ×, 250 and 150 m with l = 1,465 m in all three cases, except for internal reductions E_i for trailing bogie vehicles or similar stock, where l = 1,435 m should be used;
- **non-linearly**, in addition to the above determinations, the reductions for the value of R for which variation of w as a function of $\frac{1}{R}$ shows a discontinuity must be determined, this is the value of R, always greater than 250 m, from which the variable stops come into play, with the projections being calculated using the formula opposite:

2,5	The value 2,5 applies to those parts no more than 0,400 m above the running surface and those which may descend below this level as a result of wear and vertical movements assessed as per point 6.1 - page 17.
or	
$\frac{3,75}{R} + \frac{l - 1,435}{2}$	l having the value indicated in the previous paragraph. The value 1,435 applies to parts located more than 0,400 m above the running surface, with the exception of those covered by footnote (1) above.

For each vehicle section, the reduction to be used is the greatest of those determined in this way.

B.2.1 - Methods of geometric dimensioning

B.2.1.1 - Plotting the curve

Although diagrams showing the passing of a vehicle over a curve of radius R can be produced using computer plotting methods, a precise plotting of the curve can be obtained using traditional study methods by taking different scales to represent arrows (ordinates) and chords (abscissae).

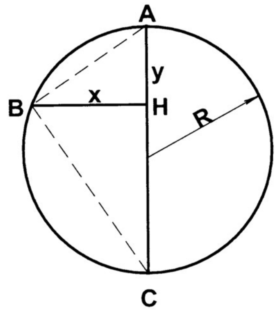
Since a precise knowledge of the value of the arrows is required, they are shown life size (scale of 1:1), with the chords shown on a smaller scale (1:100 for example).

Under these conditions, the curve may be assimilated to a parabola which may be easily constructed. In fact in the figure below, the x and y coordinates of point B satisfy the relation:

$$\frac{x}{2R-y} = \frac{y}{x} \qquad \frac{x^2}{2R-y} = y$$

The value of y is very small compared to 2 R and can be disregarded in the denominator, giving:

$$y = \frac{x^2}{2R}$$



Using this formula the curve can be plotted corresponding to the chosen radius; R can be infinitely large.

B.2.1.2 - Preparation of the diagram

The diagram is made up of the following elements:

- a front view of the vehicle;
- the least favourable representation that its longitudinal centreline can take on the following track configurations (see point B.2.1.3 - page 72):
  - straight track,
  - 250 m curve,
  - a curve of a chosen radius, if necessary, in accordance with the case under study.

In addition, a graph below or alongside each representation allows the lateral movements to be converted into ordinates (see point B.2.1.4 - page 72).

The scale of the abscissae is of course the same in all cases.

B.2.1.3 - Positioning of the vehicle on the diagram

The front view of the vehicle shall be shown in such a way that its lateral centreline coincides with the symmetrical axis of the curves under consideration.

The positions of the axles, pivots and stops are indicated on the curves in parallel to the axis of the ordinates.

The values of the lateral movements between the axles and the track $\left(\text{play } \frac{1,465 - d}{2}\right)$ are given on the axle datum lines from the point where they intersect with the curve (see Fig. 19 - page 28) for the different possible positions of the axles of a same bogie on the track.

By correcting the values of the movements above by the value of the movement between axle-box and bogie underframe (play q), in the direction shown in the table in Fig. 19, the bogie underframe centreline can be determined (see Fig. 2a - point C.2 - page 77).

The play limit stops, when present, are placed on a datum line from this centreline (see point C.1 - page 74) except when the movement between vehicle body and bogie (play w) varies non-linearly in relation to the curvature of the track. In this case, play w(R) corresponding to the curve should be transferred to the datum line of the fictional pivot (see point C.2).

In certain cases it is permissible, in order to simplify the design of the drawing, to give the algebraic sum of the plays q and w directly from the movements of the axles in the directions fixed for each axle in Fig. 19.

The centrelines thus obtained are the longitudinal centrelines of the bogie underframes (see figures 1 and 2b of point C.2).

The two methods give the same position for the vehicle centreline.

The vehicle body centreline is plotted in the position shown in Fig. 19 with the play of the vehicle itself taken into account.

B.2.1.4 - E_i or E_a reduction values for the vehicle body without considering z

The movements of the vehicle body in relation to the track for curves and straight sections, included life size in ordinates on the diagrams and reduced by the corresponding projection values (see point 6.2.1 - page 26), enable the E_i or E_a reductions curve to be established without considering z.

B.2.1.5 - Values for inclination of the vehicle body: z

The curve produced on the basis of the formulae given in point 7.1.3 - page 33 enables the movements due to the inclination of the vehicle body to be calculated as a function of the height.

B.2.1.6 - E_i or E_a reduction values for the vehicle body taking into account z

By adding the values of z from point B.2.1.5 to the values obtained in point B.2.1.4, we obtain the E_i or E_a reductions for all sections and for all heights.

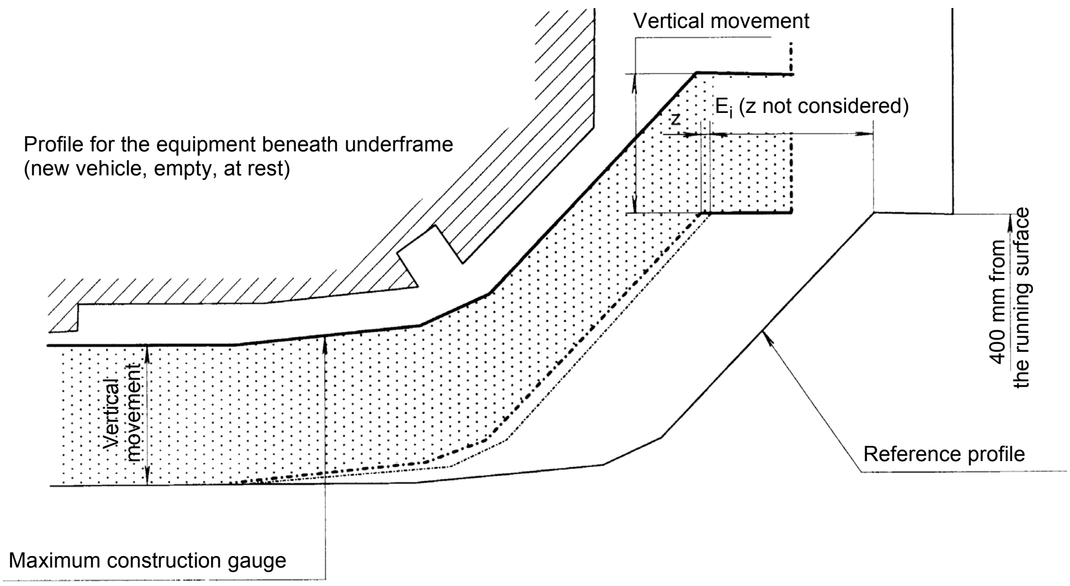
B.2.2 - Example of verification of the space limits for equipment beneath the underframe

1. Plotting
   The diagram uses a plot of the reference profile restricted to the areas concerned by the parts to be studied; the following example requires the plotting of the lower parts for h ≤ 400.

2. Lateral movements
   The lateral area of the lower parts of the reference profile (see point 5 - page 11) is translated by the E_i reduction value, without considering z, as determined by the graphic method described in point B.2.1.4 - page 72.
   The resulting plotting is translated taking z into account, where z has the value corresponding to the height of the determining points of each segment of the straight line, to the point where the plotting thus translated intersects with the horizontal line of the lower part reference profile (common gauge for Rolling Stock and Permanent Way Departments).

3. Vertical movements
   The plotting obtained is then translated vertically upwards by the value of the vertical movements defined in point 6.1 - page 17, increased by the vertical reductions applicable to the section of the vehicle considered for crossing gradient transition curves.
   The resulting plotting defines the maximum construction gauge for the section under consideration.
   No part of the empty vehicle in running order at rest and in new condition must then infringe that gauge.

4. Drawing



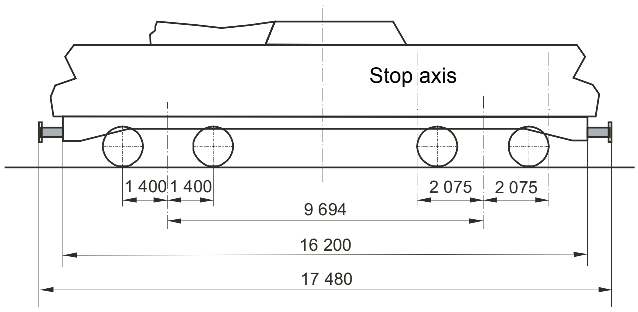
Appendix C - Examples of application of the kinematic gauge by the graphic method

C.1 - Determining reductions for powered units

Only the dimensions on the diagrams are given in millimetres, all others being expressed in metres.

Locomotives - Reductions applicable to the vehicle body (for h > 0,400)

NB : The numerical values are examples only and are given purely by way of indication.



Bogie-track movement

Play of the axle on the track

$$\frac{1,465 - 1,410}{2} = 0,0275$$

$$q = 0,0060$$

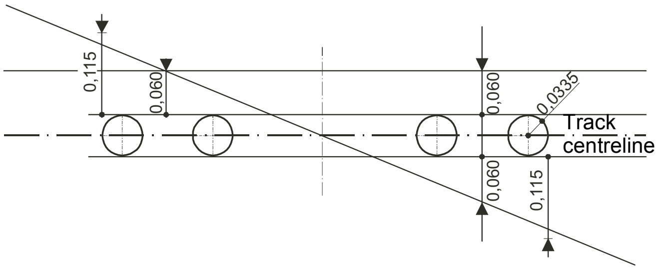
Total: 0,0335

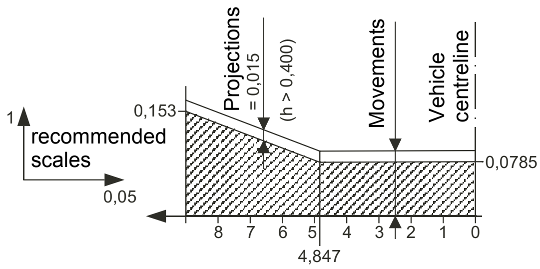
Vehicle - bogie movements

$$W = 0,060$$

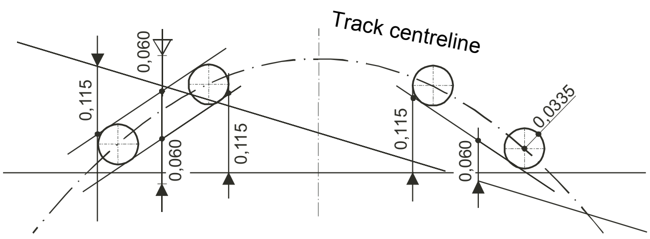
Play at the rotational stops = 0,115

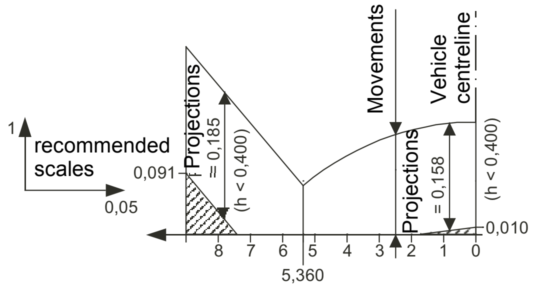
1. On straight track



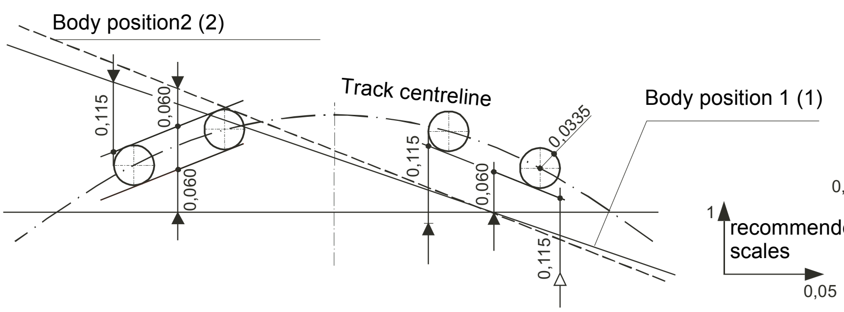


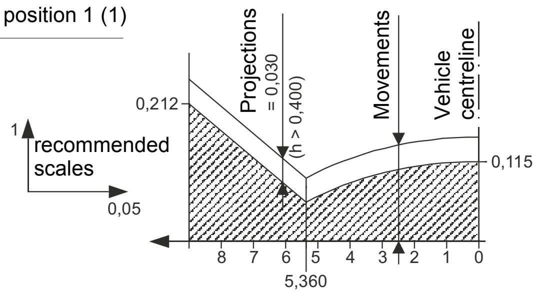
2. On 150 m curve



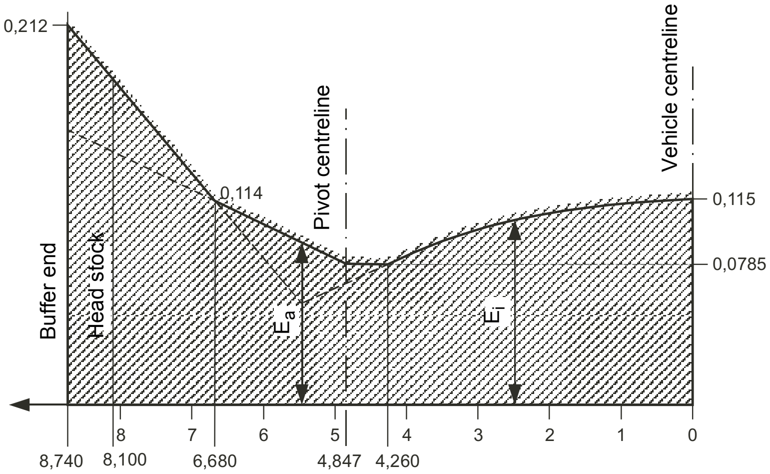


3. On 250 m curve

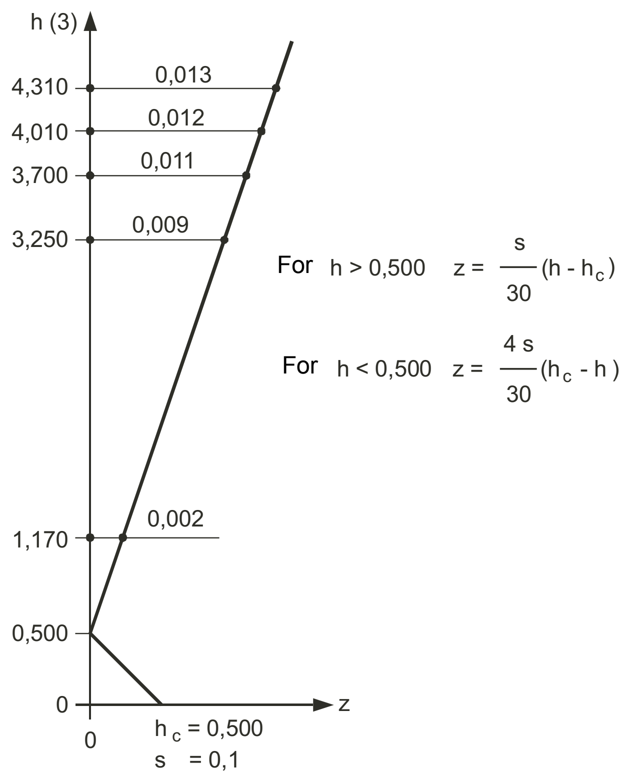




4. E_a and E_i reductions not considering z (resulting from 1 and 3) h > 0,400



5. Movement z due to inclination of the vehicle body



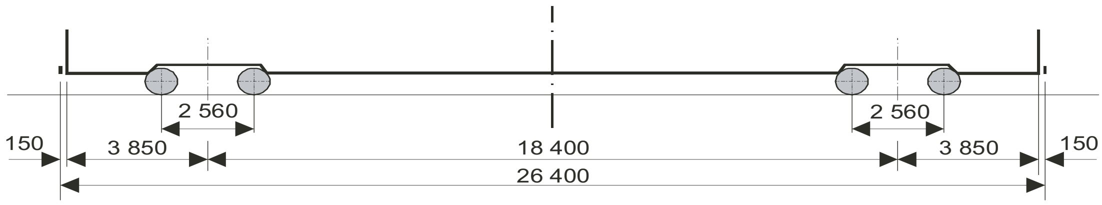
6. E_a and E_i reductions taking account of z

		External reduction E_a				Internal reduction E_i			
Distance from the vehicle centreline		8,740	8,100	6,680	4,847	4,847	4,260	2	0
Distance from pivit n		3,893	3,253	1,833	0	0	0,587	2,847	4,847
h (3)	4,310	0,225	0,193	0,127	0,091	0,091	0,091	0,120	0,128
	4,010	0,224	0,192	0,126	0,090	0,090	0,090	0,119	0,127
	3,700	0,223	0,191	0,125	0,089	0,089	0,089	0,118	0,125
	3,250	0,221	0,189	0,123	0,087	0,087	0,087	0,116	0,124
	1,170	0,214	0,182	0,116	0,080	0,080	0,080	0,109	0,117
	0,500	0,212	0,180	0,114	0,078	0,078	0,078	0,107	0,115

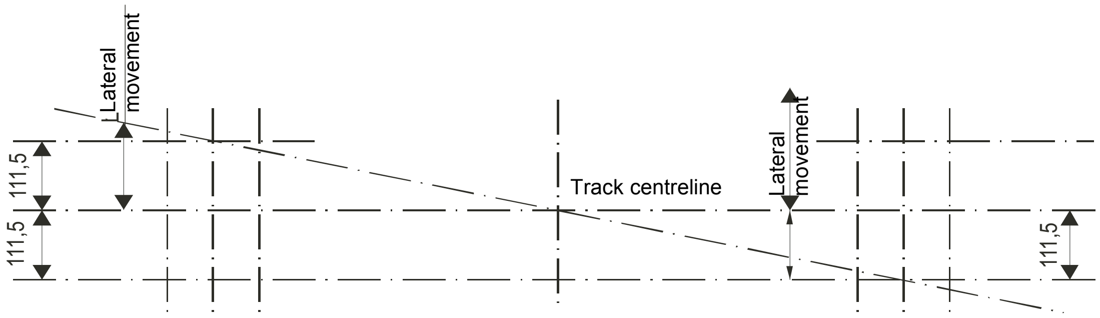
(1) Graphic method (2) Method by calculation (3) See the second note to Appendix A

C.2 - Determination of reductions for trailing stock

Reductions applicable to the vehicle body for h > 0,400

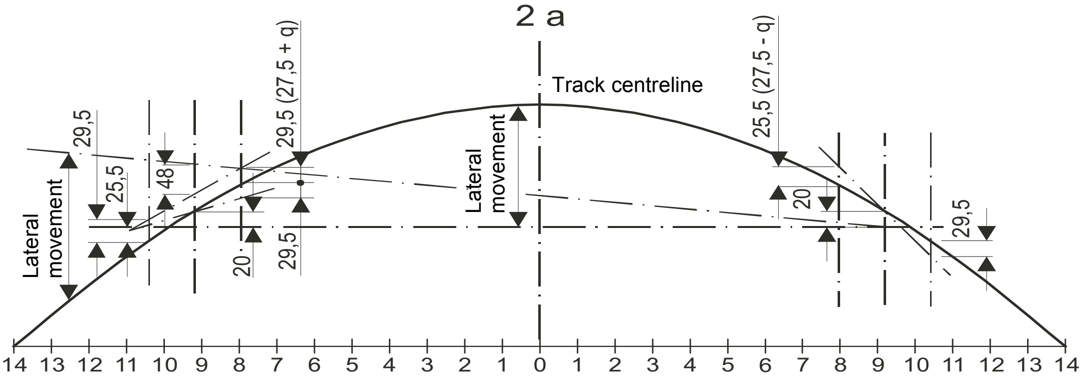


1. On straight track

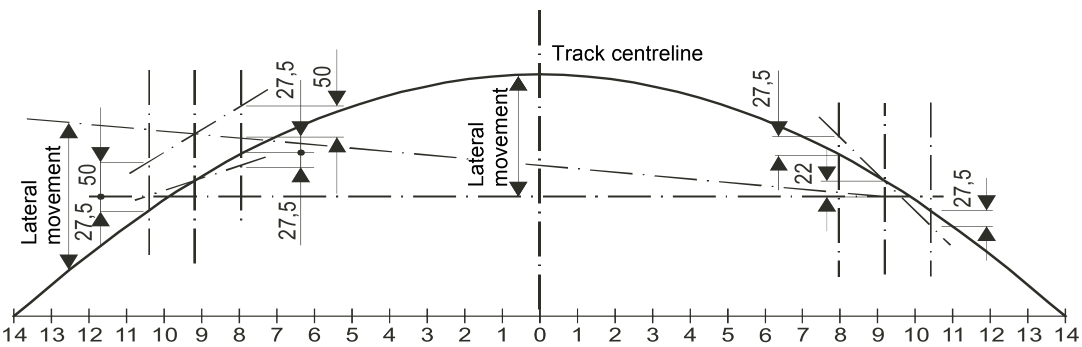


2. On 250 m curve

2 a



2 b



NB : for the plotting, dimensions are given in millimetres.

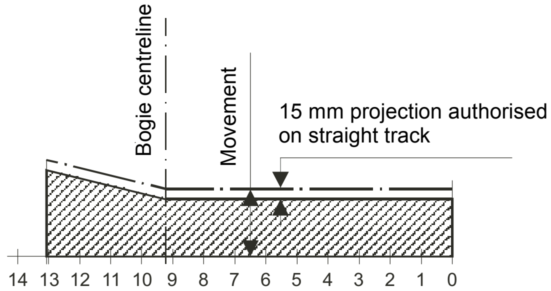
Note:
The numerical values are given only by way of example and as such are merely indicative in nature.

Play of the axle on track $\frac{1,465 - 1,410}{2} = 0,0275$

Lateral movement between axle-box and underframe q = 0,002

Lateral play between vehicle body and bogie:

- towards inside of curve w_i = 0,02 m
- towards outside of curve w_a = 0,048 m
- on straight track w_∞ = 0,082 m



3. Value of E_a and E_i not considering z

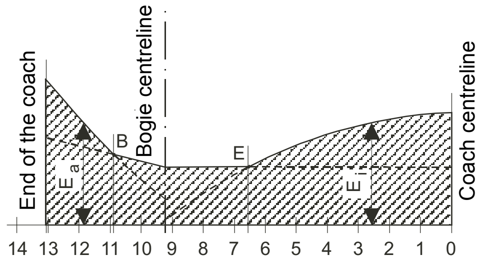
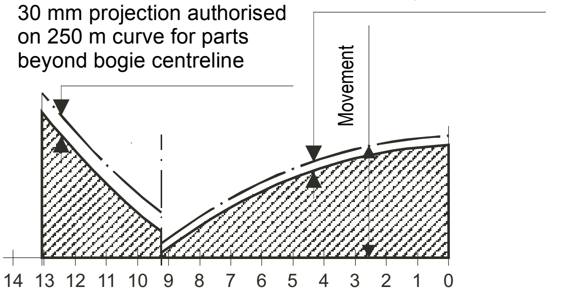
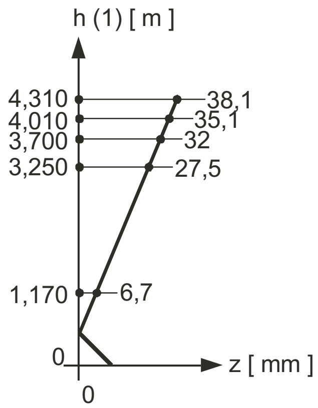


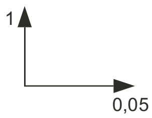
Figure obtained by superimposing results 1 and 2



4. Movement z due to inclination of the vehicle body



recommended scales



For h > 0,500 m

$$z = \frac{s}{30}(h - h_c)$$

For h < 0,500 m

$$z = \frac{4s}{30}(h_c - h)$$

Coefficient of flexibility s = 0,3

h_c = 0,500

(1) See the second note to Appendix A

Appendix D - Theoretical basis for bilateral or multilateral agreements covering application of a superelevated gauge

NB : The provisions of this Appendix are given for guidance.

The kinematic gauge for powered units used on international services defined in this leaflet is applicable to powered units able to run over the standard gauge lines of the UIC Railways.

Railways may conclude bilateral or multilateral agreements among themselves with the object of authorising the circulation of larger powered units than those constructed in accordance with this leaflet over the whole or part of their respective systems.

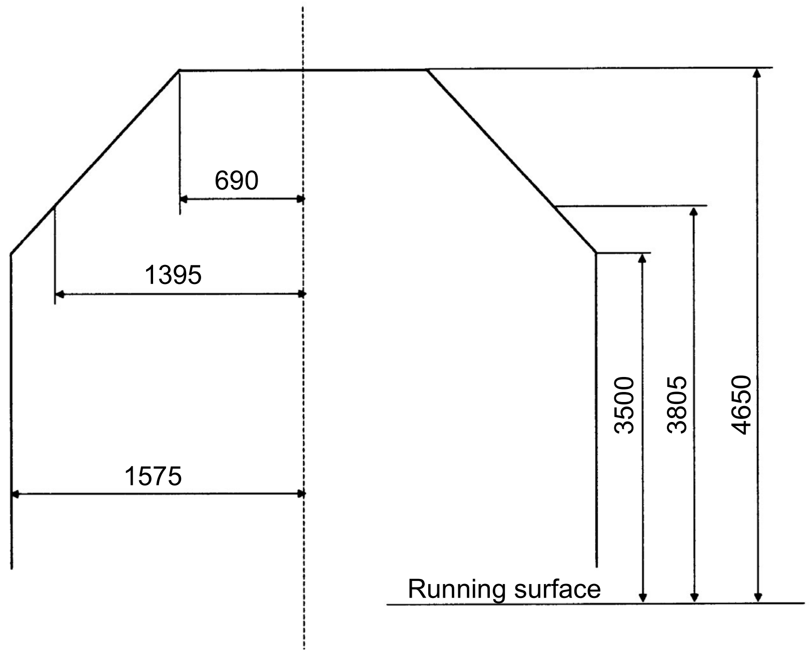
It is sufficient, for the conclusion of such agreements, to define a kinematic reference profile to be substituted for the one shown in point 5.1 - page 12, all the rules set down in point 6 - page 17 remaining applicable on the basis of the new reference profile.

The rules in *UIC Leaflet 505-4* (see Bibliography - page 114) enable the structure gauge related to the rolling stock gauge defined in this way to be calculated or, conversely, enable a rolling stock gauge to be deduced from an existing clearance gauge.

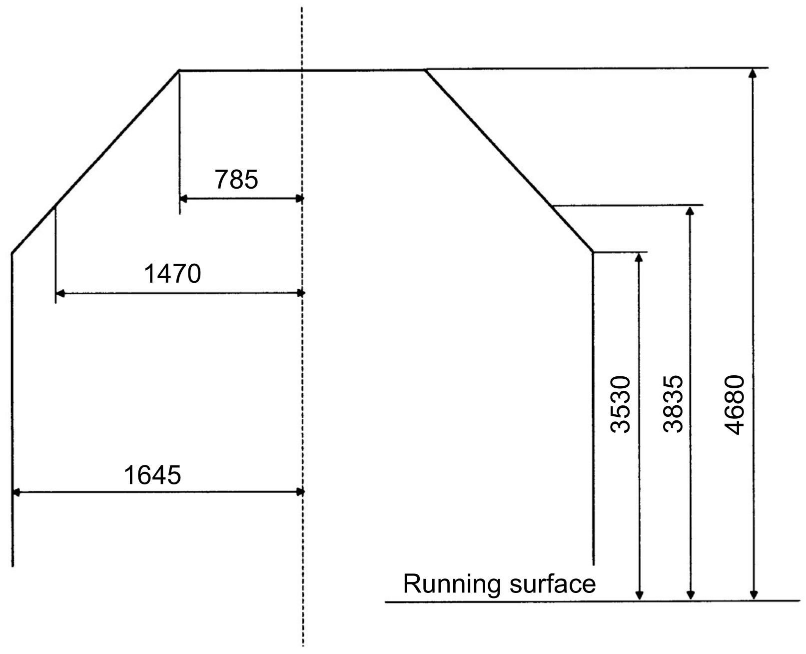
Example of application

Certain Railways authorise the transit on their respective systems of loads to which the rules of Railway Technical Unity are applicable on the static reference profile shown below.

NB : Accepted by: HSH, GySEV, BHEV, PKP, BDZ, CFR, CD, ZSR, MAV, JZ, CH, TCDD, DB AG, ÖBB, CFL, NS, DSB, CFS, IRR, Green Cargo. With the exception of the following stations: JZ: Divaca, Sezana, Hrpelje-Kozina, Koper, Kilovce, Ilirska, Bistrica, Sapljane, Jurdani, Opatija-Matulji, Rijeka. MAV: Budapest-Déli pu. -Budapest. Kelenföld. Green Cargo: Vassijaure gränsen.



The following kinematic reference profile will be considered equally valid for the application of the regulations of this leaflet.



UIC Leaflet 505-4 enables the corresponding structure gauge to be calculated.

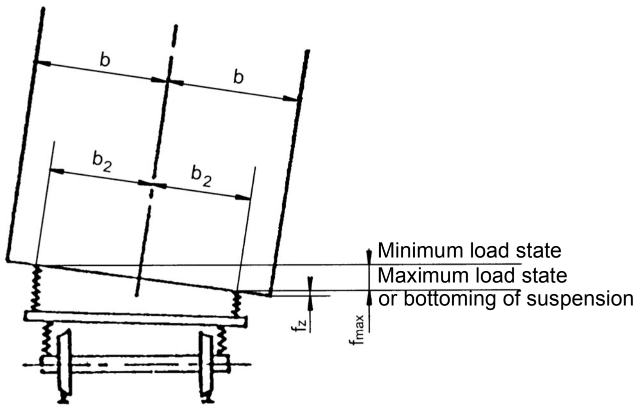
Appendix E - Depression of the suspensions for areas outside the support polygon B, C and D

(see point 6.1.1 - page 17)

For all vehicles and wagons in particular, it is recommended that account be taken of additional vertical movements f_z due to inclination of the vehicle body (roll, pitching) resulting, for example, from an off-centre load or deflation of pneumatic suspension.

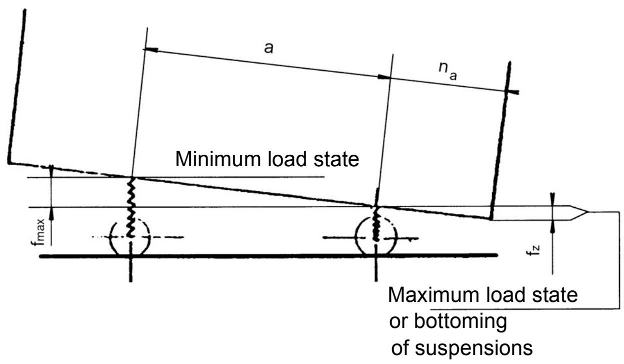
The following simplified formulae should be used for these additional depressions:

- Lateral: zones concerned B and C
  Depression in phase on 2 bogies and a single rail.



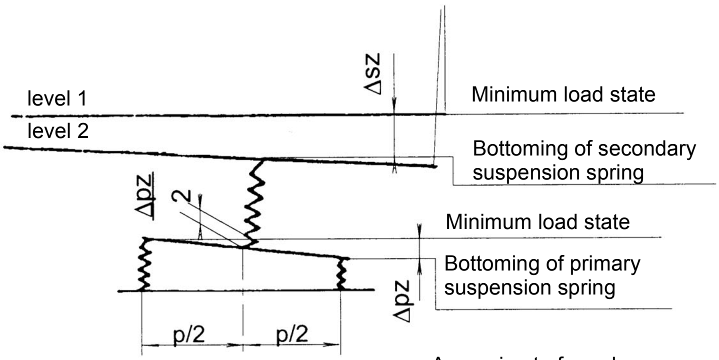
$$\frac{f_{max}}{2b_2} = \frac{f_z}{b-b_2} \qquad f_z = \frac{f_{max}(b-b_2)}{2b_2}$$

- Longitudinal: zones concerned C and D
  Depression on single bogie or axle.

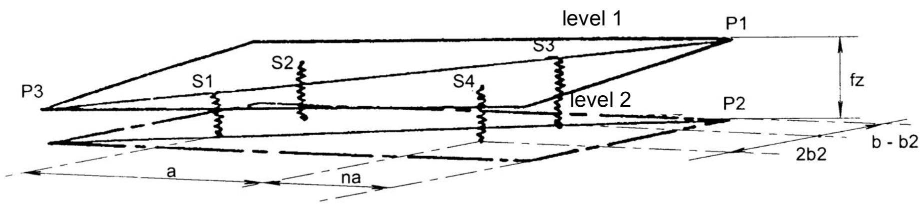


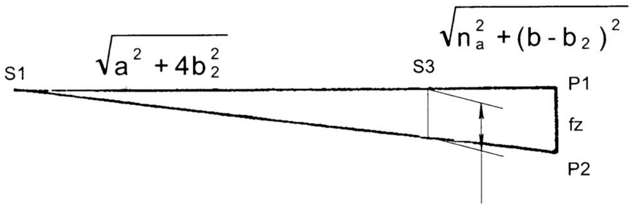
$$\frac{f_{max}}{a} = \frac{f_z}{n_a} \qquad f_z = \frac{f_{max} n_a}{a}$$

- Deflection of a primary suspension spring and a secondary suspension spring or deflated pneumatic suspension (calculation principle zone C).
  Deflection (in an initial approach).



Approximate formula:





$$f_{max} = \Delta sz + \frac{\Delta pz}{2}$$

$$f_z = (\Delta sz + \Delta pz / 2)\ (1 + \frac{\sqrt{n_a^2 + (b - b_2)^2}}{\sqrt{a^2 + 4b_2^2}})$$

Appendix F - Calculation of the construction gauge of tilting vehicles or vehicles subject to $I_p > I_c$

F.1 - General

F.1.1 - Scope

This Appendix deals with the method of calculating the loading gauge of tilting body vehicles (referred to hereafter as TBV).

Points F.2 - page 84, F.3 - page 86 and F.4 - page 90 deal with the technical analysis of the calculation of the loading gauge of TBV.

Point F.5 - page 91 gives two examples which show how the principles described are applied.

Point F.6 - page 101 gives a commentary on the conditions of tilting and the speed of TBV.

F.1.2 - Field of application

A TBV is defined as a vehicle in which the body can perform a rolling movement relative to the running gear when the vehicle goes round a curve, with the object of compensating for the centrifugal acceleration.

The appearance and the introduction into international service of trainsets made up of vehicles fitted with tilting body systems require certain modifications to be made to the rules in this leaflet regarding the loading gauge calculations.

This Appendix deals with the calculation rules for TBV to obtain the maximum loading gauge as specified in the rules in *UIC Leaflet 505* (see Bibliography - page 114).

The acceptance into international service of rolling stock fitted with tilting body systems shall be subject to bilateral or multilateral agreements between the railways concerned.

F.1.3 - Background

The TBV concept began to be developed in the years 1970-80 in several European countries in order to run with higher speeds on existing lines without detriment to the comfort of the passengers.

The speed in curves of railway vehicles is restricted because of the transverse acceleration which acts on the passengers: this limit of uncompensated acceleration is of the order of 1 to 1,3 m/s^2.

TBV units, in particular those fitted with active systems, can run with high values of uncompensated acceleration (for example 1,82 m/s^2 for the ETR450, equivalent to a cant deficiency of 278 mm) because the tilting of the body enables the values of the transverse acceleration felt by the passengers to be reduced.

F.1.4 - Conditions related to safety

The builders of TBV units must provide evidence that the vehicles meet the loading gauge specified in the *UIC 505 series leaflets*, under all the different cases of operation that are planned.

In addition to the calculation of the loading gauge, the builder shall supply an additional report on the criteria adopted and on the devices on which safety depends.

Certain defects which might result in TBV units exceeding the loading gauge shall be investigated by the builders. Depending on the seriousness of their effects, special measures shall be taken by the railways (e.g. alarms, warning to the driver etc. when the unit is in service).

The builder shall also guarantee that the tilting system is designed to prevent the units running with values of uncompensated acceleration higher than the values allowed for conventional vehicles if the tilting system is defective.

F.1.5 - Symbols used

The symbols defined in the *UIC 505 series leaflets* have been used in this Appendix.

The following additional symbols have also been used:

- I_p = value of the cant deficiency considered for the TBV
- I_c = value of the maximum cant deficiency permitted by the Permanent Way Department of the railway

NB : The justification of the need to take account of this parameter, fixed by the Permanent Way Department of the railways, in the calculations carried out to design the rolling stock, is given in point F.3.2.2.

- E = value of cant
- z_p = quasi-static displacements determined according to the needs of the TBV units.

F.2 - Basic conditions to determine the gauge of TBV units

For the calculation of the gauge of the TBV units, all the running conditions should be examined depending on whether the tilt system is active or not.

The least favourable cases shall be examined, in particular:

Situation 1 :
Case of a vehicle running in a curve with maximum cant deficiency (maximum body tilt);

Situation 2 :
Case of a vehicle stationary in a curve. When an active TBV is stationary on a curve its position does not differ from that of a conventional vehicle, and, therefore, can be dealt with according to the principles and formulae of this leaflet.

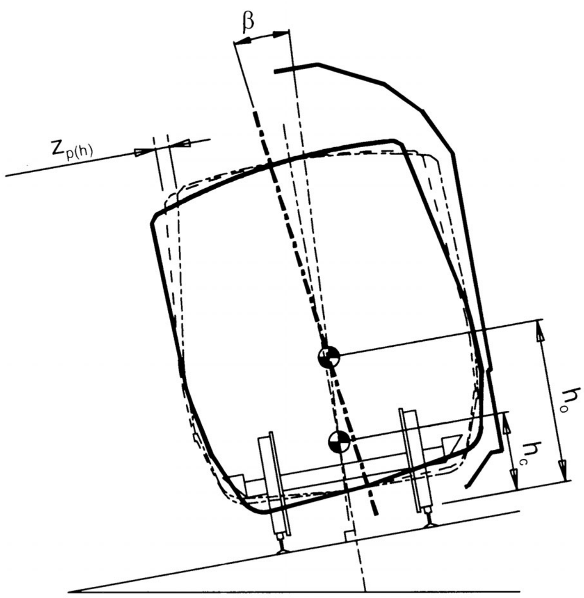
Types of body tilting systems

The various designs of systems can be grouped according to the method of tilt of the bodies. This tilt can be obtained either with a natural tilting movement or equivalent (passive tilt) when the centre of rotation of the body is above the position of the centres of gravity of the bodies as in the TALGO system (see List of abbreviations - page 113) or by jacks which tilt the body depending on the radius of curvature and the speed (active tilting movement as in the FIAT system (see List of abbreviations - page 113)).

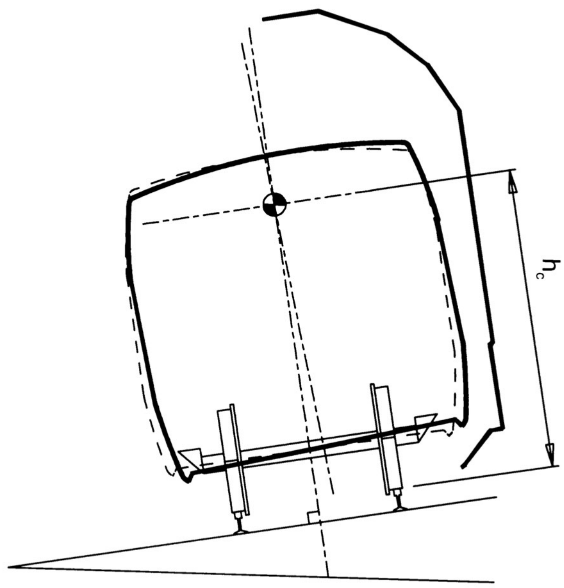
Let us examine the inclination of the body allowed by the different tilting body systems:

In the case of TBV fitted with **ACTIVE systems**, the bodies are subjected to a quasi-static tilt caused by the uncompensated acceleration. This acceleration is not, however, connected to the tilting of the body which is applied separately by the system. The figure below shows the principle of the inclination of a vehicle with an active tilt system.

In the case of the **PASSIVE systems** the body tilts naturally under the effect of the centrifugal force applied, in proportion to the value of the cant deficiency.
The figure below shows the principle of inclination of a vehicle with natural or passive tilt.



ACTIVE system



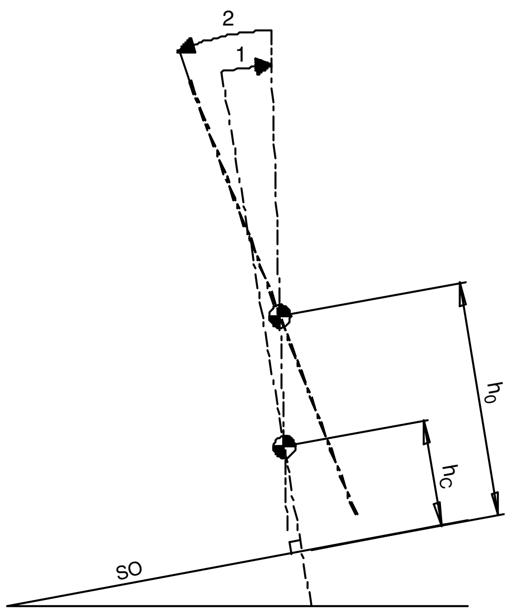
PASSIVE system

The effective movements can be broken down into a rotation due to the roll (movement 1) to which is added the rotation (movement 2) which is superimposed by the system.
Two schematic diagrams are given below for a more detailed explanation.

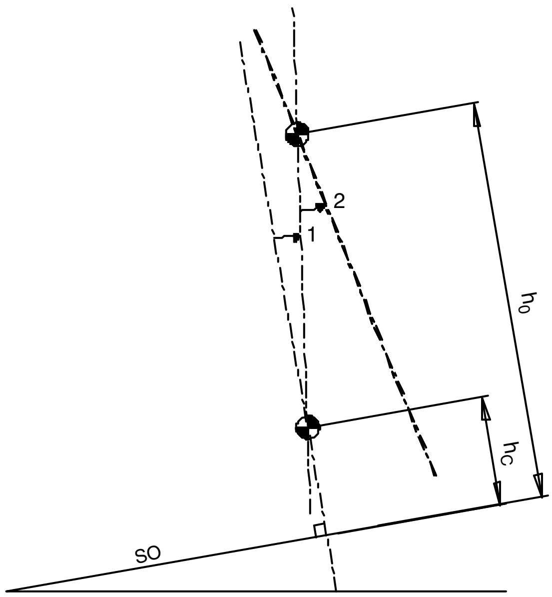
The rotation 2 of the body takes place around a point of which the height above rail level is indicated, in general, by h_0.

One of the methods of tilt that is possible for the TBV unit with passive systems is shown below.
A rotation of the body around the centre of roll followed by a rotation around a point situated at the height h_0 above rail level.

An example of the calculation of an active TBV unit (the FIAT system) is given in point F.5.1 - page 91.



An example of the calculation of passive TBV (TALGO principle) is given in point F.5.2 - page 95



F.3 - Analysis of the formulae

F.3.1 - Basic formulae

Depending on the different types of TBV trains to be designed (coaches, power cars or railcars) users are invited to refer to the corresponding formulae which are given in the main part of this leaflet, to which must be added all the modifications covered in this Appendix.

F.3.2 - Modifications to be made to the formulae for TBV

For the TBV the maximum tilt of the body corresponding to the maximum cant deficiency I_p must be considered. In this condition, the following terms of the reduction formulae need to be reconsidered:

1. Transverse play: (1,465 - d)/2; for q and w - see note below).
   The sign of the transverse displacements, in general, should take account of the centrifugal effect. The changes are discussed in point F.3.2.1 below.

NB : For the TBV calculation this term should be measured at the height h_c above rail level. For the same vehicle, this term can have different values from one calculation to the next, depending on the tilt technology and the recentring of the body that may occur. To explain the concept of the parameter w, see the example in point F.5 and especially the last paragraph of point F.5.2.3.1 - page 97.

2. Quasi-static displacements "z"
The term z as defined in this leaflet and *UIC Leaflet 505-5* is valid provided that vehicles do not exceed, when running, the value of the cant deficiency I_p = 200 mm.
As the TBV can exceed this value and, in general, because of the fact that they can run with values of cant deficiency I_p much greater than those specified by the Permanent Way Department (I_c), the formula needs some modifications which are discussed in point F.3.2.2 - page 87.

3. For certain types of TBV, especially the active ones, a term should be included in the formulae to take account of the tilting of the body imposed by the system.

F.3.2.1 - Expression for the values of the transverse play when the body is tilted

Maximum body tilt only occurs when the vehicle is running in a curve at the maximum value of I_p.

As the vehicle is subjected to a very high centrifugal force towards the outside of the curve, the terms of the transverse displacements should be reconsidered.

The play w is taken towards the outside of the curve.

For the plays (1,465 - d)/2 and q, it is necessary to distinguish between:

- **Bogie vehicles**

  Calculation for the inside of the curve:
  The results of tests on the line have shown that for bogie vehicles, some axles run round the curve with the flange in contact with the outer rail, while for others this contact is not constant. As a result and for safety reasons the play mentioned above will be taken equal to zero.

  Calculation for the outside of the curve:
  The plays (1,465 - d)/2 and q are taken, again for safety reasons, towards the outside of the curve.

- **Vehicles with independent wheels:**
  The tests have confirmed that the plays (1,465 - d)/2 and q are towards the outside of the curve.

F.3.2.2 - Quasi-static displacement of the TBV

To obtain the lineside structure gauge, the Permanent Way Department must add certain terms to the dimension of the reference profile given in *UIC Leaflet 505-4*. The quasi-static displacements of the vehicles are calculated with the formula below:

$$\frac{0,4}{1,5} \cdot [E \text{ or } I - 0,05]_{>0} \cdot (h - 0,5)_{>0}$$

According to *UIC Leaflet 505-5*, the maximum allowable value for E or I is 200 mm.

Each railway fixes for its lines its own maximum value for I. The values generally used are between 90 and 180 mm.

Ordinary vehicles must not exceed this maximum value of I when running.

On the other hand, the TBV units reach higher values. This means that their dimensions need to be checked using a different calculation for the quasi-static displacements.

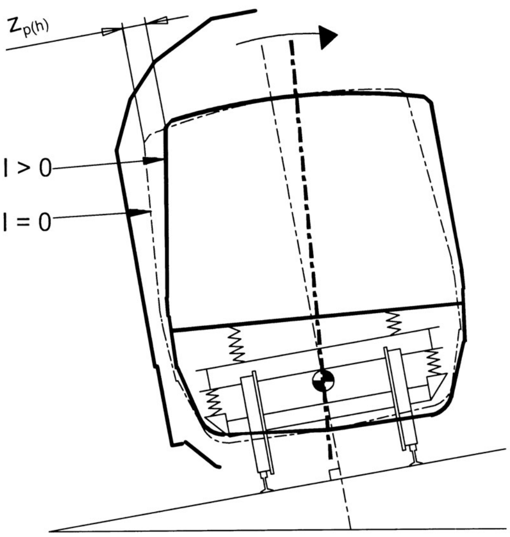
Just as for conventional vehicles, the effect of cant deficiency induces in TBV units a tilting of the body around a longitudinal axis, a rotation which is due to the flexibility of the suspension system. In the formulae of the *UIC 505 series leaflets*, the quasi-static displacements corresponding to this rotation are taken into consideration in the term "z". Because the TBVs can run with cant deficiencies of up to I_p, it is necessary to revise the calculation of this term (z_p).

Hence the introduction of this new term z_p, the formulation of which takes account of the total quasi-static tilt due to I_p, in relation to that considered by the Permanent Way Department, I_c (see points F.3.2.2.1 and F.3.2.2.2 - page 89).

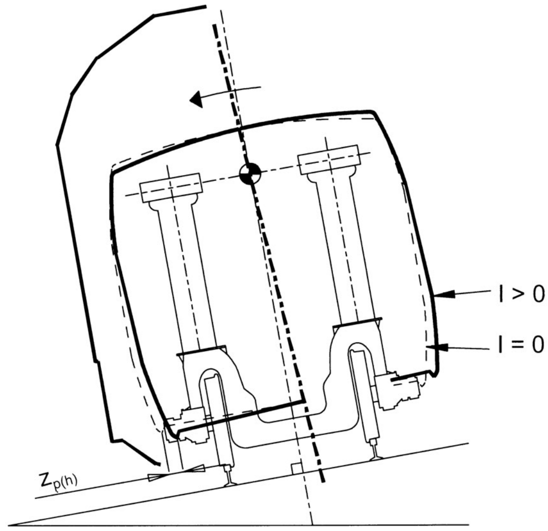
Moreover for the active systems, it is necessary to consider an additional term (see point F.5.1.1 - page 91), because the tilting of the body to compensate for the centrifugal acceleration is independent of the tilt due to the rolling.

F.3.2.2.1 - Expression of the quasi-static displacements z_p for the reductions on the inside of the curve

Under the effect of the transverse acceleration (corresponding to values $I_p > 0$) because of the flexibility of the suspension systems, the body of the vehicle tilts towards the outside of the curve for active TBV units and towards the inside of the curve for passive TBV units. The following figures show this type of displacement from the position I = 0: because of the different mechanisms involved, with the active system the largest movements occur in the upper parts of the body and in the lower parts for the passive system.



ACTIVE system



PASSIVE system

NB : The tilt imposed by the system is not shown here.

- Considering the reference profile on the inside of the curve, the points of the vehicle situated at a height h > h_c move away from the profile. The value of this displacement in the calculation will have a minus sign.
- The opposite is true for points situated at a height h < h_c.

- Considering the reference profile on the inside of the curve, the points of the vehicle situated at a height h < h_c move away from the profile. The value of this displacement in the calculation will have a minus sign.
- The opposite is true for points situated at a height of h > h_c.

The displacements corresponding to different tilts shown in the figures above are indicated below.

For a TBV unit with an active system which runs in curves with a cant deficiency I_p the quasi-static displacements are:

$$z_p = -\frac{s}{1,5} \cdot I_p \cdot (h - h_c) \text{ with } \eta_0 < 1°$$

For a TBV unit with a passive system subjected to a cant deficiency I_p the quasi-static displacements are:

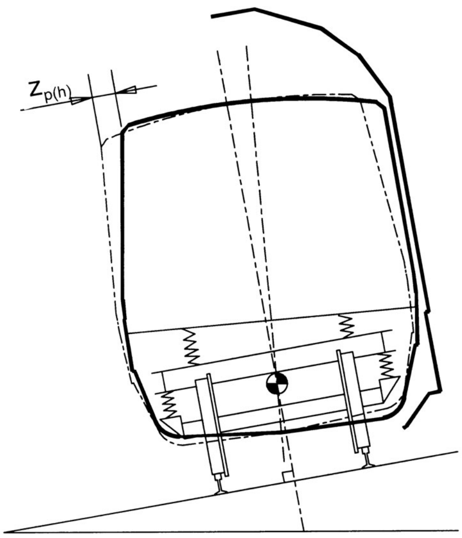
$$z_p = -\frac{s}{1,5} \cdot I_p \cdot (h - h_c) \text{ with } \eta_0 < 1°$$

It is necessary to draw attention to the fact that the value of "s" is specific to the situation calculated and can, therefore, be influenced by the action of the body tilt system.

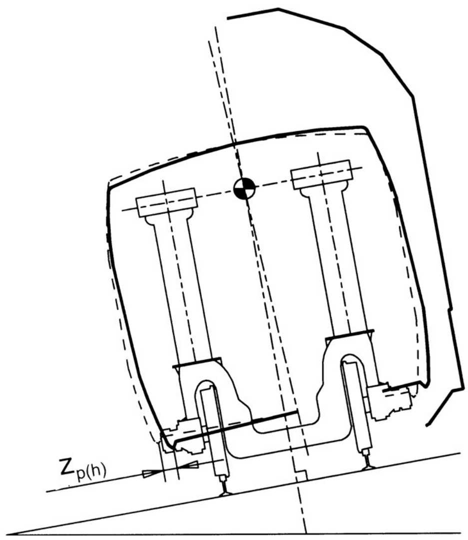
F.3.2.2.2 - Expression of the quasi-static displacements z_p for the reductions on the outside of the curve

Under the effect of the transverse acceleration (corresponding to values I_p > 0), the body of an active TBV unit tilts towards the outside of the curve because of the flexibility of the suspension system and towards the inside of the curve for a passive TBV unit.

Similarly to figures shown in point F.3.2.2.1 - page 88, the following figures represent this type of displacement, from the position I = 0.



ACTIVE system



PASSIVE system

NB : The tilt imposed by the system is not shown here.

- Considering the reference profile on the outside of the curve, the points of the vehicle situated at a height h > h_c move closer to the profile. The value of this displacement in the calculation will have a plus sign.

- The opposite is true for points situated at a height h < h_c.

- Considering the reference profile on the outside of the curve, the points of the vehicle situated at a height h < h_c move closer to the profile. The value of this displacement in the calculation will have a plus sign.

- The opposite is true for points situated at a height of h > h_c.

When the vehicles run in a curve, they move closer to the reference profile (on the outside) in proportion to the value of I_p. Where I_p > I_c, the distances considered by the Permanent Way Department for the positioning of obstacles (as specified in *UIC Leaflet 505-4*) will not be sufficient. Since the position of obstacles cannot be changed, the reductions calculated for vehicles should, if necessary, be increased by a value corresponding to the difference between the quasi-static displacements due to I_p and those taken into account by the Permanent Way Department, in other words:

- Active system

$$z = \left[\frac{s}{1,5}\cdot l_p\cdot(h-h_c)-\frac{0,4}{1,5}\cdot(l_c-0,05)\cdot(h-0,5)\ _{>0}\right]_{>0}$$

- Passive system

$$z = \left[-\frac{s}{1,5}\cdot l_p\cdot(h-h_c)-\frac{0,4}{1,5}\cdot(l_c-0,05)\cdot(h-0,5)\ _{>0}\right]_{>0}$$

It is necessary to remember that:

- the formulae apply where $l_p > l_c$;
- it will be necessary to find, in the application phase corresponding to a real case, the combination of the values for l_p and l_c which give a value of z_p that maximises the reduction: (z_{pi}, z_{pa});
- the intermediate values of l_p must meet the conditions given in point F.6.1 - page 101 and in the note under point F.5.1.2 - page 92.

The justification of the procedure followed to obtain the two expressions above is based on the method indicated in *UIC Leaflet 505-5*.

F.4 - Associated rules

- The formulae in this Appendix apply for $l_p > l_c$.
- The expression of the term z_p should be set out clearly and in detail for each case of application of the formulae for each type of system, bearing in mind the different stops, centre of rolling, etc.
- **It should be stressed that, in keeping with the technical principles of the TBV unit, the parameters s, hc and w for any given vehicle will have different values depending on the calculation cases involved.**
- The maximum values of the reductions shall be calculated depending on the different values likely to be taken by l_p, l_c (and by the angle β for active TBVs (see point F.5.1.1 - page 91)). For this purpose, the TBV builder should bear in mind the most prominent points permitted on the bodies when running over different sections of line (straight track, transitions, curves) and the tolerance possible with regard to the actual position of the vehicle (due to the delay in the activation of the system, inertia, friction, etc.).
- This Appendix has been developed on the basis of knowledge gained from TBV units in service today. Other hypotheses and modifications to the formulae may be added, in the future, after new types of TBV units have been developed.
- **When the examination of all the cases which were thought to be critical has been completed, a comparison should be made between the different permissible half-width dimensions and the smallest value then selected for each of the heights h considered selected.**

F.5 - Examples of application of the general principles

Two examples, one for a vehicle with an active tilt system and another for a vehicle with a passive tilt system, are given below:

F.5.1 - Example of the calculation for a TBV with an "active" tilt system

The example given here is based on the FIAT ETR 450 "Pendolino" vehicles.

Compared with the calculations actually done, the following simplifications have been adopted.

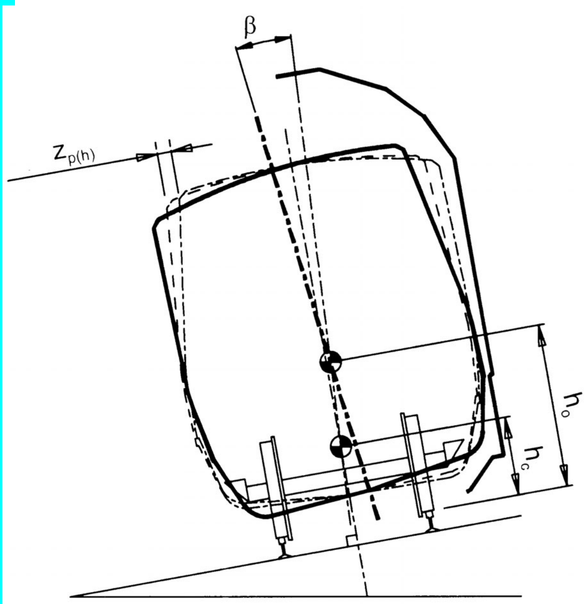
- the values of s and h_c have been taken as constant, although in reality they have different values depending on the case examined;
- the least favourable value has been taken for the displacement factor;
- it should be noted that to determine the tilt applied to the body, the approximate expression used does not take account of the vertical component of the movements.

The numerical values obtained in this way are given for information.

F.5.1.1 - Principle of operation and characteristics

When a vehicle with a tilting body runs over curved track with a speed such that $I_p > 0$, the system works out the angle of tilt of the body β by measuring the value of certain parameters (speed, cant, radius of the curve) (see following figure).

The angle β is independent of the tilt due to the flexibility of the suspension system.



Below 70 km/h, the system does not operate on this train.
In the figure opposite, the following values are shown:
h_0: height of the centre of rotation of the body set by the system.
β: value of the angle of tilt of the body, in relation to the bearing plane of the system; this angle imposed by the system depends on the value of the cant deficiency I_p.
As the angle β can reach values of up to 10°, the vertical component of the movement must not be neglected, and in the case of a real calculation needs to be taken into account.
In this example, account is taken only of the transverse movements where the approximate values are calculated by the following expression:

$$\tan\beta \cdot (h - h_0)$$

This term, bearing in mind the direction of rotation imposed by the system:
- will have a positive sign for the calculations for the inside of the curve,
- will have a negative sign for the calculations for the outside of the curve.

F.5.1.2 - Data

For this example, the following data have been used as a guide, with the simplifications given in point F.5.1 - page 91:

a = 18,9 m	q = 0,001 m	$w_{i(250)}$ = 0,051 m	
d = 1,41 m	s = 0,09 (9/100)	w_{∞} = 0,08 m	h_0 = 1,5 m
p = 2,4 m	h_c = 0,5 m	$w_{a(250)}$ = 0,051 m	β = 8° for I_p = 0,278 m

The two bogies of the TBV are powered. The formulae used are those for power cars. The verification is done with the maximum value calculated for $I_p \cong 0{,}278$ m and for $I_c \cong 0{,}150$ m.

NB : For the intermediate values of cant deficiency I'_p between 0 and 278 mm, for which the corresponding permanent way values I'_c are between 0 and 150 mm, the tilt system must always guarantee the following conditions:

$$I'_p \leq \frac{I_p}{I_c} \cdot I'_c$$

Resilience and deflection are not taken into account in this example.

F.5.1.3 - SITUATION 1 verification: running in a curve with maximum cant deficiency

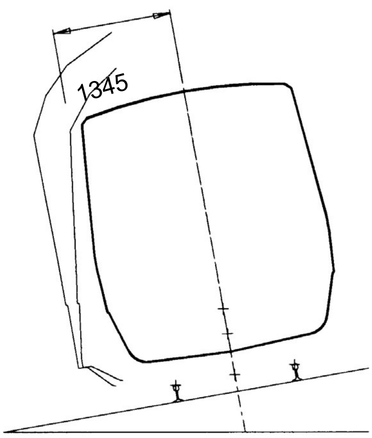
SECTION IN THE MIDDLE OF THE BODY (n = a/2 = 9,45 m).

The formula used is as follows:

$$E_i = \frac{an - n^2 + p^2/4}{500} - w_{a(250)} + z_{pi} + \tan\beta \cdot (h - h_0) + [x_i]_{>0} - \begin{vmatrix} 0,025 \\ 0,030 \end{vmatrix}$$

with:

$$z_{pi} = -\frac{s}{1,5} \cdot I_p \cdot (h - h_c)$$



h	z_{pi}	Reference profile half-width	E_i	Available half-width
4,01	-0,0585	1,12	0,398	0,722
3,75	-0,0542	1,425	0,362	1,063
3,25	-0,0459	1,645	0,3	1,345
1,17	-0,0112	1,645/1,620	0,043	1,602/1,570
0,5	0	1,62	0	1,62

SECTION AT THE END OF THE BODY (n = 3,15 m).

In this case, the calculation shall be done for the sections beyond the pivots.

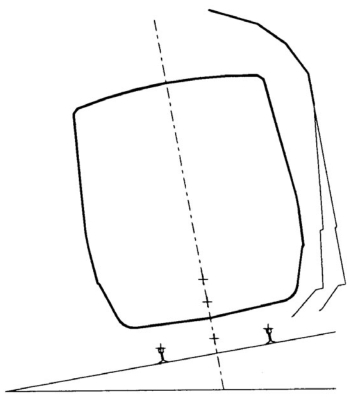
The formula used is as follows:

$$E_a = \frac{an + n^2 - p^2/4}{500} + \frac{1{,}465 - d}{2}(A) + q(A) + w_{a(250)}(A) + z_{pa} - \tan\beta \cdot (h - h_0) + [x_a]_{>0} - \begin{vmatrix} 0,025 \\ 0,030 \end{vmatrix}$$

For this example, the least favourable values of the displacement factor A have been considered, corresponding to case 5 in the table of displacement factors (see Fig. 19 - page 28), although such a position of the vehicle on the track would not necessarily be checked.

$$E_a = \frac{an + n^2 - p^2/4}{500} + \left(\frac{1{,}465 - d}{2} + q\right) \cdot \left(\frac{2n + a}{a}\right) + w_{a(250)}\left(\frac{n + a}{a}\right) + z_{pa} - \tan\beta \cdot (h - h_0) + [x_a]_{>0} - \begin{vmatrix} 0,025 \\ 0,030 \end{vmatrix}$$

with: $z_{pa} = \left[\frac{s}{1{,}5} \cdot l_p \cdot (h - h_c) - \frac{0,4}{1{,}5} \cdot (l_c - 0,05) \cdot (h - 0,5)_{>0}\right]_{>0}$

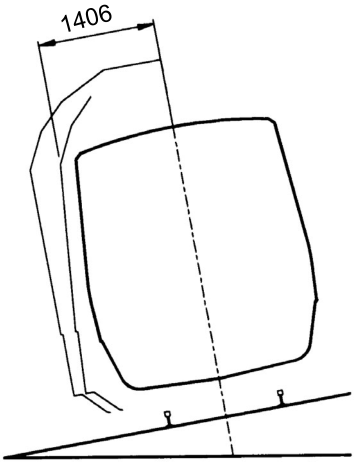


h	z_{pa}	Reference profile half-width	E_a	Available half-width
4,01	0 (-0,035)	1,12	0 (-0,149)	1,120
3,75	0 (-0,032)	1,425	0 (-0,113)	1,425
3,25	0 (-0,027)	1,645	0 (-0,042)	1,645
1,17	0 (-0,0067)	1,645/1,620	0,250	1,395/1,37
0,5	0	1,62	0,344	1,276

F.5.1.4 - SITUATION 2 verification: train stopped on a curve with cant and in a curve at the equilibrium speed

1. TRAIN STOPPED ON A CURVE WITH CANT
   The stationary vehicle shall be checked on a curve with cant.
   In this case, the system is not acting on the position of the body. In all respects, the TBV unit can be assimilated with a conventional vehicle.
   The formulae to be used are those given in this leaflet.

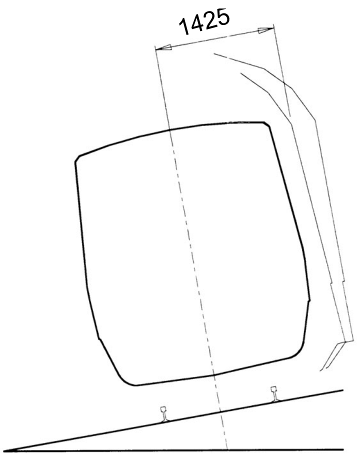
SECTION IN THE MIDDLE OF THE BODY (n = a/2 = 9,45 m).



h	z	Reference profile half-width	E_i	Available half-width
4,31	0,011	0,525	0,242	0,283
4,01	0,01	1,12	0,241	0,878
3,75	0,009	1,425	0,24	1,184
3,25	0,008	1,645	0,239	1,406
1,17	0,002	1,645/1,620	0,233	1,412/1,387
0,5	0	1,62	0,23	1,389

2. TRAIN IN A CURVE AT THE EQUILIBRIUM SPEED

SECTION AT THE END OF THE BODY (n = 3,15 m)

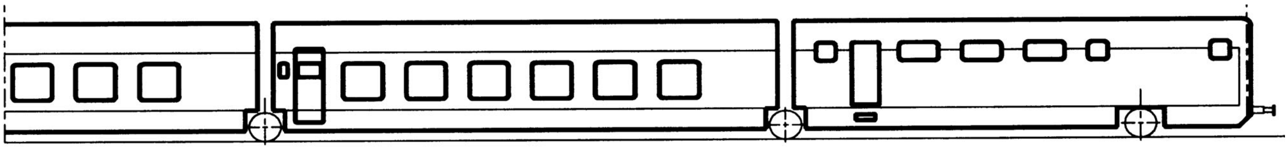


h	z	Reference profile half-width	E_a	Available half-width
4,31	0,011	0,525	0,223	0,302
4,01	0,01	1,12	0,222	0,898
3,75	0,009	1,425	0,222	1,203
3,25	0,008	1,645	0,22	1,425
1,17	0,002	1,645/1,620	0,214	1,431/1,406
0,5	0	1,62	0,212	1,408

F.5.2 - Example of the calculation for a TBV with a "passive" system

The example given here is based on the TALGO PENDULAR vehicles.

F.5.2.1 - Characteristics



The TALGO train has certain characteristics which differ from conventional vehicles:

1. It is made up of short, articulated vehicles forming uniform trainsets.

2. The coaches are fitted with pneumatic cushions situated above the centre of gravity of the body which enable the body to swing out naturally, thereby reducing part of the uncompensated centrifugal acceleration when running in curves. The centre of roll of the body is situated at the height of the centres of the pneumatic cushions of the suspension.

3. The running gear is connected to a structure, the upper part of which also supports the pneumatic cushions and the body. The structure and, therefore, the wheels are installed between the bodies. The end coaches have an additional structure.

4. The wheels are not connected by axles, but turn independently and are guided with an angle of attack that is almost zero.

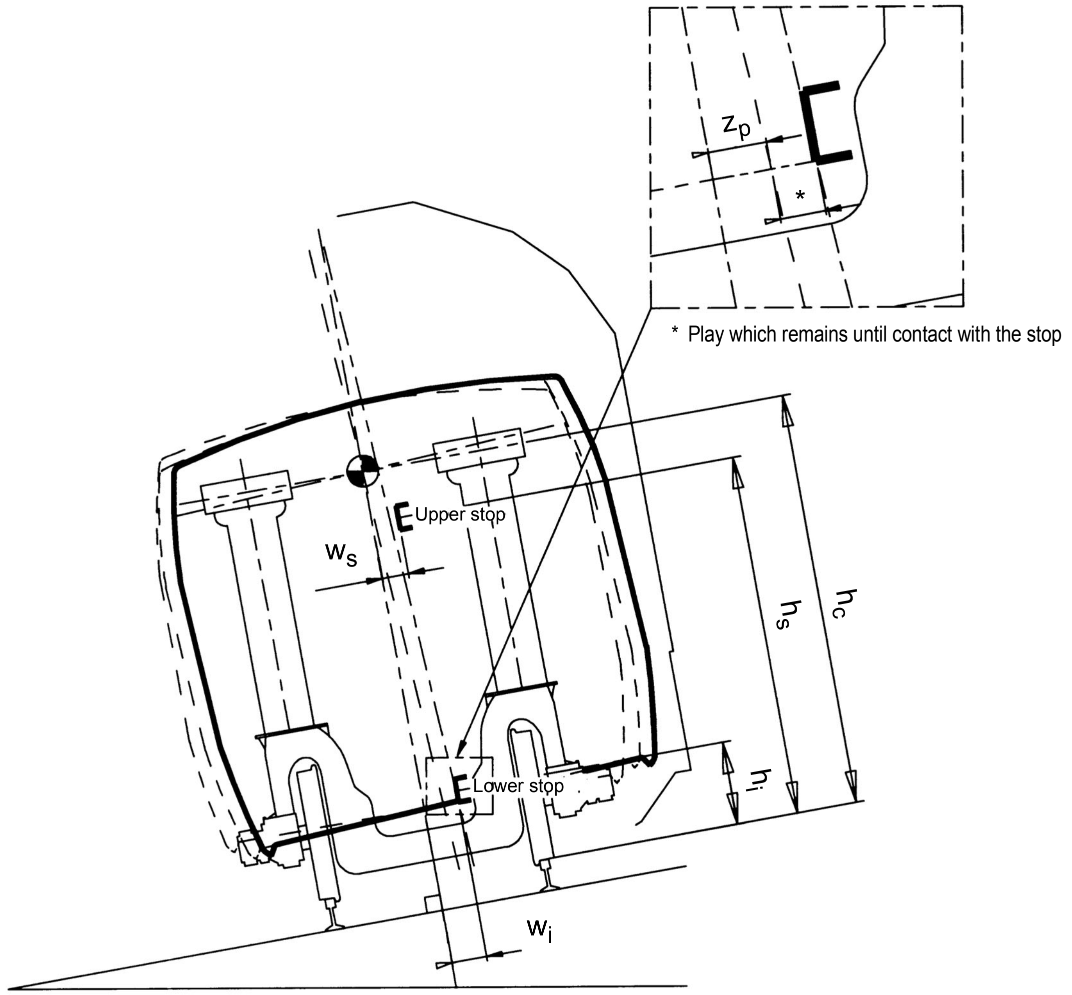
5. The coaches have two lateral stops between body and structure, one situated on the upper part and the other on the lower part of the bodies (see following figure).

F.5.2.2 - Method of operation

1. When the vehicles are stationary (or are subjected to excess cant and $V < 60$ km/h) the suspension system holds the bodies parallel to the plane of the track, that is to say $s = 0$.

2. When the vehicle runs in a curve with cant deficiency, the body rotates through an angle corresponding to I_p, and can then move laterally through the play that remains up to contact with one of its stops (see following figure). The gauge calculation only needs to take account of the contact of one of these stops, the lower or the upper. The movement which results is the least favourable that is found in service.
   The method of tilt shown in the figure below is as follows: the axis of the body rotates (broken line -----) around the centre of rotation towards the top and there is a transverse movement which can

result in contact with the lower stop (mixed line -).



The presence of the two lateral stops means that it is necessary to consider the following parameters:
w_s = value of the play in the upper lateral stop,
w_i = value of the play in the lower lateral stop,
h_s = height of the upper stop above the plane of the track,
h_i = height of the lower stop above the plane of the track.

3. For the TALGO TBV trains, as for conventional trains, any second phase rotation of the body which might occur after contact with the stop is not taken into account since it is not checked during normal operation.

F.5.2.3 - SITUATION 1 verification: running in a curve with maximum cant deficiency

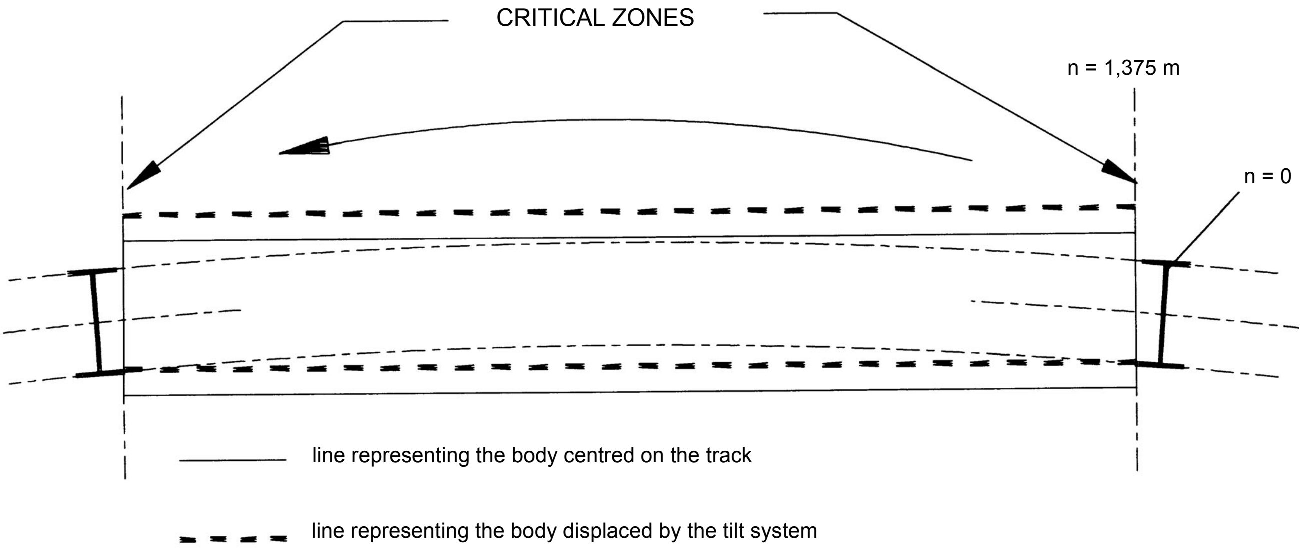
It is possible to specify the following common conditions, for the calculation of E_i and E_a:

- as the TBV unit is not a bogie vehicle: p = 0;
- the vehicle rests on the outer rail of the curve: the plays q, (1,465-d)/2 and w have the appropriate sign.

Since the bodies of the TALGO train tilt towards the outside of the curve, the movement towards the loading gauge on the outside of the curve is considered.

For intermediate coaches, the sections of the bodies concerned are those close to the ends (calculation of E_i).

The drawing below, for $h < h_c$, gives a better idea of the overall dimensions.



For the end vehicles, the most unfavourable section is the overhanging end (calculation of E_a).

F.5.2.3.1 - Formulae used to calculate SITUATION 1

For the calculation of the reductions E_i:

It will be recalled that for this type of vehicle with a tilting body, the critical zone (the section between the axles) is situated towards the outside of the curve and at the bottom of the vehicle (see figure above).

In the case of verification on the outside of the curve, the term for the geometric overthrow in the formula has a negative sign.

The formula below is used, which is derived from that specified in this leaflet for vehicles with axles:

$$E_i = -\frac{an-n^2}{500} + q + \frac{1{,}465-d}{2} + z_{pa} + \left| \begin{array}{l} \overbrace{w_i - \frac{s \cdot l_p}{1{,}5} \cdot |h_i - h_c|}^{(1)} \\ \underbrace{w_s - \frac{s \cdot l_p}{1{,}5} \cdot |h_s - h_c|}_{(2)} \end{array} \right. + [x_i]_{>0} - \left| \begin{array}{l} 0{,}025 \\ 0{,}030 \end{array} \right.$$

In this formula:

- (1) and (2) will be calculated and the smaller of these values will be used; this corresponds to the stop which comes into contact first.

- the term z_{pa} has the following expression:

$$z_{pa} = \left[\frac{s \cdot l_p}{1,5} \cdot (h - h_c) - \frac{0,4}{1,5} \cdot (l_c - 0,05) \cdot (h - 0,5)_{>0}\right]_{>0}$$

- Regarding the movements w, the actual values of w_i (internal) and w_a (external) for curves with 150 m and 250 m radius depend on w_s (above) and w_i (below). When introduced into the formulae of terms $(x_i) > 0$ or $(x_a) > 0$, these have a value of zero.

To calculate the reductions E_a:

The following formula is used:

$$E_a = -\frac{an - n^2}{500} + \frac{1,465 - d}{2} + q + z_{pa} + \left| \begin{matrix} \overbrace{w_i - \frac{s \cdot l_p}{1,5} \cdot |h_i - h_c|}^{(1)} \\ \underbrace{w_s - \frac{s \cdot l_p}{1,5} \cdot |h_s - h_c|}_{(2)} \end{matrix} \right. + [x_a]_{>0} - \left| \begin{matrix} 0,025 \\ 0,030 \end{matrix} \right.$$

The terms (1), (2) and z_{pa} are calculated as indicated above.

F.5.2.3.2 - Application of the formulae in SITUATION 1

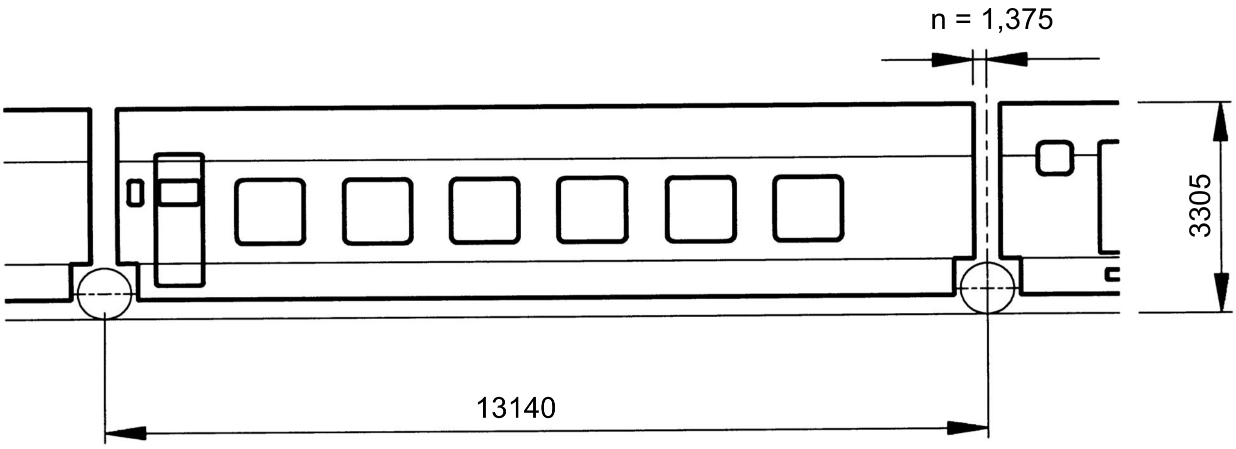
The checks are made for the intermediate coach and for the end coach.

INTERMEDIATE COACH

The following figures have been used:

a = 13,14 m	s = 0,25	l_p = 0,225 m	l_c = 0,2 m
h_i = 0,53 m	h_s = 2,654 m	h_c = 2,654 m	q = 0,001 m
w_i = 0,085 m	w_s = 0,154 m		

The calculations are limited to a height of 3,25 m because of the height of the vehicles.



The results of the calculations are as follows:

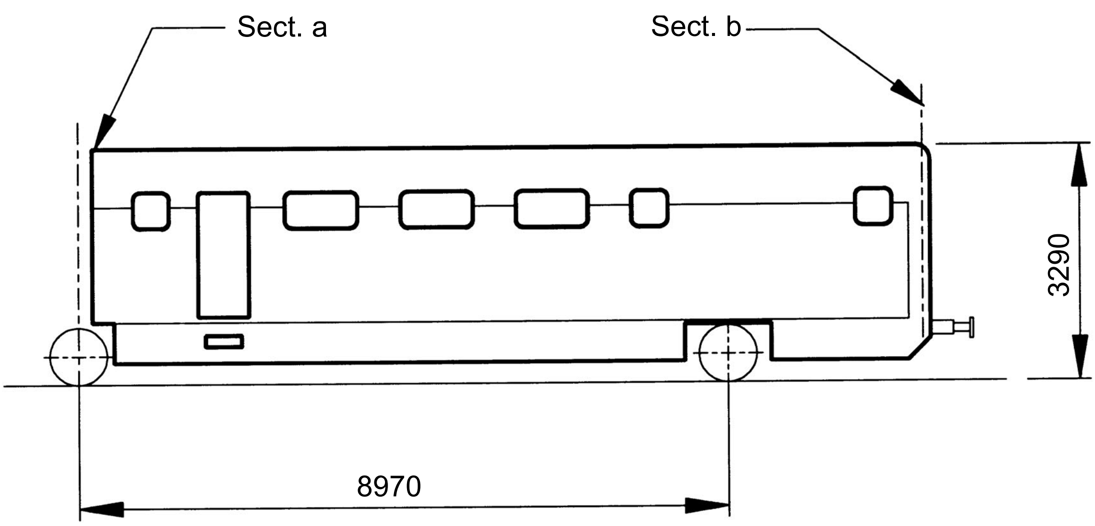
n = 1,375 m

h	z_{pa}	Reference profile half-width	E_i	Available half-width
3,25	0 (-0,132)	1,645	0,0404	1,604
1,17	0,029	1,645/ 1,620	0,069	1,576/ 1,551
0,5	0,081	1,620	0,121	1,499

n = 0

h	z_{pa}	Reference profile half-width	E_i	Available half-width
3,25	0(-0,132)	1,645	0,0728	1,572
1,17	0,029	1,645/ 1,620	0,102	1,543/ 1,518
0,5	0,081	1,620	0,154	1,466

END COACH:



The following figures have been used:

a = 8,97m	s = 0,25	l_p = 0,225 m	q = 0,001 m
h_l = 0,53 m	h_c = 2,135 m	l_c = 0,2 m	
h_s = 2,135 m	w_l = 0,101 m	w_s = 0,085 m	

Calculation for section a, n = 1,4 m (see figure above): OUTSIDE OF THE CURVE

h	z_{pa}	Reference profile half-width	E_i	Available half-width
3,25	0(-0,152)	1,645	0,0181	1,626
1,17	0,009	1,645/1,620	0,027	1,617/1,592
0,5	0,061	1,620	0,079	1,541

Calculation for section b, n = 2,63 m (see figure above): OUTSIDE OF THE CURVE

h	z_{pa}	Reference profile half-width	E_a	Available half-width
3,25	0(-0,152)	1,645	0,1	1,545
1,17	0,009	1,645/1,620	0,109	1,536/1,511
0,5	0,061	1,62	0,161	1,459

F.5.2.4 - SITUATION 2 verification: train stationary on a canted curve

Here, the position of the vehicle is studied in relation to the loading gauge on the inside of the curve. The section in the middle of the body is the critical point.

Formulae for the calculation of SITUATION 2

The following formula is used for the calculation of the reductions E_i:

$$E_i = \frac{an - n^2}{500} + q + \frac{1,465 - d}{2} + z_p + w + [x_i]_{>0} - \left| \begin{matrix} 0,025 \\ 0,030 \end{matrix} \right.$$

See point F.5.2.3.1 - page 97 for the calculation of the term $(x_i) > 0$.

INTERMEDIATE COACH

Calculation for the SECTION IN THE CENTRE OF THE BODY.

As already explained in point F.5.2.2, paragraph 1 (see page 95), s = 0: the term z_p is equal to zero.

The value of w depends on the value of the cant considered: This value is 0,057 m (curve of radius 250 m, cant 0,150 m).The following data were used:

a = 13,14 m	s = 0	l_p = 0,225 m
h_l = 0,53 m	h_c = 2,654 m	l_c = 0,2 m
h_s = 2,654 m	q = 0,001 m	w_{i250} = 0,057 m

n = 6,57 m

h	z_p	Reference profile half-width	E_i	Available half-width
3,25	0	1,645	0,142	1,503
1,17	0	1,645/1,620	0,142	1,503/1,478
0,5	0	1,62	0,142	1,478

F.6 - Comments

F.6.1 - Condition for adjusting the inclination (TBV units with active system)

For the fomulae given in this Appendix for the calculation of the construction gauge of TBV units to be valid, the tilt system must guarantee that the body is inclined in a way that is proportional to the variation of the cant deficiency. For passive systems, this condition is obviously fulfilled as the tilt of the body is caused by the cant deficiency itself.

For TBV units with active tilt system, on the other hand, the values that the system imposes on the bodies are determined by the design or the settings of the system.

These values must meet the following conditions to ensure that the bodies do not exceed the specified profile:

1. The intermediate values l'_p, l'_c and E' between 0 and the maximum value of the respective quantities, should meet, from the point of view of the tilt system settings, the following condition:

$$\frac{l'_p}{l_p} = \frac{l'_c}{l_c} = \frac{E'}{E}$$

2. Moreover, for verification at the outside of the curve, in view of the fact that the centrifugal force tilts the body towards the outside (quasi-static movement z_p), the following condition, regarding the value of β for the settings, must be observed:

$$\tan\beta \cdot (h - h_0) \geq z_p$$

effect of the system quasi-static effect

F.6.2 - Condition concerning the speed of TBV units

It is possible to calculate a maximum value for the speed of TBV units from the point of view of the gauge.

Reference is made to the expression given in *UIC Leaflet 505-5* which relates the cant deficiency to the speed:

$$I_{p\ or\ c} = 0,0118 \cdot \frac{V^2_{p\ or\ c}}{R} - E$$

The speeds V_p and V_c are respectively the value taken by the TBV unit and the corresponding value allowed for the track, depending on the maximum speed permitted on the line.

Thus:

$$V_p \leq \sqrt{\frac{I_p + E}{I_c + E}} \cdot V_c$$

From this formula, it is possible to deduce the maximum value of the speed that must not be exceeded by a TBV unit, according to the following formula:

$$V_p \leq \sqrt{\frac{I_p + E}{I_c + E}} \cdot V_c$$

F.7 - Pantograph gauge verification

Commonness.

The resulting transverse movement of a pantograph placed on a tilting vehicle, normally being inadmissible, the solution had been to fix the pantograph to structures that doesn't tilt or to make it active and counter-rotating. Conventional vehicles running in curve with $I_P > I_C$ are in a similar situation

The vehicle manufacturer shall certify that the counter-rotating system should be so designed that the vehicle cannot run with values of uncompensated acceleration higher than the values allowed for conventional vehicles, when the tilting system of pantograph is defective.

When tilting device is on, or when $I_p > I_c$, the points F7.1 or F7.2.must be fulfilled.

Degraded modes of counter-rotating system must be submitted to a risk analysis by the vehicle builder, such to avoid any contact with catenary parts and mainly the ripping of the wire.

Symbols:

S_n: flexibility coefficient of the structure carrying the pantograph:

1. Pantograph on a rigid frame fixed to the bogie (type ETR 460 Fiat): the value is referred to this frame;

2. Active pantograph and counter-rotating: the value is the one of the vehicle body.

F.7.1 - Pantographs uncoupled to the tilting body

F.7.1.1 - Pantographs located between bogie pivot (or end axles)

F.7.1.1.1 - Vehicle in stationary condition in canted track

The formulas are the same as for conventional vehicles.

F.7.1.1.2 - Vehicle running in a curve with cant deficiency

This case can be leaded back to the straight line, where overthrow and projections are nihil.

$j'_a = q + w_a - 0{,}0375$

$$z'_p = \left[\frac{l_p(6{,}5 - h_c)}{1{,}5} . s_n\right] - 0{,}9 I_c + \sqrt{t^2 + \tau^2 + [\theta(6,5 - h_c)]^2} - 0{,}0575$$

$$z''_p = \left[\frac{l_p(5 - h_c)}{1{,}5} . s_n\right] - 0{,}675 I_c + \sqrt{\left[t \cdot \frac{5 - h_t}{6{,}5 - h_t}\right]^2 + \tau^2 + [\theta(5 - h_c)]^2} - 0{,}0475$$

$$E'_a = j'_a + z'_p \qquad (127)$$

If $E'_a \leq 0$ the pantograph remain inside the gauge in its upper collecting point

$$E''_a = j'_a + z''_p \qquad (128)$$

If $E''_a \leq 0$ the pantograph remain inside the gauge in its lower collecting point

F.7.1.2 - Pantograph located beyond bogie pivots (or end axles)

Vehicle in running conditions on tracks with can't deficiency

The maximum values for E'_a and E''_a must be found searching the appropriate value for R.

$$j'_a = (q + w_{aR}) . \frac{2.n_a + a}{a} - 0{,}0375$$

$$z'_p = \left[\frac{l_p(6{,}5 - h_c)}{1{,}5} . s_n\right] - 0{,}9 I_c + \sqrt{t^2 + \tau^2 + [\theta(6{,}5 - h_c)]^2} - 0{,}0575$$

$$z''_p = \left[\frac{l_p(5-h_c)}{1{,}5}.s_n\right] - 0{,}675 I_c + \sqrt{\left[t.\frac{5-h_t}{6{,}5-h_t}\right]^2 + \tau^2 + [\theta(5-h_c)]^2} - 0{,}0475$$

(129)

$$E'_a = \left[\frac{a.n_a + n_a^2 - \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + \frac{1{,}465 - d}{2}.\frac{2n_a + a}{a} + j'_a + z'_p$$

If $E'_a \leq 0$ the pantograph remain inside the gauge in its upper collecting point

(130)

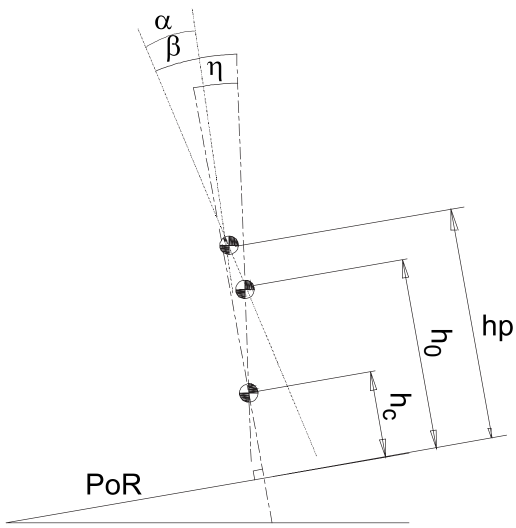
$$E''_a = \left[\frac{a.n_a + n_a^2 - \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + \frac{1{,}465 - d}{2}.\frac{2n_a + a}{a} + j'_a + z''_p$$

If $E''_a \leq 0$ the pantograph remain inside the gauge in its lower collecting point

F.7.2 - Pantographs coupled to the tilting body or equipped by a centering system

F.7.2.1 - Pantographs with counter rotating system

The pantograph must be centered to counterbalance the transverse movement of vehicle body and the its frame must counter-rotate, to assure a proper contact angle with catenary.



With:

β:	tilting angle of vehicle body
α:	pantograph tilting angle
ho:	height of the center of rotation of the tilting body
hp:	height of the center of rotation of the tilting pantograph

NB : The drawing is not constraining on:
- The relative position relative of the several centers of rotation;
- The amount and the direction of the rotation angles;
- Taking into account the effective movements of the tilting system of the body and of the pantograph.

Like for bodies the rotation of the pantograph will be calculated by mean of an additional part tan β (6,5 - h_o) or tan β (5 - h_o), to add to the formulas (127) (128) (129) and (130):

Pantographs located between bogie pivot (or end axles)

$$E'_a = j'_a + z'_p - \tan\beta(6,5 - h_o) + \tan\alpha(6,5 - h_p) \qquad (127a)$$

$$E''_a = j'_a + z''_p - \tan\beta(5 - h_c) + \tan\alpha(5 - h_p) \qquad (128a)$$

Pantograph located beyond bogie pivots (or end axles)

$$E'_a = \left[\frac{a.n_a + n_a^2 - \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + \frac{1{,}465 - d}{2} \cdot \frac{2n_a + a}{a} + j'_a + z'_p - \tan\beta(6,5 - h_o) + \tan\alpha(6,5 - h_p) \qquad (129a)$$

$$E''_a = \left[\frac{a.n_a + n_a^2 - \frac{p^2}{4} - 5}{2 \cdot R}\right]_{>0} + \frac{1{,}465 - d}{2} \cdot \frac{2n_a + a}{a} + j'_a + z''_p - \tan\beta(5 - h_o) + \tan\alpha(5 - h_p) \qquad (130a)$$

See also the nota at the next paragraph

F.7.2.2 - Pantographs having a centering system (non tilting vehicles)

To balance the transverse movement of the vehicle body, the pantograph will be shifted depending on the non compensated transverse acceleration.

Since the values E'_i , E''_i , E'_a and E''_a must be less or equal to zero, the vehicle manufacturer will center the pantograph of an amount almost equal to the positive value given by the formulas (127) (128) (129) or (130).

NB : The centering system must assure that the shifting movement does not exceed the one of the body vehicle. For this, the pantograph must be verified in the internal side of the curve, when the pantograph is in its shifted position, using the effective value for parameters (as plays, unsymmetries etc.).
The maximum value allowed for pantograph bow movement, internal side of the curve, measured from its centered position, will be:

$$0,110 + \frac{0,04}{1,5}(h-5)_{>0}$$

Appendix G - Use of the available spaces of the infrastructure by vehicles with fixed parameters

Application must be covered by mutual agreement.

For the symbols used, see *UIC Leaflet 505-4*.

Example:

For a straight section of track in well-maintained condition and with the usual geometric irregularities, the critical parameter is the distance between the track centres, which is equal to the width of the reference profile plus the margins covering random vehicle movements caused by track geometry defects (D).

$$D = \sqrt{d_i^2 + d_a^2}$$

$$d_{i,a} = 1,2\sqrt{\sum t_{i,a}^2}$$

$$t_i \Big|_{i=1}^{i=5} \qquad t_a \Big|_{a=1}^{a=5}$$

t_1 = lateral movement of the track

t_2 = effect of a defect in the cant or the transverse levelling of 0,015 m

$t_{3i,a}$ = oscillations towards the inside or outside

t_4 and t_5 = effect of uneven load and asymmetry

t_1 = 0,025

$$t_2 = 0,015\frac{h}{1,5} + 0,015(h - h_c)\frac{s}{1,5}$$

$$t_{3,i} = 0,007(h - h_c)\frac{s}{1,5}$$

$$t_{3,a} = 0,039(h - h_c)\frac{s}{1,5}$$

$$t_4 = 0,05(h - h_c)\frac{s}{1,5}$$

$$t_5 = 0,015(h - h_c)\frac{s}{1,5}$$

The following parameters are used to determine the margins to be added to the UIC reference profile:

h = 3,25 m

h_c = 0,5 m

s = 0,4

The fixed parameters of the vehicle to be studied can be used, for example:

h = 1,8 m (height above rail level for a certain section of the body)

h_c = 0,7 m

s = 0,24

Application of the parameters mentioned above gives the following values:

- for the UIC reference profile D = 0,113 m
- for the vehicle with fixed parameters D' = 0,058 m

The difference D - D' = 0,055 m may be used for widening the vehicle with fixed parameters.

When the margin to cover random movements is not calculated in this way but defined as a fixed amount, and if this leads to smaller dimensions, this should be taken into account when calculating D-D'.

Example SNCF, V $\leq$ 120 km/h: D_{SNCF} = 0,05 + 0,03 = 0,08 m.

The vehicle with fixed parameters could then be widened by 0,022 m at a height of 1,8 m.

Glossary

A:	displacement factor (see point 6.2.2)
a:	distance between the end axles of vehicles not fitted with bogies or between the pivots of bogie vehicles (see Note)
b:	half width of the vehicle (see diagram Appendix E)
b1:	half distance between the primary suspension springs (see diagram Appendix E)
b2:	half distance between the secondary suspension springs (see diagram Appendix E)
bG:	half distance between the transoms (see point 7.1.3.2)
bw:	half width of the pantograph bow (see point 7.2.1.3 and UIC Leaflet 608)
C:	roll centre (see Figure 3)
d:	the outer distance between the wheel flanges measured at a point 10 millimetres below the running treads, with the flanges worn to the permissible limit, the absolute limit being 1,410 m. This limit may vary according to the maintenance criteria for the vehicle under consideration (see point 7.1.2)
dga:	external geometric overthrow (see point 3.3)
dgi:	internal geometric overthrow (see point 3.3)
D:	lateral movement (see point 6.2)
E:	cant (mm)
Ea:	external reduction (see point 3.12)
Ei:	internal reduction (see point 3.12)
E'a:	external deviation in relation to the movement authorised at the pantograph upper verification point (6,5 m) (see point 7.2.3.1)
E'i:	internal deviation in relation to the movement authorised at the pantograph upper verification point (6,5 m) (see point 7.2.3.1)
E''a:	external deviation in relation to the movement authorised at the pantograph lower verification point (5,0 m) (see point 7.2.3.1)
E''i:	internal deviation in relation to the movement authorised at the pantograph lower verification point (5,0 m) (see point 7.2.3.1)
ea:	external vertical reduction at the lower part of vehicles (see point 6.1.1.3)

ei:	internal vertical reduction at the lower part of vehicles (see point 6.1.1.3)
f:	vertical sag (see Appendix E)
h:	height in relation to the running surface (see point 6.2.3)
hc:	height of the roll centre of the transverse cross-section of the vehicle in relation to the running surface (see point 3.4)
h0:	height of the roll centre of TBV (see Appendix F)
ht:	installation height of the pantograph lower articulation in relation to the running surface (see point 7.2.3.1)
I, Ic, Ip:	cant deficiency (mm) (see Appendix F)
J:	transom play (see point 7.2.3.2)
J'a, J'i:	difference between the movements resulting from the calculation and movements due to play effects (see point 7.2.1.3)
l:	track gauge (see points 5 and 6)
n:	distance of the section considered to the adjacent end axle or to the nearest pivot (see Note)
na:	n for the sections located outside the axles or bogie pivots
ni:	n for the sections located between the axles or bogie pivots
n:	distance of the section considered to the motor bogie pivot of multiple units (see Note)
p:	bogie wheelbase (see point 7.1)
p':	trailer bogie wheelbase for multiple units
q:	lateral play between axle and bogie frame or between axle and vehicle body in the case of axle vehicles (see point 7.1.2)
R:	level curve radius (see point 7)
Rv:	vertical curve radius (see point 6.1.1.3)
s:	vehicle flexibility coefficient (see point 3.6)
S:	projection (see points 3.10 and 6.2.1)
S0:	maximum projection (see points 3.10 and 6.2.1)
t:	pantograph flexibility index: lateral movements expressed in metres to which the bow is subjected when raised to 6,50 m under the effect of a 300 N lateral force (see point 7.2.3.1)

V: running speed of the rolling stock (km/h)

w: lateral play between bogie and vehicle body (see point 7.1.2)

w¥: lateral play between the bogie and the vehicle body on straight track (see point 7.1.2)

wa: lateral play between the bogie and vehicle body on the outside of the curve (see point 7.1.2)

wi: lateral play between the bogie and vehicle body on the inside of the curve (see point 7.1.2)

wa(R): lateral play between the bogie and vehicle body on the outside of an R radius curve (see point 7.1.2)

wi(R): lateral play between the bogie and vehicle body on the inside of an R radius curve (see point 7.1.2)

w'_{∞} - w'a - w'i - w'a(R) - w'i(R)
are the same for the trailer bogies of multiple units.

xa: additional reduction for extra-long vehicles outside the bogie pivots (see point 7.1.4)

xi: additional reduction for extra-long vehicles between the bogie pivots (see point 7.1.4)

y: distance from the fictional pivot to the geometric centre of the bogie (see Note)

z: deviation in relation to the median position due to quasi-static inclination and to asymmetry (see point 7.1.3)

z': difference between the lateral inclination based on calculation and the actual inclination of the pantograph upper verification point

z": difference between the lateral inclination based on calculation and the actual inclination of the pantograph lower verification point

zp: quasi-static displacements of TBV units (see Appendix F)

zpa: quasi-static displacement of TBV units on the outside of the curve (see Appendix F

zpi: quasi-static displacement of TBV units on the inside of the curve (see Appendix F

a : additional vehicle body inclination due to transom play

b : angle of tilt of the body of TBV (see Appendix F)

d: inclination of canted track (see figure 3)

h: inclination of the vehicle body due to suspension flexibility (see point 3.6)

ho: angle of vehicle asymmetry due to construction tolerances, to suspension adjustment and to uneven load distributions (in degrees) (see point 3.5)

q: suspension adjustment tolerance: inclination which the vehicle body may attain as a result of suspension adjustment imperfections when the vehicle is resting empty on level track (in radians) (see point 7.2.3.1)

: rail-wheel adhesion coefficient (see point 6.2.2.1)

t: pantograph construction and installation tolerance: deviation tolerated between the vehicle body centreline and the middle of the bow presumed to be raised to 6,5 m without any lateral stress (see point 7.2.3.1)

N.B.: In the case of vehicles without fixed bogie pivots, in order to determine the a and n values, the meeting point of the bogie longitudinal centreline with that of the vehicle body will be considered as a fictional pivot, determined graphically, when the vehicle is on a 150 m radius curve, the play effects being evenly distributed and the axles centred on the track: if "y" is the distance of the fictional pivot from the geometric centre of the bogie (at equal distance from the end axles), "p" will be replaced by (p - y) and "p'" by (p' - y) in the formulae.

List of abbreviations

FIAT	Manufacturer of tilting trains
ORE/ERRI	European Rail Research Institute
OSJD	Organisation for Collaboration between Railways
q.s.	Quasi-static
RIC	Agreement governing the exchange and use of coaches in international traffic
RIV	Agreement governing the exchange and use of wagons between Railway Undertakings
SNCF	French Railways
TALGO	Manufacturer of tilting trains
TBV	Tilting body vehicle

Bibliography

1. UIC leaflets

International Union of Railways(UIC)
UIC Leaflet 430-3: Freight wagons - Technical conditions for freight wagons capable of running on both standard-gauge and Finnish broad gauge systems, 2nd edition of 1.7.95

UIC Leaflet 503: Continental wagons running in Great Britain - General conditions (Reference profile, axle-load, etc.) for the acceptance, in international traffic with Great-Britain, of 2-axle and bogies wagons registered with other UIC Railways, 6th edition, November 2004

UIC Leaflet 505-4: Effects of the application of the kinematic gauges defined in the 505 series of UIC Leaflets on the positioning of structures in relation to the tracks and of the tracks in relation to each other, 3rd edition of 1.1.77 and 2 Amendments (4th under preparation)

UIC Leaflet 505-5: Basic conditions common to UIC Leaflets 505-1 to 505-4 - Notes on the preparation and provisions of these UIC Leaflets, 2nd edition of 1.1.77 and 4 Amendments

UIC Leaflet 506: Rules governing application of the enlarged GA, GB and GC gauges, 1st edition of 1.1.87 and 4 Amendments (2nd edition under preparation)

UIC Leaflet 507: Wagons - Conditions governing wagons conveyed on ferries, 1st edition of 1.7.89 - Reprint dated 1.7.97

UIC Leaflet 510-2: Trailing stock. Conditions concerning the use of wheels of various diameters with running gear of different types, 4th edition, May 2004

UIC Leaflet 522: Technical conditions to be fulfilled by the automatic coupler of the UIC and OSJD Member Railways, 4th edition of 1.1.90

UIC Leaflet 560: Doors, footboards, windows, steps, handles and handrails of coaches and luggage vans, 12th edition, March 2002

UIC Leaflet 567: General conditions for coaches, 2nd edition, November 2004

UIC Leaflet 569: Regulations to be observed in the construction of coaches and vans suitable for conveyance by train ferry, 2nd edition of 1.7.79 and 2 amendments

UIC Leaflet 606-1: Consequences of the application of the kinematic gauges defined by UIC UIC Leaflets in the 505 series on the design of the contact lines, 1st edition of 1.1.87 and 1 Amendment

UIC Leaflet 608: Conditions to be complied with for the pantographs of tractive units used in international services, 3rd edition, April 2003

UIC Leaflet 822: Technical specification for the supply of helical compression springs, hot or cold coiled for tractive and trailing stock, 5th edition, November 2003

2. ERRI reports

European Rail Research Institute (ERRI)
DT 135 B12. Generally applicable calculation methods for studying new wagon and bogie types (exists only in French and German), 01.10.1995

3. Miscellaneous

International Union of Railways (UIC)
RIV. Agreement governing the exchange and use of wagons between Railway Undertakings (RIV 2000), Corrigendum 2 of 1.11.02

RIC. Agreement governing the exchange and use of coaches in international traffic, Corrigendum 1 of 15.12.02

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