



BSI Standards Publication

Railway applications - Track - Track alignment design parameters - Track gauges 1 435 mm and wider

National foreword

This British Standard is the UK implementation of EN 13803:2017. It supersedes BS EN 13803-1:2010 and BS EN 13803-2:2006+A1:2009, which are withdrawn.

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A list of organizations represented on this committee can be obtained on request to its secretary.

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Bahnanwendungen - Oberbau - Trassierungsparameter - Spurweiten 1 435 mm und größer

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European foreword

This document (EN 13803:2017) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2017, and conflicting national standards shall be withdrawn at the latest by October 2017.

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

This document supersedes EN 13803-1:2010 and EN 13803-2:2006+A1:2009.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive 2008/57/EC.

For relationship with EU Directive 2008/57/EC, see informative Annex ZA, which is an integral part of this document.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

The purpose of this European Standard is to specify rules and limits for track alignment design parameters, including alignments within switches and crossings. Several of these limits are functions of speed. Alternatively, for a given track alignment, it specifies rules and limits that determine permissible speed.

This European Standard applies to nominal track gauges 1 435 mm and wider with speeds up to 360 km/h. Normative Annex A describes the conversion rules which shall be applied for tracks with nominal gauges wider than 1 435 mm. Normative Annex B is applied for nominal track gauges 1 520 mm, 1 524 mm and 1 668 mm.

This European Standard is also applicable where track alignment takes into account vehicles that have been approved for high cant deficiencies (including tilting trains).

More restrictive requirements of Technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union (TSI INF) and other (national, company, etc.) rules will apply.

This European Standard need not be applicable to lines, or dedicated parts of railway infrastructure that are not interoperable with railway vehicles tested and approved according to EN 14363.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13848-5, *Railway applications — Track — Track geometry quality — Part 5: Geometric quality levels — Plain line*

EN 14363, *Railway applications - Testing and Simulation for the acceptance of running characteristics of railway vehicles - Running Behaviour and stationary tests*

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

EN 15273-2, *Railway applications — Gauges — Part 2: Rolling stock gauge*

EN ISO 80000-3, *Quantities and units - Part 3: Space and time (ISO 80000-3)*

3 Terms and definitions

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

3.1

track gauge

distance between the corresponding running edges of the two rails

3.2

nominal track gauge

single value which identifies the track gauge but may differ from the design track gauge, e.g. the most widely used track gauge in Europe that has a nominal value of 1 435 mm although this is not the design track gauge normally specified

3.3

limit

design value not to be exceeded

Note 1 to entry: These values ensure maintenance costs of the track are kept at a reasonable level, except where particular conditions of poor track stability can occur, without compromising passenger comfort. However, the actual design values for new lines should normally have substantial margins to the limits.

Note 2 to entry: For certain parameters, this European Standard specifies both a normal limit and an exceptional limit. The exceptional limits represent the least restrictive limits applied by any European railway, and are intended for use only under special circumstances and can require an associated maintenance regime.

3.4

alignment element

segment of the track with either vertical direction, horizontal direction or cant obeying a unique mathematical description as a function of chainage

Note 1 to entry: Unless otherwise stated, the appertaining track alignment design parameters are defined for the track centre line and the longitudinal distance for the track centre line is defined in a projection in a horizontal plane.

3.5

chainage

longitudinal distance along the horizontal projection of the track centre line

3.6

curvature

derivative of the horizontal direction of the track centre line with respect to chainage

Note 1 to entry: In the direction of the chainage, curvature is positive in a right-hand curve and negative on a left-hand curve. The magnitude of the curvature corresponds to the inverse of the horizontal radius.

3.7

circular curve

curved alignment element of constant curvature

3.8

transition curve

alignment element where curvature changes with respect to chainage

Note 1 to entry: The clothoid (sometimes approximated as a 3rd degree polynomial, “cubic parabola”) is normally used for transition curves, giving a linear variation of curvature. In some cases, curvature is smoothed at the ends of the transition.

Note 2 to entry: It is possible to use other forms of transition curve, which show a nonlinear variation of curvature. Informative Annex C gives a detailed account of certain alternative types of transitions that may be used in track alignment design.

Note 3 to entry: Normally, a transition curve is not used for the vertical alignment.

3.9

compound curve

sequence of curved alignment elements, including two or more circular curves in the same direction

Note 1 to entry: The compound curve can include transition curves between the circular curves and/or the circular curves and the straight tracks.

3.10**reverse curve**

sequence of curved alignment elements, containing alignment elements which curve in the opposite directions

Note 1 to entry: A sequence of curved alignment elements can be both a compound curve and a reverse curve.

3.11**cant**

amount by which one running rail is raised above the other running rail, in a track cross section

3.12**equilibrium cant**

cant at a particular speed at which the vehicle will have a resultant force perpendicular to the running plane

3.13**cant deficiency**

difference between applied cant and a higher equilibrium cant

Note 1 to entry: When there is cant deficiency, there will be an unbalanced lateral force in the running plane. The resultant force will move towards the outer rail of the curve.

3.14**cant excess**

difference between applied cant and a lower equilibrium cant

Note 1 to entry: When there is cant excess, there will be an unbalanced lateral force in the running plane. The resultant force will move towards the inner rail of the curve.

Note 2 to entry: Cant on a straight track results in cant excess, generating a lateral force towards the low rail.

3.15**cant transition**

alignment element where cant changes with respect to chainage

Note 1 to entry: Normally, a cant transition coincides with a transition curve.

Note 2 to entry: Cant transitions giving a linear variation of cant are usually used. In some cases, cant is smoothed at the ends of the transition.

Note 3 to entry: It is possible to use other forms of cant transition, which show a nonlinear variation of cant. Informative Annex C gives a detailed account of certain alternative types of transitions that may be used in track alignment design.

3.16**cant gradient**

absolute value of the derivative (with respect to chainage) of cant

3.17**rate of change of cant**

absolute value of the time derivative of cant

3.18**rate of change of cant deficiency**

absolute value of the time derivative of cant deficiency (and/or cant excess)

3.19**track distance**

lateral distance between two tracks, measured at the horizontal projection of the track centre lines

Note 1 to entry: Other standards can define track distance as the sloping length parallel to a canted track plane.

4 Symbols and abbreviations

No.	Symbol	Designation	Unit
1	dD/ds	cant gradient	mm/m
2	dD/dt	rate of change of cant	mm/s
3	dI/dt	rate of change of cant deficiency (and/or cant excess)	mm/s
4	D	cant	mm
5	D_{EQ}	equilibrium cant	mm
6	E	cant excess	mm
7	g	acceleration due to gravity according to EN ISO 80000-3	m/s^2
8	I	cant deficiency	mm
9	L_c	length between two abrupt changes of curvature	m
10	L_D	length of cant transition	m
11	L_g	length of constant gradient	m
12	L_K	length of transition curve	m
13	L_i	length of alignment elements between two linear cant transitions	m
14	L_s	length between two abrupt changes of cant deficiency	m
15	L_v	length of vertical radius	m
16	p	gradient	-
17	q_E	factor for calculation of equilibrium cant: 11,8	$mm \cdot m \cdot (h/km)^2$
18	q_N	factor for calculation of length of cant transition or transition curve with non-constant gradient of cant and curvature, respectively	-
19	q_R	factor for calculation of vertical radius	$m \cdot h^2/km^2$
20	q_s	factor for calculation of lengths between abrupt changes of cant deficiency	-
21	q_v	factor for conversion of the units for vehicle speed: 3,6	$(km/h)/(m/s)$
22	R	radius of horizontal curve	m
23	R_v	radius of vertical curve	m
24	s	longitudinal distance	m
25	t	time	s
26	V	speed	km/h
27	$CE, \lim$	limit applicable at fixed crossings and expansion devices (index)	-
28	$\lim$	general limit (index)	-
29	$R, \lim$	limit applicable at small radius curves (index)	-
30	$u, \lim$	upper limit for a parameter which also have a lower limit (index)	-

5 General

5.1 Background

This European Standard specifies rules and limits for track alignment design. These limits assume that standards for acceptance of vehicle, track construction and maintenance are fulfilled (construction and in-service tolerances are not specified in this standard). Engineering requirements specific to the mechanical behaviour of switch and crossing components and subsystems are to be found in the relevant standards. Certain design considerations for switches and crossings layouts are presented in informative annexes.

This European Standard is not a design manual. The limits are not intended to be imposed as usual design values. However, design values shall be within the limits stated in this European Standard.

Limits in this European Standard are based on practical experience of European railways. Limits are applied where it is necessary to compromise between train performance, comfort levels, maintenance of the vehicle and track, and construction costs.

Unnecessary use of design values close to limits should be avoided, substantial margins to them should be provided. There are often conflicts between the desire for margins to one parameter and another, these should be distributed over all design parameters, possibly by applying a margin with respect to speed.

For certain parameters, this European Standard also specifies exceptional limits less restrictive than normal limits, which represent the least restrictive limits applied by any European railway. Such limits are intended for use only under special circumstances and can require an associated maintenance regime. In particular, use of exceptional limits (instead of normal limits) for several parameters at the same location shall be avoided. Informative Annex D describes the constraints and risks associated with the use of design values in the range between a limit and corresponding exceptional limit.

Operational limits for speed and cant deficiency shall be applied to specific vehicles according to their approval parameters.

Due to lack of experience among the European railways, no limits are specified for higher speeds than 360 km/h.

The limits are defined for normal service operations. If and when running trials are conducted, for example to ascertain the vehicle dynamic behaviour (by continually monitoring of the vehicle responses), exceeding the limits (particularly in terms of cant deficiency) should be permitted and it is up to the infrastructure manager to decide any appropriate arrangement. In this context, safety margins are generally reinforced by taking additional steps such as ballast consolidation, monitoring of track geometric quality, etc.

5.2 Alignment characteristics

The alignment defines the geometrical position of the track. It is divided into horizontal alignment and vertical alignment.

The horizontal alignment is the projection of the track centre line on a horizontal plane. The horizontal alignment consists of a sequence of alignment elements, each obeying a unique mathematical description as a function of longitudinal distance along the horizontal projection (chainage). The elements for horizontal alignment are connected at tangent points, where two connected elements have the same coordinates and the same directions. Elements for horizontal alignment are specified in Table 1.

Table 1 — Elements for horizontal alignment

Alignment element	Characteristics
Straight line	No horizontal curvature
Circular curve	Constant horizontal curvature
Transition curve, Clothoid type	Horizontal curvature varies linearly with chainage
Transition curves, other types ^a	Horizontal curvature varies nonlinearly with chainage
^a Informative Annex C gives a detailed account of certain alternative types of transition curves that may be used in track alignment design	

Most modern switches have a tangential geometry, where the diverging track starts with an alignment that is tangential with the through track. However, switch designs may start with an abrupt change of horizontal direction at the beginning of the switch. Possible design criteria for the alignment before the switch, taking the entry angle in account, are described in informative Annex E.

When a turnout is placed on a track gradient other than zero, a vertical curve and/or cant, the horizontal geometry of the diverging track will deviate slightly from the element types in Table 1.

The vertical alignment defines the level of the track as a function of chainage (the longitudinal position along the horizontal projection of the track centre line). The elements for vertical alignment are connected at tangent points, where two connected elements have the same level and the same track gradient p (with certain exceptions). Elements for vertical alignment are specified in Table 2.

Table 2 — Elements for vertical alignment

Alignment element	Characteristics
Constant gradient	No vertical curvature
Vertical curve, parabola	Derivative of gradient with respect to chainage is constant
Vertical curve, circular	Derivative of vertical angle with respect to sloping length along the track is constant

NOTE A vertical curve in track that starts or ends in canted switches and crossings can be of a higher order polynomial than a parabola.

The applied cant D in the track is the difference in level of two running rails. Cant can be applied by raising one rail above the level of the vertical profile and keeping the other rail on the same level as the vertical profile, or by a pre-defined relationship raising one rail and lowering the other rail. The cant can be considered as a sequence of elements connected at tangent points where two elements have the same magnitude of applied cant. (At a tangent point with cant, the same rail is the high rail before and after the tangent point.) Elements for cant are specified in Table 3.

Table 3 — Elements for cant

Alignment element	Characteristics
Constant cant	Cant is constant along the entire element
Cant transition, linear	Cant varies linearly with chainage
Cant transition, nonlinear ^a	Cant varies nonlinearly with chainage
^a Informative Annex C gives a detailed account of certain alternative types of cant transitions that may be used in track alignment design.	

Cant transitions should normally coincide with transition curves, but exceptions are possible.

The geometrical consequences of placing a turnout on track gradients, vertical curves and/or applying cant in a turnout are described in informative Annex F.

The alignment of a ballasted track is normally maintained by Track Construction and Maintenance Machines. The maintenance with such machines is simplified if there is no more than one tangent point within the measuring chord of the machine (typically 10 m to 20 m).

All limits and exceptional limits in Clause 6 apply, hence the permissible range for one parameter, for example horizontal radius R , can be further restricted due to the chosen values of other parameters. For example, at a certain location in an alignment sequence, the permissible range for horizontal radius R can be limited due to applied cant D , limit for cant deficiency I and/or characteristics of adjacent elements. Informative Annex G presents certain applications of the limits.

6 Limits for 1 435 mm gauge

6.1 Radius of horizontal curve R

In this European Standard, radius is positive on both right-hand and left-hand curves.

Speed independent lower limit for horizontal radii R_{lim} is specified in Table 4.

Table 4 — Lower limit for horizontal curves R_{lim}

Normal limit ^a	Exceptional limit ^a
150 m	
^a Further requirements for the radius along platforms are defined in TSI INF.	

NOTE Not all vehicles are designed and approved for horizontal radii smaller than 150 m (for example, see EN 15273-2).

There is no upper limit for horizontal radius in this European Standard. However, local standards can have such an upper limit, related to capabilities of the alignment software to handle very large numbers or to other practical aspects.

6.2 Cant D

In this European Standard, cant on a horizontal curve is positive if the outer rail is higher than the inner rail.

NOTE 1 Negative cant is unavoidable at switches and crossings on a canted main line where the turnout is curving in the opposite direction to the main line and, in certain cases, on the plain line immediately adjoining a canted turnout. Negative cant can also be used on temporary tracks.

Upper limits for cant D_{lim} , independent of horizontal radius R , are specified in Table 5.

Table 5 — Upper limits for cant D_{lim}

	Normal limits	Exceptional limits
General ^a	160 mm	180 mm ^b
Switches and crossings ^a	120 mm	160 mm
^a Further requirements for the cant along platforms are defined in TSI INF. ^b Cant exceeding 160 mm can cause freight load displacement and deterioration of passenger comfort when a train stops or runs with low speed (high value of cant excess). On-track machines and vehicles with special loads with a high centre of gravity can become unstable. Therefore, an associated maintenance regime and other measures may be necessary (for example exclude certain types of freight traffic, avoid trains regularly stopping on such a curve, etc.).		

Upper limit for cant $D_{R,\text{lim}}$, as a function of horizontal radius R , is specified in Table 6.

Table 6 — Upper limit for cant $D_{R,\text{lim}}$ as a function of horizontal radius R

Normal limit ^a	Exceptional limit ^a
$D_{R,\text{lim}} = \frac{R - 50 \text{ m}}{1,5 \text{ m/mm}}$	
^a This limit may be relaxed provided that measures are taken to ensure safety, see EN 13848-5 or in the case of the diverging track of a turnout with an element of least 10 m length with constant cant on both sides of the curve with small radius.	

NOTE 2 High cant on small-radius curves increases the risk of derailling when vehicles are running at low speed. Under these conditions, vertical wheel forces applied to the outer rail are much reduced, especially where track twist (see EN 13848-1 and EN 13848-5) causes additional force reductions.

NOTE 3 Track twist limits are defined in EN 13848-5 as a function of applied cant. Using high cant values will impose lower twist values or other measures to ensure safety.

6.3 Cant deficiency I

For given values of local radius R and cant D , and speed V , the cant deficiency I is defined according to Formula (1):

$$I = D_{\text{EQ}} - D = q_{\text{E}} \frac{V^2}{R} - D \quad (1)$$

where

D_{EQ} is equilibrium cant (mm) and

$$q_{\text{E}} = 11,8 \text{ mm} \cdot \text{m} \cdot \text{h}^2 / \text{km}^2.$$

NOTE 1 With negative cant, the cant deficiency will be higher than equilibrium cant.

General upper limits for cant deficiency I_{lim} are specified in Table 7.

Table 7 — Upper limits for cant deficiency I_{lim}

	Normal limits ^a	Exceptional limits ^a
Non-tilting trains		
$V \leq 220 \text{ km/h}$	153 mm	180 mm ^b
$220 \text{ km/h} < V \leq 300 \text{ km/h}$	153 mm ^b	
$300 \text{ km/h} < V \leq 360 \text{ km/h}$	100 mm ^b	
Tilting trains		
$80 \text{ km/h} \leq V \leq 260 \text{ km/h}^{\text{ c}}$	275 mm	300 mm
^a It is common practice to apply different limits for cant deficiency to different categories of trains. It is assumed that every vehicle has been tested and approved according to the procedures in EN 14363 in conditions covering its own range of operating cant deficiency (denoted I_{adm} in EN 14363). Examples of local limits are shown in informative Annex H.		
^b Trains complying with EN 14363, equipped with a cant deficiency compensation system other than tilt, may be permitted by the Infrastructure Manager to run with higher cant deficiency values.		
^c Currently, there are no lines in Europe used or planned where maximum speed for tilting trains exceeds 260 km/h.		

NOTE 2 For a given vehicle, increased cant deficiency generates increasing forces between the wheel and the rail; see informative Annex I.

NOTE 3 Depending on the characteristics of specific features in track, such as bridges carrying direct-laid ballastless track, tracks with jointed rails, sections of line exposed to very strong cross winds, etc., it can be necessary to restrict the permissible cant deficiency. Rules in respect of these restrictions cannot be formulated beforehand since they will be dictated by the design of these features.

NOTE 4 High values of cant deficiency are related to passenger (dis)comfort, see informative Annex J.

For tracks with crossings in the outer rail and for expansion devices, there are more restrictive upper limits $I_{CE, \text{lim}}$, dependent on speed V , specified in Table 8.

Table 8 — Upper limits for cant deficiency for tracks with crossings in the outer rail and for expansion devices $I_{CE,lim}$

	Normal limits	Exceptional limits
Fixed common crossings		
$V \leq 230$ km/h	110 mm	Same as the normal limit in Table 7
$230 \text{ km/h} < V \leq 360$ km/h	Not permitted	Not permitted
Fixed obtuse crossings		
$V \leq 160$ km/h	100 mm	Same as the normal limit in Table 7
$160 \text{ km/h} < V \leq 230$ km/h	75 mm	Same as the normal limit in Table 7
$230 \text{ km/h} < V \leq 360$ km/h	Not permitted	Not permitted
Crossings with movable parts		
$V \leq 230$ km/h	130 mm	Same as the normal limit in Table 7
$230 \text{ km/h} < V \leq 360$ km/h	80 mm	Same as the normal limit in Table 7
Expansion devices		
$V \leq 160$ km/h	100 mm	Same as the normal limit in Table 7
$160 \text{ km/h} < V \leq 230$ km/h	80 mm	Same as the normal limit in Table 7
$230 \text{ km/h} < V \leq 360$ km/h	60 mm	Same as the normal limit in Table 7

6.4 Cant excess E

On a horizontal curve where cant deficiency (defined in Formula (2)) is negative, there is cant excess E defined by Formula (3).

$$E = -I \quad (2)$$

On canted turnouts, and on plain tracks in close conjunction to canted switch and crossing units, there may be applied cant also on straight track. Cant may also be applied on temporary straight tracks. On a canted straight track, there is cant excess E defined by Formula (3):

$$E = D \quad (3)$$

General upper limits for cant excess E_{lim} are specified in Table 9. These limits apply for the regular speed of the slowest train on the line.

Table 9 — Upper limits for cant excess E_{lim}

Normal limit	Exceptional limit
110 mm	150 mm

NOTE The value of E affects inner-rail stresses induced by slow trains, since the quasi-static vertical wheel/rail force on the inner rail is increased; see informative Annex I.

For tracks with crossings in the low rail and for expansion devices, there are more restrictive upper limits $E_{CE,lim}$, defined by Formula (4) and Table 8:

$$E_{CE,lim} = I_{CE,lim} \quad (4)$$

Requirements regarding changes in cant deficiency (6.5, 6.8, 6.11 and 6.13) apply also for changes in cant excess.

6.5 Length of cant transitions L_D and transition curves in the horizontal plane L_K

6.5.1 General

Cant transitions should normally coincide with transition curves. However, it can be necessary to provide cant transitions in circular curves and straights.

For cant transitions and transition curves the limits are as follows:

- speed independent lower limits for lengths of transition curves $L_{K,\text{lim}}$ are specified in Table 10;
- upper limits for cant gradient $\left(\frac{dD}{ds}\right)_{\text{lim}}$ are specified in 6.6;
- upper limits for rate of change of cant $\left(\frac{dD}{dt}\right)_{\text{lim}}$ are specified in 6.7; and
- upper limits for rate of change of cant deficiency $\left(\frac{dI}{dt}\right)_{\text{lim}}$ are specified in 6.8.

Table 10 — Lower limits for lengths of transition curves $L_{K,\text{lim}}$

Normal limit	Exceptional limit
20 m	0

6.5.2 Lengths of linear cant transitions and clothoids

For linear cant transitions and clothoids, cant gradient $\left(\frac{dD}{ds}\right)$, rate of change of cant $\left(\frac{dD}{dt}\right)$ and rate of change of cant deficiency $\left(\frac{dI}{dt}\right)$ can be calculated according to Formulae (5) to (7):

$$\frac{dD}{ds} = \frac{\Delta D}{L_D} \quad (5)$$

$$\frac{dD}{dt} = \frac{V}{q_V} \cdot \frac{\Delta D}{L_D} \quad (6)$$

$$\frac{dI}{dt} = \frac{V}{q_V} \cdot \frac{\Delta I}{L_K} \quad (7)$$

where

ΔD is the change of cant over the length L_D , as defined in normative Annex K,

ΔI is the change of cant deficiency over the length L_K , as defined in normative Annex K,

V is the speed in km/h and

$q_V = 3,6 \text{ (km/h)/(m/s)}$.

Formula (7) assumes that any cant transition coincides with a transition curve, $L_K = L_D$, and Formulae (5) to (7) assume that the mathematical properties are constant over this length. Otherwise,

the transition curve and the cant transition shall be divided in parts (with constant properties) which are evaluated separately.

6.5.3 Lengths of transition curves with non-constant gradient of curvature and cant

For transition curves with non-constant gradient of curvature and cant, cant gradient $\left(\frac{dD}{ds}\right)$, rate of change of cant $\left(\frac{dD}{dt}\right)$ and rate of change of cant deficiency $\left(\frac{dI}{dt}\right)$ can be calculated according Formulae (8) to (10):

$$\frac{dD}{ds} = q_N \cdot \frac{\Delta D}{L_D} \quad (8)$$

$$\frac{dD}{dt} = q_N \cdot \frac{V}{q_v} \cdot \frac{\Delta D}{L_D} \quad (9)$$

$$\frac{dI}{dt} = q_N \cdot \frac{V}{q_v} \cdot \frac{\Delta I}{L_K} \quad (10)$$

where

- ΔD is the change of cant over the length L_D , as defined in normative Annex K,
- ΔI is the change of cant deficiency over the length L_K , as defined in normative Annex K,
- V is the speed in km/h,
- $q_v = 3,6 \text{ (km/h)/(m/s)}$, and
- the factor q_N is defined in Table 11.

For certain types of transitions with non-constant gradient of curvature and cant, the value of the factor q_N is specified in Table 11.

Table 11 — Factor q_N for transitions with non-constant gradient of curvature and cant

Bloss	Cosine	Helmert (Schramm)	Sine (Klein)
1,5	$\pi/2$	2	2

Formula (10) assumes that any cant transition coincides with a transition curve, $L_K = L_D$, and Formulae (8)-(10) assume that the mathematical properties are constant over this length. Otherwise, the transition curve and the cant transition shall be divided in parts (with constant properties) which are evaluated separately.

The criterion for rate of change of cant $\left(\frac{dD}{dt}\right)$ may be replaced with a criterion for the second derivative of cant with respect to time $\left(\frac{d^2D}{dt^2}\right)$, as defined in 6.7.

NOTE Informative Annex C gives further information on clothoids with linear cant transitions and alternative types of transition curves and cant transitions.

6.6 Cant gradient dD/ds

Upper limits for cant gradients $\left(\frac{dD}{ds}\right)_{\text{lim}}$ are specified in Table 12.

Table 12 — Upper limits for cant gradients $\left(\frac{dD}{ds}\right)_{\text{lim}}$

	Normal limits	Exceptional limits
$V \leq 50 \text{ km/h}$	2,50 mm/m	3,33 mm/m ^a
$V > 50 \text{ km/h}$	2,50 mm/m	
^a According to EN 13848-5, a more restrictive limit for cant than the limit in Table 6 can apply.		

6.7 Rate of change of cant dD/dt

Upper limits for rate of change of cant $\left(\frac{dD}{dt}\right)_{\text{lim}}$ for linear and nonlinear cant transitions are specified in Table 13 and Table 14, respectively.

Table 13 — Upper limits for rate of change of cant $\left(\frac{dD}{dt}\right)_{\text{lim}}$ for linear cant transitions

	Normal limits	Exceptional limits
Non-tilting trains $V \leq 200 \text{ km/h}$		
$I \leq 160 \text{ mm}$	50 mm/s	70 mm/s ^a
$160 \text{ mm} < I \leq 180 \text{ mm}$	50 mm/s	60 mm/s
Non-tilting trains $200 \text{ km/h} < V \leq 360 \text{ km/h}$		
	50 mm/s	60 mm/s
Tilting trains $V \leq 200 \text{ km/h}$		
	75 mm/s	95 mm/s
Tilting trains $200 \text{ km/h} < V \leq 260 \text{ km/h}$^b		
	60 mm/s	70 mm/s
^a Where $I \leq 153 \text{ mm}$ and $dI/dt \leq 70 \text{ mm/s}$, the exceptional limit for dD/dt may be raised to 85 mm/s.		
^b Currently, there are no lines in Europe used or planned where maximum speed for tilting trains exceeds 260 km/h.		

Table 14 — Upper limits for rate of change of cant $\left(\frac{dD}{dt}\right)_{\text{lim}}$ for nonlinear cant transitions

Normal limit	Exceptional limit
$V \leq 300 \text{ km/h}^a$	
55 mm/s	76 mm/s ^b
^a Currently, there are no lines in Europe used or planned where maximum speed on nonlinear cant transitions exceeds 300 km/h. ^b Where the absolute value of second derivative of cant with respect to time (d^2D/dt^2) is less than 150 mm/s ² this limit may be raised.	

6.8 Rate of change of cant deficiency dI/dt

Upper limits for rate of change of cant deficiency $\left(\frac{dI}{dt}\right)_{\text{lim}}$ for clothoids and for transition curves with non-constant gradients are specified in Table 15 and Table 16, respectively.

Table 15 — Upper limits for rate of change of cant deficiency $\left(\frac{dI}{dt}\right)_{\text{lim}}$ for clothoids

	Normal limits	Exceptional limits
Non-tilting trains $V \leq 220$ km/h		
$I \leq 160$ mm	55 mm/s	100 mm/s
$160 \text{ mm} < I \leq 180$ mm	55 mm/s	90 mm/s
Non-tilting trains $220 \text{ km/h} < V \leq 300$ km/h		
	55 mm/s	75 mm/s
Non-tilting trains $300 \text{ km/h} < V \leq 360$ km/h		
	30 mm/s	55 mm/s
Tilting trains $V \leq 225$ km/h		
	100 mm/s	180 mm/s
Tilting trains $225 \text{ km/h} < V \leq 260$ km/h ^a		
	80 mm/s	
^a Currently, there are no lines in Europe used or planned where maximum speed for tilting trains exceeds 260 km/h		

Table 16 — Upper limits for rate of change of cant deficiency $\left(\frac{dI}{dt}\right)_{\text{lim}}$ for transition curves with non-constant gradients

Normal limits	Exceptional limits
Non-tilting trains $V \leq 300$ km/h	
95 mm/s	120 mm/s
Non-tilting trains $300 \text{ km/h} < V \leq 360 \text{ km/h}$	
30 mm/s	55 mm/s
Tilting trains $V \leq 225$ km/h	
100 mm/s	180 mm/s
Tilting trains $225 \text{ km/h} < V \leq 260 \text{ km/h}$ ^a	
95 mm/s	120 mm/s
^a Currently, there are no lines in Europe used or planned where maximum speed for tilting trains exceeds 260 km/h	

Where a transition curve is of substandard length with respect to the $\frac{dI}{dt}$ criterion, this criterion shall be replaced with the criterion that the change of cant deficiency over its length shall be less than the upper limit for abrupt change of cant deficiency ΔI , as defined in 6.11.

NOTE High values for rate of change of cant deficiency are related to passenger (dis)comfort; see informative Annex J.

For tilting trains, both active and passive tilt systems need time to adapt the angle of tilt to the curve radius and it is for this reason that horizontal curves shall include transition curves of sufficient length. The transition curves should coincide with the cant transitions. If they do not, special running tests are recommended to determine whether permissible speed needs to be reduced.

On lines with tilting trains, the clothoid is normally used for transition curves, giving a linear variation of curvature. Where using transition curves with non-constant gradients, the function of the tilt system shall be taken into account for the analysis of the complex interaction between the vehicle and the track.

6.9 Length of constant cant between two linear cant transitions L_i

Lower limits for length of constant cant placed between two linear cant transitions $L_{i,\text{lim}}$ are specified in Table 17.

Table 17 — Lower limits for lengths of constant cant between two linear cant transitions $L_{i,\text{lim}}$

Normal limit	Exceptional limit ^a
20 m	0
^a The use of the exceptional limit between two linear cant transitions with a total change of cant gradient more than the upper limits in Table 12 should be avoided.	

For an alternative method to define the minimum lengths, see informative Annex L.

6.10 Abrupt change of horizontal curvature

An abrupt change of curvature may occur in close conjunction to switches and crossings, at alignment for low speeds (sidings etc.) or at small deviations in alignment within a limited length. It is unavoidable on at least one track of a turnout. In most other cases, transition curves should be used.

For abrupt changes of curvature there are limits as follows:

- upper limits for abrupt change of cant deficiency ΔI_{lim} are specified in 6.11;
- lower limits for length between two abrupt changes of curvature $L_{c,\text{lim}}$ in 6.12;
- lower limits for length between two abrupt changes of cant deficiency $L_{s,\text{lim}}$ in 6.13.

6.11 Abrupt change of cant deficiency ΔI

An abrupt change of cant deficiency ΔI occurs where there is an abrupt change of curvature. A tangent point with an abrupt change of cant deficiency generates disturbed vehicle dynamics.

The magnitude of the abrupt change of cant deficiency is defined by the sign rules given in normative Annex K.

Upper limits for abrupt change of cant deficiency ΔI_{lim} are specified in Table 18.

Table 18 — Upper limits of abrupt change of cant deficiency (ΔI_{lim})

	Normal limits	Exceptional limits
$V \leq 60 \text{ km/h}$	110 mm	130 mm ^a
$60 \text{ km/h} < V \leq 200 \text{ km/h}$	100 mm	125 mm
$200 \text{ km/h} < V \leq 230 \text{ km/h}$	85 mm	
$230 \text{ km/h} < V \leq 360 \text{ km/h}$	25 mm ^b	
^a Where $V \leq 40 \text{ km/h}$ and $ I \leq 75 \text{ mm}$ both before and after an abrupt change of curvature, the exceptional limit for ΔI may be raised to 150 mm.		
^b The limit is aimed to be applicable for plain track. Currently, no turnouts are designed for higher speeds in the diverging track than 230 km/h.		

Outside zones with switches and crossings, design values for abrupt changes of cant deficiency (if used) should be much lower than the upper limits in Table 18.

Where there is an abrupt change of cant deficiency, some European railways use the principle of virtual transition described in informative Annex M. The values for abrupt change of cant deficiency, when based on the principle of virtual transition, shall also conform to the upper limits specified in Table 18.

6.12 Length between two abrupt changes of horizontal curvature L_c

There are limits on how much end throws may differ between two adjacent vehicles. The criterion is related to buffer locking, but also vehicles with central couplers can have similar limits. The end throw is the geometrical overthrow d_{ga} for the end of the vehicle, as defined in EN 15273-1.

This European Standard bases on the criterion on the static end throw differences. The limit refers to a long circular curve of 190 m radius to be connected to a long circular curve, also of 190 m radius, in the opposite direction, with an intermediate straight of 6,00 m length. This leads to a maximum for the end throw difference of 395 mm for two 26,4 m long passenger coaches with a bogie distance of 19,0 m and allows a long circular curve of 213 m radius to be directly connected to a long circular curve, also of

213 m radius, in the opposite direction. It also allows for any combination of circular curves where the change of curvature is less than $1/106,5 \text{ m}^{-1}$.

NOTE The EUROFIMA coach with the following characteristics (length: 26,4 m, bogie distance: 19,0 m, buffer width: 635 mm, transversal play of the vehicle: $\pm 60 \text{ mm}$) fulfils the requirements concerning buffer recovery for the above mentioned reference situation.

For dedicated freight tracks, the criterion is based on the static end throw differences for two 18,0 m long freight vehicles with a bogie distance of 12,0 m, which shall be limited to a maximum of 225 mm. This criterion allows a long circular curve of 200 m radius to be directly connected to a long circular curve, also of 200 m radius, in the opposite direction. It also allows for any combination of circular curves where the change of curvature is less than $1/100 \text{ m}^{-1}$.

Where the horizontal curves have curvatures that differ more than $1/106,5 \text{ m}^{-1}$ or $1/100 \text{ m}^{-1}$, respectively, an intermediate element shall be inserted to reduce the differences in end throw, using the static method in EN 15273-1, down to less than or equal to 395 mm or 225 mm, respectively. This intermediate element may be a straight line, a transition curve, or a circular curve. The required length of the intermediate element depends on the radii of the small radius curves as well as the type of intermediate element.

For vehicles with other characteristics, it is assumed that running gear, couplers and buffers are designed for the minimum length of the intermediate element L_c .

Infrastructure managers can specify more restrictive, longer lengths on (dedicated parts of) their network in order to prevent buffer locking for existing vehicles that do not fulfil these assumptions.

Table 19 specifies certain lower limits for the lengths of a straight intermediate element for certain combinations of long circular curves in opposite directions. The track has a maximum in-service gauge value of 1 470 mm (nominal gauge 1 435 mm plus 35 mm, see EN 13848-5). Normative Annex N specifies more details and more examples.

Table 19 — Certain lower limits for the length between two abrupt changes of curvature $L_{c,lim}$

Alignment sequence	Limits for tracks for passenger coaches	Limits for dedicated freight tracks
$R = 150 \text{ m} - \text{straight} - R = 150 \text{ m}$	10,78 m	6,79 m
$R = 160 \text{ m} - \text{straight} - R = 160 \text{ m}$	9,48 m	6,01 m
$R = 170 \text{ m} - \text{straight} - R = 170 \text{ m}$	8,30 m	5,20 m
$R = 180 \text{ m} - \text{straight} - R = 180 \text{ m}$	7,20 m	4,25 m
$R = 190 \text{ m} - \text{straight} - R = 190 \text{ m}$	6,00 m	3,01 m
$R = 200 \text{ m} - \text{straight} - R = 200 \text{ m}$	4,50 m	0
$R = 210 \text{ m} - \text{straight} - R = 210 \text{ m}$	2,11 m	0
$R = 213 \text{ m} - \text{straight} - R = 213 \text{ m}$	0	0

6.13 Length between two abrupt changes of cant deficiency L_s

The disturbed vehicle dynamics created by an abrupt change of cant deficiency are damped as a function of time.

Speed-dependent lower limits for length of intermediate element(s) between two abrupt changes of cant deficiency $L_{s,lim}$ are specified in Formula (11) and Table 20:

$$L_{s,lim} = q_{s,lim} \cdot V \quad (11)$$

where

$q_{s,lim}$ is a factor (m·h/km) defined in Table 20 and

V is the train speed (km/h).

Table 20 — Lower limits of the factor $q_{s,lim}$ defining the minimum length between two tangent points with abrupt changes of cant deficiency ($L_{s,lim}$)

	Normal limits	Exceptional limits
$V \leq 70$ km/h	0,20	0,10 ^a
70 km/h $< V \leq 100$ km/h	0,20	0,15 ^b
100 km/h $< V \leq 360$ km/h	0,25	0,19
^a Where $\Delta I \leq 110$ mm and $V \leq 50$ km/h, $q_{s,lim}$ may be reduced to 0,08 m·h/km.		
^b Where $\Delta I \leq 100$ mm and $V \leq 90$ km/h, $q_{s,lim}$ may be reduced to 0,10 m·h/km.		

NOTE For switches and crossings placed on transition curves, the length between two abrupt changes of cant deficiency may involve more than one intermediate element.

The intermediate element is normally an element with constant cant deficiency (or constant cant excess). Where cant deficiency is not constant, rate of change of cant deficiency shall not be higher than the upper limit in 6.8.

The lower limit $L_{s,lim}$ does not apply where the total change of cant deficiency over the two (or more) tangent points does not exceed the upper limit in 6.11. The magnitude of total change of cant deficiency is defined by the sign rules given in normative Annex K.

Where there is an abrupt change of cant deficiency, some European railways use the principle of virtual transition described in informative Annex M. The length between two tangent points with abrupt changes of cant deficiency, when based on the principle of virtual transition, shall also conform to the lower limits specified in Table 20.

6.14 Track gradients p

The absolute magnitudes of track gradients p shall be limited due to available traction in relation to train mass, as well as braking performances of the trains. No upper limits for the magnitudes of gradients are specified in this European Standard. For certain design considerations, see informative Annex O.

NOTE 1 Upper limits for the track gradients are defined in TSI INF.

Lower limits for lengths of constant track gradients $L_{g,lim}$ are specified in Table 21.

Table 21 — Lower limits for lengths of constant track gradients $L_{g,lim}$

Normal limit	Exceptional limit
20 m	0

For lines for certain rolling stock with secondary air suspension, between a convex vertical curve and a concave vertical curve which both have vertical radii close to the lower exceptional limits as defined in 6.15, it is recommended to apply a lower limit of $0,5 \text{ m}/(\text{km/h}) \cdot V$ for the length of an intermediate constant gradient.

No upper limits for lengths of constant track gradients $L_{g,u,lim}$ are specified in this European Standard.

NOTE 2 Certain upper limits for the lengths of track gradients are defined in the TSI INF.

6.15 Vertical radius R_v

Vertical curves are normally designed as parabolas (2nd degree polynomials) or as circular curves. They may be designed without transition curves.

NOTE A vertical curve in the diverging track of canted switches and crossings unit can be of a higher order polynomial than a parabola.

Switch and crossing units should be installed where the tracks are level, on a constant gradient, or at large vertical radius. Speed independent lower limits for vertical radii $R_{v,lim}$ are specified in Table 22.

Table 22 — Lower limits for vertical radii $R_{v,lim}$

	Normal limits	Exceptional limits
General	2 000 m	500 m ^a
Switches and Crossings, Convex curves	5 000 m	2 000 m
Switches and Crossings, Concave curves	3 000 m	2 000 m
Marshalling humps, convex curves	250 m ^a	
Marshalling humps, concave curves	300 m ^a	
^a Not all vehicles are designed and approved for vertical radii less than 500 m (see EN 15273–2).		

The vertical radius for both plain track and switches and crossing units shall also comply with the speed-dependent lower limits specified in Formula (12) and Table 23.

$$R_v \geq q_{R,lim} \cdot V^2 \quad (12)$$

Table 23 — Lower limits for the factor for vertical radius $q_{R,lim}$

	Normal limits	Exceptional limits
Convex curves	0,35 m·h ² /km ²	0,15 m·h ² /km ²
Concave curves	0,35 m·h ² /km ²	0,13 m·h ² /km ²

There is no upper limit for vertical radius in this European Standard. However, local standards may have such an upper limit, related to capabilities of the alignment software to handle very large numbers or to other practical aspects.

6.16 Length of vertical curves L_v

Lower limits for the lengths for vertical curves $L_{v,lim}$ are specified in Table 24.

Table 24 — Lower limits for the lengths for vertical curves $L_{v,lim}$

Normal limit	Exceptional limit
20 m	0

6.17 Abrupt change of track gradient Δp

Two constant track gradients shall normally not be connected to each other without an intermediate vertical curve. In exceptional cases, there may be an abrupt change of track gradient Δp . The magnitude of the abrupt change of track gradient Δp is defined by the sign rules given in normative Annex K.

Upper limits for an abrupt change of track gradient Δp_{lim} are specified Table 25.

Table 25 — Upper limits for an abrupt change of track gradient in plain track Δp_{lim}

	Normal limits	Exceptional limits
$0 < V \leq 230 \text{ km/h}$	1 mm/m	2 mm/m
$230 \text{ km/h} < V \leq 360 \text{ km/h}$	0,5 mm/m	1 mm/m

For sidings, with a permissible speed not exceeding 40 km/h, the exceptional limit may be raised to 4,5 mm/m, provided that the abrupt change of gradient occurs outside switches and crossings.

Inside a switch and crossing unit placed over a tangent point where there is an abrupt change of cant gradient, there will be an associated abrupt change of track gradient for the diverging track. This effect may be neglected since it is taken into account by the upper limit for the cant gradient.

NOTE For ferry ramps, limits for abrupt change of track gradient are specified in EN 15273-3.

Two abrupt changes of track gradients should not be arranged in close conjunction. However, the arrangement can be justified in the diverging track between two switch and crossing units. The distance between two such abrupt changes of track gradients should exceed the length of a vertical curve, with a radius according to 6.15, which generates the same total change of track gradient.

Annex A

(normative)

Rules for converting parameter values for track gauges wider than 1 435 mm

A.1 Scope

This annex describes the rules, which shall be applied for converting the values and limits in the standard for gauges wider than 1 435 mm.

Normative Annex B specifies the limits of the track alignment parameters, based on the following rules, which shall be applied to tracks with a gauge of 1 520 mm, 1 524 mm and 1 668 mm.

A.2 Symbols and abbreviations

Unless otherwise indicated, the symbols and abbreviations of Table A.1 apply to Annex A.

Table A.1 — Symbols and abbreviations

No.	Symbol	Designation	Unit
31	a_i, a_{i1}	quasi-static lateral acceleration, at track level, but parallel to the vehicle floor	m/s ²
32	a_q, a_{q1}	non-compensated lateral acceleration in the running plane	m/s ²
33	b	vehicle wheelbase	m
34	B, B_1	distance between the spring suspension points on a wheelset	mm
35	$da_i/dt, da_{i1}/dt$	rate of change of quasi-static lateral acceleration at track level but parallel to the vehicle floor	m/s ³
36	$dD/ds, dD_1/ds$	cant gradient	mm/m
37	$dD/dt, dD_1/dt$	rate of change of cant	mm/s
38	$dI/dt, dI_1/dt$	rate of change of cant deficiency	mm/s
39	D, D_1	Cant	mm
40	e, e_1	distance between the nominal centre points of the two contact patches of a wheelset (e.g. about 1500 mm for nominal track gauge 1435 mm)	mm
41	E, E_1	cant excess	mm
42	H_s	quasi-static lateral force applied by a wheelset to the track	N
43	h_g	height above the top of the rails for the mass centre of a vehicle	m
44	I, I_1	cant deficiency	mm
45	K, K_1	suspension stiffness coefficient	N/m
46	q_E, q_{E1}	factor for calculation of equilibrium cant	mm·m·h ² /km ²
47	Q_N	nominal vertical wheel/rail force	N
48	s_r	roll flexibility coefficient, equivalent to flexibility coefficient s in EN 15273-1	-
49	s_t	tilt compensation factor of a tilt system	-
50	u	cross level variation between wheelsets linked by the suspension system	m
51	W	ratio e_1/e ($e_1/1500$ mm)	-
52	$\Delta a_i, \Delta a_{i1}$	abrupt change of quasi-static lateral acceleration Δa_i	m/s ²
53	$\Delta D, \Delta D_1$	overall track cant variation along a cant transition	mm
54	$\Delta I, \Delta I_1$	overall cant deficiency (and/or cant excess) variation over a transition, or abrupt change of cant deficiency at a tangent point	mm
55	$\Delta Q, \Delta Q_1$	quasi-static vertical wheel/rail force increment	N
56	$\dot{\phi}, \dot{\phi}_1$	roll velocity	rad/s

Parameters quoted with the index 1 relate to the values converted for nominal track gauges wider than 1 435 mm, as opposed to the original 1 435 mm gauge values, which are not indexed.

A.3 Basic assumptions and equivalence rules

A.3.1 General

The conditions are based on the same criteria for the following concepts:

- track forces and safety;
- economic aspects of track maintenance;
- ride comfort and roll flexibility coefficient.

It is assumed that:

- the track system and track quality are similar for the wider gauges;
- the composition of the vehicles and their wheel arrangements are similar; the masses, the positions of the centres of gravity, rigidity and dampers are similar; the same safety limits apply with regard to derailment, $\left(\frac{Y}{Q}\right)_{lim}$;
- the same levels of safety with regard to track shift limit will be obtained using the same levels for H_s and, in the case of derailment and overturning, by using the same values of reduced vertical forces, ΔQ , on the wheels (the guiding wheels in the case of derailment);
- the same degree of track fatigue will be obtained if the H_s and Q values are maintained;
- the same ride passenger comfort for passenger will be obtained if the values of a_i , $\frac{da_i}{dt}$ and Δa_i are kept unchanged.

A.3.2 Basic formulae

Formula (A.1) quantifies the influence of cant deficiency I on the quasi-static lateral force between a wheelset and the track H_s :

$$H_s = 2 \cdot Q_N \cdot \frac{I}{e} \quad (\text{A.1})$$

Formula (A.2) quantifies the influence of cant deficiency I on the quasi-static vertical wheel/rail force increment ΔQ :

$$\Delta Q = 2 \cdot Q_N \cdot I \cdot \frac{hg}{e^2} \quad (\text{A.2})$$

In the case of cant excess, I is replaced by E in Formulae (A.1) and (A.2) (see 6.4).

Formula (A.3) quantifies the influence of cross level variation u on the quasi-static vertical wheel/rail force increment ΔQ :