

Railway applications — Track alignment design parameters — Track gauges 1435 mm and wider —

Part 1: Plain line

ICS 45.080

National foreword

This Draft for Development is the official English language version of ENV 13803-1:2002.

This publication is not to be regarded as a British Standard.

It is being issued in the Draft for Development series of publications and is of a provisional nature in order to encourage industry to comment on the appropriateness of achieving its requirements, more particularly when carrying out works in connection with the upgrading of existing lines. It should be applied on this provisional basis, so that information and experience of its practical application may be obtained.

Comments arising from the use of this Draft for Development are requested so that UK experience can be reported to the European organization responsible for its conversion to a European standard. A review of this publication will be initiated 2 years after its publication by the European organization so that a decision can be taken on its status at the end of its 3-year life. Notification of the start of the review period will be made in an announcement in the appropriate issue of *Update Standards*.

According to the replies received by the end of the review period, the responsible BSI Committee will decide whether to support the conversion into a European Standard, to extend the life of the prestandard or to withdraw it. Comments should be sent in writing to the Secretary of BSI Technical Committee RAE/2, Railway track components, at British Standards House, 389 Chiswick High Road, London W4 4AL, giving the document reference and clause number and proposing, where possible, an appropriate revision of the text.

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

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

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Partie 1: Voie courante

Bahnanwendungen - Linienführung in Gleisen - Spurweiten
1435 mm und grösser - Teil 1: Durchgehendes Hauptgleis

This European Prestandard (ENV) was approved by CEN on 19 July 2002 as a prospective standard for provisional application.

The period of validity of this ENV is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the ENV can be converted into a European Standard.

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Foreword

This document ENV 13803-1:2002 has been prepared by Technical Committee CEN/TC 256 "Railway applications", the secretariat of which is held by DIN.

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 the following EC Directives:

- Council Directive 96/48/EC of 23 July 1996 on the interoperability of the European high-speed network¹
- European Parliament and Council Directive 98/4/EC of 16 February 1998 in amendment of Council Directive 93/38/EC of 14 June 1993 co-ordinating the procurement procedures of entities operating in the water, energy, transport and telecommunications sectors²
- Council Directive 91/440/EEC of 29 July 1991 on the development of the Community's railways³

For the relationship with the EU Directives, see annex ZA.

This European Prestandard is one of a series of European Prestandards as listed below:

- *Railway applications - Track alignment design parameters - Track gauges 1435 mm and wider - Part 1: Plain line.*
- *Railway applications - Track alignment design parameters - Track gauges 1435 mm and wider - Part 2: Switches and crossings.*

Annexes A, B, C, D, E, F, H and I are informative. Annex G is normative.

This document contains bibliographical references.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this European Prestandard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This European Prestandard specifies the track alignment design parameters, the rules and the values that shall be used to determine the maximum operating speed for both new and existing lines. Alternatively, for a given specified speed, it defines the track alignment design parameters either for a new line or an upgraded line.

The track alignment designer is free to specify the values most appropriate for the various parameters, when considering safety, geographical, engineering, historical and economic constraints. These values are defined in the contract document. However, the choice should be such that the selected values are no worse than the maximum (or minimum) limiting values for the safety-related parameters.

Whenever necessary, the track alignment designer should take into account any specific requirements of the appropriate national standards.

¹ Official Journal of the European Communities N° L 235 of 17.9.96 ; see annex ZA to this Prestandard

² Official Journal of the European Communities N° L 199 of 9.8.93 and N° L 101 of 1.4.98

³ Official Journal of the European Communities N° L 237 of 24.8.91

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The designer should endeavour to use the recommended limiting values specified in this European Prestandard and avoid unnecessary use of the maximum (or minimum) limiting values.

This European Prestandard applies to main lines with track gauges 1435 mm and wider with mixed or dedicated passenger traffic, running at operating speeds between 80 km/h and 300 km/h. Annex F (informative) describes the conversion rules which can be applied for tracks with gauges wider than 1435 mm. Annex G has a normative character and is applied for corresponding specific national conditions.

However, the values and conditions stated for this speed range can also be applied to lines where operating speeds are less than 80 km/h, but in this case, more or less restrictive values may need to be used and should be defined in the contract.

This European Prestandard does not apply to urban and suburban lines.

This European Prestandard also considers the possibility of increasing the performance of line operation, without major alignment modifications, by means of particular rail vehicle types, such as:

- vehicles with a low axle mass;
- vehicles with a low suspension roll coefficient;
- vehicles equipped with tilting body systems to compensate for cant deficiency (active or passive systems).

The attention of the designer is drawn to the fact that this European Prestandard does not apply to track alignment design for tilting vehicles. However, annex E draws the attention of the designer to the consequences of track resistance, wear and fatigue due to the operation of such vehicles.

2 Terms and definitions

For the purposes of this European Prestandard, the following terms and definitions apply:

2.1

curves

this covers both horizontal and vertical curves and their related transitions.

Unless otherwise stated, the curve parameters are defined for the track centreline

2.1.1

circular curve

a curve of constant radius

2.1.2

transition curve

a curve of variable radius.

Transition curves may be found between two circular curves, each of a different radius, and between a circular curve and a straight. The clothoid (or cubic parabola) is normally used for transition curves, giving a uniform variation of curvature and cant. In some cases, the ends of the transition curves are even rounded by a larger radius.

Within these types of transitions, there is generally proportionality between curvature and cant.

It is possible to use other forms of transition curve which show a non-uniform variation of curvature and cant.

In principle, a transition curve is not used for the vertical alignment.

Annex A gives a detailed account of the alternative types of transitions that may be used in track alignment design

2.1.3

compound curve

a curve formed by two circular curves of different radii which curve in the same direction.

The two adjacent curves may be joined by a transition curve

2.1.4

reverse curve

a curve formed by two circular curves which curve in the opposite direction.
The two adjacent curves may be joined by a transition curve

2.2**cant**

the amount by which one gauge rail is raised above the other gauge rail.

Cant is positive when the outer rail on curved track is raised above the inner rail and is **negative** when the inner rail on curved track is raised above the outer rail.

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 or on the plain line immediately adjoining the turnout (see *Part 2: Track alignment design parameters - Track gauges 1435 mm and wider - Switches and crossings*).

When the speed of a vehicle negotiating a curve is such that the resultant of the weight of the vehicle and the effect of centrifugal force is perpendicular to the plane of the rails, the vehicle is not subjected to unbalanced centripetal force and is said to be in equilibrium. Obtaining this condition on curved track implies raising one gauge rail above the level of the other gauge rail by a designed amount. This amount is known as the **equilibrium cant**

2.3**cant excess**

when the speed of a vehicle negotiating a curve is lower than the **equilibrium speed**, there will be an unbalanced centripetal force. The equilibrium cant is excessive for the lower speed and the resultant force will move towards the inner rail of the curve. Equilibrium conditions may be restored theoretically by taking into consideration the amount by which the equilibrium cant is in excess for the lower speed. This amount is known as **cant excess**

2.4**cant deficiency**

when the speed of a vehicle negotiating a curve is higher than the **equilibrium speed**, there will be an unbalanced centrifugal force. The equilibrium cant is therefore insufficient for the higher speed and the resultant force will move towards the outer rail of the curve. Equilibrium conditions may be restored theoretically by taking into consideration the amount by which the equilibrium cant is deficient for the higher speed. This amount is known as deficiency of cant or **cant deficiency**

2.5**rate of change of cant as a function of length**

the amount by which the cant is increased or decreased in a given transition length

2.6**rate of change of cant as a function of time**

the rate at which cant is increased or decreased relative to the maximum speed of a vehicle negotiating a transition curve, for example 35 mm per second means that a vehicle travelling at the maximum speed permitted will experience a change in cant of 35 mm in each second

2.7**rate of change of cant deficiency as a function of time**

the rate at which cant deficiency is increased or decreased relative to the maximum speed of a vehicle negotiating a transition curve, for example 35 mm per second means that a vehicle travelling at the maximum speed permitted will experience a change in cant deficiency of 35 mm in each second

2.8**maximum permissible speed**

maximum speed permitted on a curve with associated transitions when radius, cant, cant deficiency, cant gradient and rates of change of cant and cant deficiency and other parameters have been taken into consideration

2.9

line speed

maximum speed at which vehicles are allowed to run on a line or branch or on sections of a line or branch.

The line speed limit is usually established after taking into consideration the incidence of permanent speed restrictions on the line or branch. On mixed traffic lines, several different line speed limits may exist at the same time due to the different types of traffic categories

2.10

recommended limiting values

values to be applied by the designer for the design of new railway lines or sections of such lines, or for the upgrading of existing lines. Such values ensure maintenance costs of the track are kept at a reasonable level, except where particular conditions of poor track stability may occur, without compromising passenger comfort

2.11

maximum (or minimum) limiting values

extreme but permissible values used at maximum speed for most railway vehicles. As these values are extreme, it is essential that the use of maximum (or minimum) limiting values is as infrequent as possible on any given line

Annex H describes the constraints and risks associated with the use of maximum (or minimum) limiting values.

3 Symbols and abbreviations

1	2	3	4
No.	Symbol	Designation	Unit
1	a_q	non-compensated lateral acceleration in the track plane	m/s ²
2	da_q / dt	rate of change of non-compensated lateral acceleration as a function of time	m/s ³
3	a_i	quasi-static lateral acceleration parallel to the vehicle floor	m/s ²
4	da_i / dt	rate of change of quasi-static lateral acceleration parallel to the vehicle floor as a function of time	m/s ³
5	a_v	quasi-static vertical acceleration on vertical curve	m/s ²
6	D	Cant	mm
7	D_l	cant limit	mm
8	dD/dt	rate of change of cant as function of time	mm/s
9	$dD/d\ell$	rate of change of cant as function of length	mm/m
10	E	cant excess	mm
11	e	distance between wheel treads of an axle (about 1500 mm)	mm
12	h_g	height of the centre of gravity	mm
13	I	cant deficiency	mm
14	dI/dt	rate of change of cant deficiency as function of time	mm/s
15	L	length of transition curve or cant gradient	m
16	L_i	length of alignment elements (circular curves and straights)	m
17	R	radius of horizontal curve	m
18	R_v	radius of vertical curve	m
19	s	roll flexibility coefficient according to UIC 505-5 OI	—
20	t	Time	s
21	V	line speed	km/h
22	V_{max}	maximum curving speed of fast trains	km/h
23	V_{min}	minimum curving speed of slow trains	km/h
24	g	acceleration due to gravity - 9,81 m/s ²	m/s ²
25	lim	limiting value (index)	—
26	Δa_q	overall variation of non-compensated lateral acceleration along the whole transition curve	m/s ²
27	ΔI	overall cant deficiency variation along a transition curve, between straight track and plain curve or between two adjacent curves of different radii	mm
28	ΔD	overall cant variation along a transition curve, between straight track and plain curve or between two adjacent curves of different radii	mm
29	Q	dynamic wheel load	N
30	Q_N	nominal wheel load	N
31	ΔQ	overall wheel load variation	N
32	Y	guiding force at the wheel rail contact	N

4 Requirements

4.1 Background

The following technical normative rules assume that standards for acceptance of vehicle, track construction and maintenance cover the conditions defined in the cited informative annexes.

A good compromise has to be found between train dynamic performance, maintenance of the vehicle and track and construction costs. The choice of alignment elements depends upon the operation requirements, the parameters specified (and their values) and on local conditions. The specified parameters and values within this European Prestandard may have to be adjusted in consultation with the train operator.

4.1.1 Track alignment design parameters

The following parameters are specified in 4.2:

- radius of horizontal curve R (m) **(*S)**
- cant D (mm) **(*S)**
- cant deficiency I (mm) **(*S)**
- uncompensated (quasi-static) lateral acceleration at track level a_q (m/s²) **(*S)**
- cant excess E (mm)
- rate of change of cant as a function of time dD/dt (mm/s)
- rate of change of cant as a function of length dD/dl (mm/m) **(*S)**
- rate of change of cant deficiency as a function of time dI/dt (mm/s)
- length of alignment elements (circular curves and straights) L_i (m)
- length of transition curves in the horizontal plane L (m)
- radius of vertical curve R_v (m)
- vertical acceleration a_v (m/s²)
- speed V (km/h) **(*S)**

Parameters followed by the **(*S)** note indicate **safety-related parameters**.

Annex B describes an alternative means of classification for the above mentioned parameters, as a function of their relative influence on safety, comfort and cost efficiency of the track/vehicle system.

4.1.2 Parameter quantification

For each of the parameters, two different types of limiting values are specified:

- a recommended limiting value,
- a maximum limiting value which may have two different meanings:

a) **For safety-related parameters**, it shall be considered as the absolute maximum limit of this parameter; this maximum limit may depend upon the actual track mechanical and geometrical state. See annex B for further information.

It should also be noted that the maximum limiting value is safety-related and may (for some parameters) induce a reduced comfort level : most operators will reduce these values by at least 10%, and refer to the proposed limits as "exceptional" values to be used only under special circumstances or after a specific safety case analysis.

The attention of the operators is drawn to the fact that limiting values are defined with respect to a commercial train operating pattern. If and when running trials are conducted, for example to ascertain the vehicle dynamic behaviour (by continually monitoring of the vehicle responses), exceeding the limiting values (particularly in terms of cant deficiency) shall be permitted and it shall be 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.

b) **For non-safety related parameters**, the values shall be considered as the limit above which passenger comfort may be affected and track maintenance significantly increased; however, to cope with special situations, operators may choose values in excess of these specified values, but they should not exceed the safety limits.

NOTE The following parameters for interoperable high speed lines, are specified by the Technical Specification for Interoperability:

- cant;
- cant deficiency.

4.1.3 Traffic categories

A distinction is made between the following traffic categories:

- I - mixed traffic lines, with passenger train speeds from 80 km/h to 120 km/h maximum;
- IIa - mixed traffic lines, with passenger train speeds greater than 120 km/h and up to 160 km/h maximum;
- IIb - mixed traffic lines, with passenger train speeds greater than 160 km/h and up to 200 km/h maximum;
- III - mixed traffic lines, designed for passenger train speed higher than 200 km/h to 300 km/h;
- IV - mixed traffic lines, with passenger train speeds up to 230 km/h (or 250 km/h on upgraded lines) with vehicle incorporating special technical design characteristics (low axle mass, low roll flexibility coefficient, etc...);
- V - dedicated passenger lines with speeds between 250 km/h and 300 km/h.

For the purposes of this European Prestandard, the reference speed is that for passenger trains.

The above classification uses speed as the most relevant criteria to be considered when defining operational conditions for the different traffic categories.

Other criteria may be considered for the production of such a traffic classification, namely, aspects related to safety, comfort and cost efficiency. Further information on such systems of classifications can be found in annex D.

4.2 Recommended limiting values and maximum (or minimum) limiting values for track alignment design parameters

4.2.1 Radius of horizontal curve R

The track alignment designer shall endeavour to use the largest curve radii permitted by track design constraints. This will cater for any future increase of speed. In any event, the track alignment designer shall not use curve radii less than 180 m for new alignments.

The parameters that shall be considered in the determination of the minimum curve radius are:

- the maximum and minimum operating speeds,
- the applied cant,
- the limiting values for cant deficiency and cant excess.

The minimum allowable curve radius for the maximum operating speed, usually with cant deficiency **I**, shall be calculated using the following equation:

$$R = \frac{118}{D + I} V_{\max}^2 \quad [\text{m}]$$

The minimum allowable curve radius for the minimum operating speed, usually with cant excess **E**, shall be calculated using the following equation:

$$R = \frac{118}{D - E} V_{\min}^2 \quad [\text{m}]$$

The minimum curve radius shall be determined such that the values of **D**, **I** and **E** comply with the limits specified in this European Prestandard and satisfy the following condition:

$$\frac{118 \cdot V_{\min}^2}{D - E} \geq R \geq \frac{118 \cdot V_{\max}^2}{D + I} \quad [\text{m}]$$

NOTE 1 Compliance with the above formulae generates a minimum radius of around 200 m. It should be noted that on existing main lines sharper radii curves (minimum radius around 150 m) and operating speeds under 80 km/h can occur.

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NOTE 2 Sharp radius curves generally necessitate a widening of the track gauge in order to improve vehicle curving. This widening of the track gauge can be used in conjunction with the installation of a check rail. The installed check rail serves a dual purpose:

- it increases stiffness of the track panel;
- it provides better guidance of the inner face of the wheel and absorption of part of the curving force.

NOTE 3 It is recommended that the radius of tracks alongside platforms should not be less than 500 m. This is to restrict the gap between platform and vehicles to facilitate safe vehicle access and egress by passengers.

4.2.2 Cant D

Cant shall be determined in relation to the following considerations:

high cant on small-radius curves increases the risk of low-speed freight wagons derailing. Under these conditions, vertical wheel loading applied to the outer rail is much reduced, especially when track twist causes additional reductions (see as reference [ORE B55/Rp 8]);

cant exceeding 160 mm may cause freight load displacement and the deterioration of passenger comfort when a train makes an unscheduled stop at a location where high cant has been applied. Furthermore, with such high cant, works vehicles and special loads with a high centre of gravity may become unstable;

high cant increases cant excess values on curves where there are large differences between the speeds of fast trains and slow trains.

Table 1 - Cant D_{lim}

Traffic categories (speed in km/h)	I Mixed traffic lines $80 \leq V \leq 120$	IIa Mixed traffic lines $120 < V \leq 160$	IIb Mixed traffic lines $160 < V \leq 200$	III Mixed traffic lines designed for passenger train speed $200 < V \leq 300$	IV Mixed traffic lines with passenger train speeds $V \leq 230$ (or 250) (with vehicles incorporating special technical design characteristics)	V High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$
Recommended Limiting value a [mm]	160	160	160	160	160	160
Maximum limiting value a [mm]	180	180	180	180	180	200
^a To avoid the risk of derailment of torsionally-stiff freight wagons on sharp radii curve, cant should be restricted to the following limit (see as reference [ORE B 55/Rp 5 and 8]). $D_l = \frac{R - 50}{15} \quad [\text{mm}]$						

NOTE It is recommended that cant should be restricted to 110 mm for tracks adjacent to passenger platforms. Some other track features, such as level crossings, bridges and tunnels may also, in certain local circumstances, impose cant restrictions.

4.2.3 Cant deficiency I

For given values of local radius R and cant D, the cant deficiency I shall determine the maximum speed through a full curve such that:

$$I = 118 \frac{V_{\max}^2}{R} - D \leq I_{\lim} \quad [\text{mm}]$$

$I_{\lim}$ can be replaced with the value $(a_q)_{\lim}$:

$$a_q = \frac{V_{\max}^2}{12,96 \cdot R} - \frac{g \cdot D}{1500} = \frac{I}{153} \leq (a_q)_{\lim} = \frac{I_{\lim}}{153} \quad [\text{m/s}^2]$$

Table 2 - Limiting cant deficiency I_{lim}

Traffic categories (speed in km/h)		Recommended limiting value ^a [mm]		Maximum limiting value [mm]	
		Freight	Passenger	Freight	Passenger
I - Mixed traffic lines $80 \leq V \leq 120$	$R < 650$ m	110	130	130	160
	$R \geq 650$ m	110	150	130	165
IIa - Mixed traffic lines $120 < V \leq 160$		110	150	160 ^d	165
IIb - Mixed traffic lines $160 < V \leq 200$		110	150	160 ^d	165
III - Mixed traffic lines designed for passenger train speed $200 < V \leq 300$	$200 < V \leq 250$	100	100	150 ^d	150
	$250 < V \leq 300$	80	80	130 ^c	130 ^c
IV - Mixed traffic lines with passenger train speeds up to 230 km/h (or 250 km/h on upgraded lines) with vehicle incorporating special technical design characteristics	$V \leq 160$	110	160 ^b	160 ^d	180 ^b
	$160 < V \leq 200$	x	140	x	160
	$200 < V \leq 230$	x	120	x	160
	$230 < V \leq 250$	x	100	x	150
V - High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$	$V = 250$	x	100	x	150
	$V > 250$	x	80	x	130 ^c
NOTE 1 The designer should endeavour to keep cant deficiency at 20 mm below the recommended limiting value. NOTE 2 The previous Table takes into consideration most of the maximum limiting values used by different European Railways in commercial operation, for both new and existing lines (either for line speed upgrading or for optimising speeds where both freight trains and passenger trains use the same tracks). Vehicle testing procedure for dynamic vehicle behaviour is based on the values indicated. NOTE 3 The preceding values apply only to progressive increases of cant deficiency for speeds above 80 km/h; in the case of cant deficiency discontinuities (sudden application of a lateral acceleration) the specific rules for switches and crossings for the diverging line (see Part 2) may be taken into account ^a For jointed tracks, cant deficiency values shall be as specified by the contract. ^b These cant deficiency limits shall only be applied to dedicated vehicle types with special mechanical characteristics such as low axle load, reduced unsprung masses, low roll coefficient. ^c A cant deficiency of 150 mm can be used on non-ballasted tracks for speeds in excess of 250 km/h. ^d These values apply only to dedicated freight wagons with special mechanical characteristics whose performance is similar to passenger vehicles.					

NOTE The values of I_{lim} and $a_{q lim}$ are based on the following considerations:

a) Track forces and safety

Cant deficiency affects the vertical and lateral forces on the outer rail and the lateral forces of the loaded track panel. The magnitude of these forces depends, among other factors, upon:

- type of track structure (welded or jointed track);
- track maintenance condition;
- track geometry;

- type of vehicle running-gear and suspension;
- axle-load and unsprung masses of vehicles;
- vehicle maintenance condition.

Any authorisation of a higher I_{lim} value would presuppose that the rail section, sleeper type, sleeper spacing, rail fastenings, ballast bed and carrying capacity of the infrastructure are suitable for this higher value.

Furthermore, it is assumed that the lateral forces exerted by the axles do not exceed the loaded track resistance to lateral deformation. This resistance is not only a function of the track structure, especially the type of ballast material, but also of the degree of ballast consolidation. After a tamping operation, for example, allowance is made for the minimum track lateral shift value (see as a reference [ORE C 138/Rp 9 and DT 150]).

b) Economic aspects of track maintenance

Any increase in the value of I means extra cost for inspection and maintenance of track quality. There will also be a resultant decrease in the service life of the track components.

c) Ride comfort and roll flexibility coefficient (s)

The quasi-static lateral acceleration parallel to the vehicle floor a_i , which is a measure of the acceleration felt by passengers inside the vehicle, is greater than the lateral non-compensated acceleration at the track plane a_q :

$$a_i = (1 + s) \cdot a_q \quad [\text{m/s}^2]$$

The maximum value of a_i considered to be acceptable is a range of 1,0 m/s² to 1,5 m/s².

The value of I should be adjusted to the suspension flexibility of the rolling stock used. Most modern vehicles, with full load, have a roll flexibility coefficient in the order of 0,4. With special arrangements, this value can be reduced to 0,20 - 0,25.

It should be emphasised that the number of curvature changes and the length of alignment elements have an additional influence on the value of a_i which may or may not be regarded as acceptable.

4.2.4 Cant excess E

In larger radii curve, there are generally significant differences between the speed of fast trains V_{max} and trains running at lower speeds V_{min} .

There is cant excess when the following has a positive value:

$$E = D - 118 \frac{V_{min}^2}{R} \quad [\text{mm}]$$

The value of E affects inner-rail stresses induced by slow trains, especially freight trains, which usually have heavier axle-loads.

On a circular curve, the vertical wheel load of the inner front wheel is increased by a factor :

$$\frac{\Delta Q}{Q_N} = \frac{2 \cdot E \cdot h_g}{e^2}$$

The designer may refer to annex C for additional information on the criteria to be considered for the determination of optimised values of cant excess and cant deficiency.

NOTE As guidance, the following limiting values may be used for cant excess:

- recommended limiting value: 110 mm;
- maximum limiting value: 130 mm.

However, for passenger-trains, cant excess should not exceed 110 mm as a maximum limiting value.

4.2.5 Rate of change of cant as a function of time dD/dt

In principle, cant variations are normally found in transition curves. However it may be necessary to provide cant transition in curves and straights. For these specifications refer to Part 2 of the European Prestandard.

For cant gradients with uniform slope, the following relationship with ΔD being the cant variation is desired:

$$\frac{dD}{dt} = \frac{\Delta D \cdot V_{\max}}{3,6 \cdot L} \leq \left(\frac{dD}{dt} \right)_{\lim} \quad [\text{mm/s}]$$

For cant gradients with variable slope, the value of dD/dt is not constant. It reaches a peak in the middle of the slope (see annex A). Normally, these transition shapes are not applied to small changes in cant.

The value of dD/dt shall be chosen taking into consideration ride comfort and the possibility of a non optimal track bed, since negotiation of cant gradients gives rise to fast rotational movement of the vehicle body around its longitudinal axis.

The designer may refer to annex A for additional information on transition curves.

Table 3 - Rate of change of cant as a function of time $(dD/dt)_{lim}$
(cant gradient with uniform slope)

Traffic categories (speed in km/h)	I Mixed traffic lines $80 \leq V \leq 120$	IIa Mixed traffic lines $120 < V \leq 160$	IIb Mixed traffic lines $160 < V \leq 200$	III Mixed traffic lines designed for passenger train speed $200 < V \leq 300$	IV Mixed traffic lines with passenger train speeds $V \leq 230$ (or 250) (with vehicles incorporating special technical design characteristics)	V High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$
Recommended limiting values [mm/s]	50	50	50	50	50	50
Maximum limiting values [mm/s]	55	60	60	60	60	60

Table 3a - Rate of change of cant as a function of time $(dD/dt)_{lim}$
(cant gradient with variable slope)

Traffic categories (speed in km/h)	I Mixed traffic lines $80 \leq V \leq 120$	IIa Mixed traffic lines $120 < V \leq 160$	IIb Mixed traffic lines $160 < V \leq 200$	III Mixed traffic lines designed for passenger train speed $200 < V \leq 300$	IV Mixed traffic lines with passenger train speeds $V \leq 230$ (or 250) (with vehicles incorporating special technical design characteristics)	V High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$
Recommended Limiting values [mm/s]	55	55	55	55	55	55
Maximum limiting values [mm/s]	70	70	70	70	70	70
NOTE 1 The cant of transition components should vary according to the same law as the curvature. NOTE 2 Due to limited experiences with transitions with variable slope, the values in the Table are indicative. The indicated values correspond to the highest values applied in countries using variable slopes. Transitions with variable slopes yield longer transitions than those with uniform slopes.						

4.2.6 Rate of change of cant as a function of length dD/dl

The designer shall use the value which is the most restrictive value resulting from safety and comfort considerations:

a) Observance of safety requirements:

on short transition curves, the maximum value of the cant slope, i.e. dD/dl with variable-slope gradients or $\Delta D/L$ in the case of gradients with constant slope, shall be set with reference to safety in relation to derailment of slow freight trains (ORE Report B 55 / Rp 8 – see annex I).

b) Observance of riding comfort requirements:

the following values are derived from the values shown in Table 3 using the following relation:

$$\frac{dD}{d\ell} = \frac{3,6}{V_{\max}} \frac{dD}{dt} \quad [\text{mm/m}]$$

with reference to a) and b) above, and considering the most severe case depending on vehicle type, the following values shall apply:

- recommended limiting value : 2,25 mm/m;
- maximum limiting value : 2,5 mm/m.

4.2.7 Rate of change of cant deficiency as a function of time dl/dt

For transitions with a uniform variation of curvature and a uniform variation of cant, the following relationship is derived, where Δl is the cant deficiency variation:

$$\frac{dl}{dt} = \frac{V_{\max}}{3,6 \cdot L} \cdot \Delta l \leq \left(\frac{dl}{dt} \right)_{\lim} \quad [\text{mm/s}]$$

Similarly, the variation of non-compensated lateral acceleration in the track plane may be determined by the overall variation of non-compensated lateral acceleration Δa_q along the whole transition as follows:

$$\frac{da_q}{dt} = \frac{V_{\max}}{3,6 \cdot L} \cdot \Delta a_q \leq \left(\frac{da_q}{dt} \right)_{\lim} \quad [\text{m/s}^3]$$

The values of dl/dt and da_q/dt are not constant for transitions with non-linear curvature variation and non linear cant application. They attain their maximum values at the middle of the transition curve.

For fast passenger trains, the selected values for $(dl/dt)_{\lim}$ shall be related to ride comfort where there is a possibility of a non optimal track bed.

The rate of change of the quasi-static lateral acceleration parallel to the vehicle floor (da_i/dt), which is a measure of the rate of change of acceleration felt by the passenger inside the vehicle, is greater than the rate of change of non-compensated acceleration in the track plane (da_q/dt):

$$\frac{da_i}{dt} = (1 + s) \frac{da_q}{dt} \quad [\text{m/s}^3]$$

(where s is the roll flexibility coefficient of the vehicle)

The maximum value of da_i/dt considered as acceptable shall be within the range 0,5 m/s³ to 0,8 m/s³

The value of $(dl/dt)_{\lim}$ shall be set taking into account the roll flexibility coefficient of fast passenger vehicles.

Table 4 - Rate of change of cant deficiency as a function of time $(dl/dt)_{lim}$

The following values apply to all forms of transition curves

Traffic categories (speed in km/h)	I Mixed traffic lines $80 \leq V \leq 120$	IIa Mixed traffic lines $120 < V \leq 160$	IIb Mixed traffic lines $160 < V \leq 200$	III Mixed traffic lines designed for passenger train speed $200 < V \leq 300$	IV Mixed traffic lines with passenger train speeds $V \leq 230$ (or 250) (with vehicles incorporating special technical design characteristics)	V High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$
Recommended limiting values [mm/s]	55	55	55	50	50	50
Maximum limiting values [mm/s]	90	90	90	75	90	75

4.2.8 Length of alignment elements (circular curves and straights) L_i

The actual length of any alignment element (other than transition curves) shall be set above a minimum value given in Table 5, taking into account the actual alignment design parameters of the neighbouring alignment elements (cant, cant deficiency and their variations); longer elements should be used for higher values of these parameters.

Table 5 - Minimum length of alignment elements L_i (circular curves and straights)

Traffic categories (speed in km/h)	I Mixed traffic lines $80 \leq V \leq 120$	IIa Mixed traffic lines $120 < V \leq 160$	IIb Mixed traffic lines $160 < V \leq 200$	III Mixed traffic lines designed for passenger train speed $200 < V \leq 300$	IV Mixed traffic lines with passenger train speeds $V \leq 230$ (or 250) (with vehicles incorporating special technical design characteristics)	V High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$
Recommended limiting value _a [m]	$\frac{V_{\max}^b}{3}$			$\frac{V_{\max}}{15}$		
Minimum limiting value _a [m]	$\frac{V_{\max}^b}{5}$			$\frac{V_{\max}}{2}$		
^a It is desirable where possible to join two reverse circular curves by a continuous transition curve instead of placing a straight line element between the two transitions curves. Hence, in this case, the length of straight line element is zero.						
^b Without going under 30 m. For shorter lengths or intersecting straights refer to Part 2 of this European Prestandard.						

On high speed lines, a rapid succession of curves and straights may induce a reduction in comfort, particularly when the length of individual alignment elements are such that the passengers are subjected to changing accelerations at a rate which corresponds to the natural frequencies of the vehicles.

4.2.9 Length of transition curves in the horizontal plane L (valid only for the linear transition curves)

The length of transition curves shall be determined by the limiting values imposed by the following parameters:

- rate of change of cant deficiency as a function of time $\frac{dI}{dt}$;
- rate of change of cant as a function of length $\frac{dD}{d\ell}$;

and by the following formulae:

$$L \geq \frac{V_{\max}}{3,6} \Delta I \left(\frac{dI}{dt} \right)^{-1} \quad [m]$$

$$L \geq \Delta D \cdot \left(\frac{dD}{d\ell} \right)^{-1} \quad [m]$$

The length of transition curve shall be the longest value derived from the above formulae for the selected values of $\frac{dI}{dt}$ and $\frac{dD}{d\ell}$.

NOTE When there is no transition curve between the components to be connected, the limit values of the permissible discontinuities for the switches, defined in Part 2 of this European Prestandard, should be complied with.

4.2.10 Vertical curves

Vertical curves may be designed without transition curves.

A vertical curve shall be provided over at least 20 m at each change in line gradient if the difference in slope between adjacent gradients is more than:

- 2 mm/m for speeds up to 230 km/h;
- 1 mm/m for speeds over 230 km/h.

4.2.11 Radius of vertical curve R_v

The radius of vertical curves shall be designed using the formula $R_v = \frac{V_{\max}^2}{12,96 \cdot a_v} \geq (R_v)_{\lim}$

Table 6 - Radius of vertical curve $(R_v)_{\lim}$

Traffic categories (speed in km/h)	I Mixed traffic lines $80 \leq V \leq 120$	IIa Mixed traffic Lines $120 < V \leq 160$	IIb Mixed traffic lines $160 < V \leq 200$	III Mixed traffic lines designed for passenger train speed $200 < V \leq 300$	IV Mixed traffic lines with passenger train speeds $V \leq 230$ (or 250) (with vehicles incorporating special technical design characteristics)	V High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$
Recommended limiting values [m]	$0,35 V_{\max}^2$ ^b	$0,35 V_{\max}^2$		$0,35 V_{\max}^2$	$0,35 V_{\max}^2$	$0,35 V_{\max}^2$
minimum limiting values [m]	$0,25 V_{\max}^2$ ^c			$0,175 V_{\max}^2$ ^a	$0,25 V_{\max}^2$ ^c	$0,175 V_{\max}^2$ ^a
^a With a tolerance of + 10 % on a crest, + 30 % on a hollow						
^b On lines where passengers may be standing, it is recommended that R_v be greater than $0,77 V^2$						
^c Without going under 2 000 m radius						

4.2.12 Vertical acceleration a_v

$$a_v = \frac{V_{\max}^2}{12,96 \cdot R_v} \leq (a_v)_{\lim} \quad [\text{m/s}^2]$$

The maximum value of $(a_v)_{\lim}$ shall be selected taking into consideration ride comfort where there is a possibility of a non optimal track bed. In addition, consideration shall also be given to safety to guard against derailment due to wheel unloading when running over humps. However, this safety limit is not considered unless the maximum limiting values for a_v are exceeded.

Table 7 - Vertical acceleration $(a_v)_{lim}$

Traffic categories (speed in km/h)	I Mixed traffic lines $80 \leq V \leq 120$	IIa Mixed traffic Lines $120 < V \leq 160$	IIb Mixed traffic lines $160 < V \leq 200$	III Mixed traffic lines designed for passenger train speed $200 < V \leq 300$	IV Mixed traffic lines with passenger train speeds $V \leq 230$ (or 250) (with vehicles incorporating special technical design characteristics)	V High-speed lines with dedicated passenger traffic $250 \leq V \leq 300$
Recommended limiting values [m/s ²]	0,22 ^b	0,22		0,22	0,22	0,22
Maximum limiting values [m/s ²]	0,31			0,44 ^a	0,31	0,44 ^a
^a With a tolerance of + 10 % on a crest, + 30 % on a hollow						
^b On lines where passengers may be standing, it is recommended that a_v not exceed 0,1						

Annex A (informative)

Supplementary information for track alignment design related to shape and length of alignment elements

Among other features of track alignment design, all changes imposed in the lateral plane to vehicle trajectory are important for providing a good ride comfort. In such situations, the vehicle is subjected to abrupt variations of cant and curvature gradients (second order derivatives). The dynamic response to these types of excitations depends upon the suspension design. However a common feature is that this response lasts a few seconds before the effect is eliminated over a following alignment element (circular curve or straight).

It is possible to provide supplementary information for the track alignment designer to select alternative transitions curves and lengths of alignment elements. This annex provides detailed analysis methods with respect to design of transition curves and track alignment elements.

This annex has 3 parts:

Part 1 includes a Table summarising the properties of the following transition curves, compared with the conventional cubic parabola :

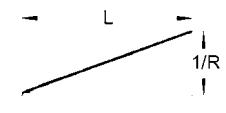
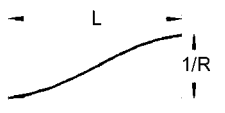
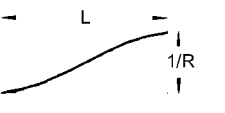
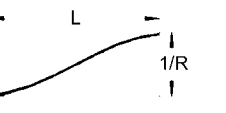
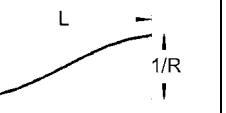
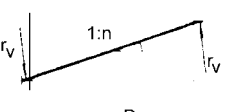
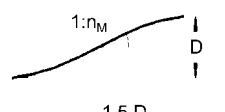
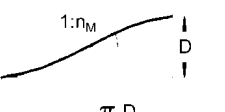
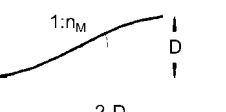
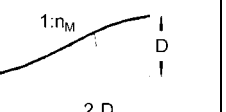
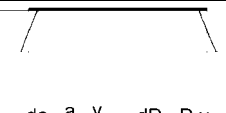
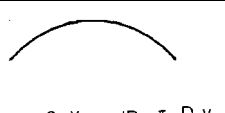
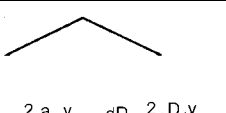
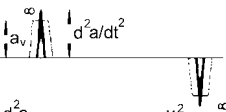
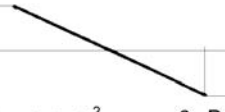
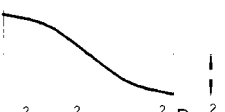
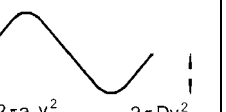
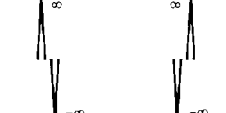
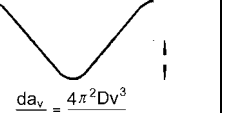
- BLOSS curve
- COSINE curve
- SCHRAMM curve
- KLEIN curve (sinewave curve)

Part 2 entitled: “ The rolling movement of a vehicle and its relation with minimum length of alignment elements ” provide a simplified method by which the effect of track element length can be assessed if design constraints are such that the proposed rules of this European Prestandard cannot be complied with.

Part 3 entitled “ Further parameters that may be considered for transition curve design and a progressive system of design rules ” provides a more comprehensive analysis method of the vehicle behaviour in complex curving situations and of the consequences in terms of track alignment assessment.

A.1 Table summarising the properties of different transition curves shapes, compared with the conventional cubic parabola and clothoid which are the bases of the Prestandard

Maximum values of transition curve (Unit length: m, Unit time: s)

	Cubic parabola	Bloss	Cos	Schramm	Klein (Sin)
Horizontal curvature K Non-compensated lateral acceleration in the track plane	 $K = \frac{1}{R}; \quad a_q = \frac{v^2}{R} \cdot \frac{gD}{1500}$	 $K = \frac{1}{R}; \quad a_q = \frac{v^2}{R} \cdot \frac{gD}{1500}$	 $K = \frac{1}{R}; \quad a_q = \frac{v^2}{R} \cdot \frac{gD}{1500}$	 $K = \frac{1}{R}; \quad a_q = \frac{v^2}{R} \cdot \frac{gD}{1500}$	 $K = \frac{1}{R}; \quad a_q = \frac{v^2}{R} \cdot \frac{gD}{1500}$
Cant Maximum rate of change of cant as function of length	 $1:n = \frac{D}{L}$	 $1:n_M = \frac{1,5 \cdot D}{L}$	 $1:n_M = \frac{\pi \cdot D}{L}$	 $1:n_M = \frac{2 \cdot D}{L}$	 $1:n_M = \frac{2 \cdot D}{L}$
Variation of non-compensated lateral acceleration (horiz. jerk), Rate of change of cant as function of time	 $\frac{da}{dt} = \frac{a_q \cdot v}{L}; \quad \frac{dD}{dt} = \frac{D \cdot v}{L}$	 $\frac{da}{dt} = \frac{1,5 \cdot a_q \cdot v}{L}; \quad \frac{dD}{dt} = \frac{1,5 \cdot D \cdot v}{L}$	 $\frac{da}{dt} = \frac{\pi \cdot a_q \cdot v}{L}; \quad \frac{dD}{dt} = \frac{\pi \cdot D \cdot v}{L}$	 $\frac{da}{dt} = \frac{2 \cdot a_q \cdot v}{L}; \quad \frac{dD}{dt} = \frac{2 \cdot D \cdot v}{L}$	 $\frac{da}{dt} = \frac{2 \cdot a_q \cdot v}{L}; \quad \frac{dD}{dt} = \frac{2 \cdot D \cdot v}{L}$
Rate of change of horizontal jerk, vertical acceleration	 $\frac{d^2a}{dt^2} = \infty; \quad a_v = \frac{v^2}{r_v}$	 $\frac{d^2a}{dt^2} = \frac{6 \cdot a_q \cdot v^2}{L^2}; \quad a_v = \frac{6 \cdot D \cdot v^2}{L^2}$	 $\frac{d^2a}{dt^2} = \frac{\pi^2 \cdot a_q \cdot v^2}{2L^2}; \quad a_v = \frac{\pi^2 \cdot D \cdot v^2}{2L^2}$	 $\frac{d^2a}{dt^2} = \frac{4 \cdot a_q \cdot v^2}{L^2}; \quad a_v = \frac{4 \cdot D \cdot v^2}{L^2}$	 $\frac{d^2a}{dt^2} = \frac{2\pi a_q v^2}{L^2}; \quad a_v = \frac{2\pi D v^2}{L^2}$
Vertical jerk	 $\frac{da_v}{dt} = \frac{4\pi^2 D v^3}{L^3}$				
Shift f_L (m)	$f = \frac{L^2}{24 \cdot R}$	$f = \frac{L^2}{40 \cdot R}$	$f = \frac{L^2}{42,23 \cdot R}$	$f = \frac{L^2}{48 \cdot R}$	$f = \frac{L^2}{61,2 \cdot R}$
Equivalent length of transition curve ($f_L = f_{clot}$)	L_{clot}	$L_{bloss} = 1,29 \cdot L_{clot}$	$L_{cos} = 1,326 \cdot L_{clot}$	$L_{shramm} = 1,414 \cdot L_{clot}$	$L_{sin} = 1,597 \cdot L_{clot}$
Rate of value of horizontal jerk ($f_L = f_{clot}$)	1,0	1,16	1,185	1,414	1,252
Rate of change of vertical acceleration ($f_L = f_{clot}$)	1,0	0,37	0,29	0,21	0,25