



BSI Standards Publication

Railway applications — Aerodynamics

Part 5: Requirements and assessment procedures for aerodynamics in tunnels

National foreword

This British Standard is the UK implementation of EN 14067-5:2021, incorporating corrigendum January 2023. It supersedes BS EN 14067-5:2006+A1:2010, which is withdrawn.

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Exigences et procédures d'essai pour l'aérodynamique
en tunnel

Bahnanwendungen - Aerodynamik - Teil 5:
Anforderungen und Prüfverfahren für Aerodynamik im
Tunnel

This European Standard was approved by CEN on 22 November 2021 and includes the Corrigendum issued by CEN on 11 January 2023.

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Contents	Page
European foreword.....	5
1 Scope	6
2 Normative references	6
3 Terms and definitions	6
4 Symbols and abbreviations	8
5 Requirements on locomotives and passenger rolling stock.....	14
5.1 Limitation of pressure variations inside tunnels	14
5.1.1 General	14
5.1.2 Requirements	14
5.1.3 Full conformity assessment.....	16
5.1.4 Simplified conformity assessment.....	16
5.2 Limitation of pressure gradient entering a tunnel (relative to micro-pressure wave generation)	18
5.2.1 General	18
5.2.2 Requirements	18
5.2.3 Simplified conformity assessment.....	20
5.3 Resistance to aerodynamic loading.....	20
5.3.1 General	20
5.3.2 Requirements	21
5.3.3 Exceptional load assessment	27
5.3.4 Fatigue load assessment	28
5.3.5 Assessment in case of modification	28
6 Requirements on infrastructure	29
6.1 Limitation of pressure variations inside tunnels to meet the medical health criterion	29
6.1.1 General	29
6.1.2 Requirements	29
6.1.3 Full conformity assessment.....	31
6.1.4 Simplified conformity assessment.....	31
6.2 Limitation of pressure gradient entering a tunnel (relative to micro-pressure wave generation)	32
6.2.1 General	32
6.2.2 Reference case.....	32
6.2.3 Requirements	32
6.2.4 Assessment	32
6.3 Further aspects of tunnel design	33
6.3.1 General	33
6.3.2 Aural pressure comfort.....	33
6.3.3 Pressure loading on installations.....	34
6.3.4 Induced airflows.....	35
6.3.5 Aerodynamic drag.....	35
6.3.6 Contact forces of pantograph to catenary	35
6.3.7 Ventilation	35
6.3.8 Workers' safety	35
6.3.9 Loads on vehicles in mixed traffic operation	36
6.4 Additional aspects for underground stations	36

6.4.1	Pressure changes	36
6.4.2	Induced airflows	36
6.4.3	Specific case for loads on platform barrier systems due to trains passing	37
7	Methods and test procedures.....	37
7.1	General	37
7.2	Methods to determine pressure variations in tunnels	39
7.2.1	General	39
7.2.2	Full-scale measurements at fixed locations in a tunnel.....	40
7.2.3	Instrumentation	41
7.2.4	Full-scale measurements on the exterior of the train.....	43
7.2.5	Predictive formulae	44
7.2.6	Assessment by numerical simulation.....	44
7.2.7	Reduced scale measurements at fixed locations in a tunnel	45
7.3	Assessment of maximum pressure changes (vehicle reference case).....	46
7.3.1	General	46
7.3.2	Transformation of measurement values by a factor (approach 1)	46
7.3.3	Transformation of measurement values based on A.3.3 (approach 2)	47
7.3.4	Transformation by simulation (approach 3).....	47
7.3.5	Assessment of the pressure time history	48
7.3.6	Assessment quantities and comparison.....	52
7.4	Assessment of maximum pressure changes (infrastructure reference case)	52
7.4.1	General	52
7.4.2	Assessment method	52
7.5	Assessment of the pressure gradient of a train entering a tunnel (vehicle reference case, with respect to micro-pressure wave generation)	54
7.5.1	General	54
7.5.2	Assessment by simulations	54
7.5.3	Assessment by moving model rig tests	55
7.6	Assessment of the micro-pressure wave (infrastructure reference case)	55
7.6.1	General	55
7.6.2	Assessment by numerical simulations.....	56
7.6.3	Assessment by moving model rig tests	58
7.7	Assessment of aerodynamic loads.....	59
7.7.1	Assessment of load due to strong wind	59
7.7.2	Assessment of open air passings for fatigue load assessments	60
7.7.3	Assessment of transient loads in tunnels	61
7.7.4	Assessment of fatigue loads	64
7.7.5	Determination of the damage-equivalent load amplitude for scenario	66
7.7.6	Documentation	67
7.7.7	Simplified load cases	68
7.8	Assessment of pressure sealing.....	69
7.8.1	General	69
7.8.2	Dynamic pressure tightness	70
7.8.3	Equivalent leakage area	70
7.8.4	Test methods.....	71
7.8.5	Dynamic tests	73
Annex A (informative)	Predictive formulae.....	75
A.1	General	75
A.2	SNCF approach.....	75
A.2.1	Entry of the nose of the train	75

A.2.2	Entry of the body of the train.....	75
A.2.3	Entry of the rear of the train	76
A.3	TU Vienna approach.....	76
A.3.1	General.....	76
A.3.2	Symbols.....	76
A.3.3	Calculation of Δp_N	77
A.3.4	Calculation of Δp_{fr}	78
A.3.5	Calculation of Δp_T	79
A.3.6	Calculation of the drag coefficient $C_{x,tu}$	80
A.4	GB approach, ignoring changes in air density and the speed of sound	83
A.4.1	General.....	83
A.4.2	Calculation of Δp_N	83
A.4.3	Calculation of Δp_{fr}	84
A.4.4	Calculation of Δp_T	84
Annex B (informative)	Pressure comfort criteria	85
B.1	General.....	85
B.2	Unsealed trains (generally $\tau_{dyn} < 0,5$ s)	85
B.3	Sealed trains (generally $\tau_{dyn} > 0,5$ s)	85
Annex C (informative)	Micro-pressure wave	86
C.1	General.....	86
C.2	Compression wave generation	86
C.3	Compression wave propagation	87
C.4	Micro-pressure wave radiation.....	87
Annex D (informative)	Pressure loading on unsealed crossing trains	89
Annex E (informative)	Validation cases for the assessment of aerodynamic loads.....	92
E.1	General.....	92
E.2	Validation procedure.....	92
Bibliography		94

European foreword

This document (EN 14067-5:2021+AC:2023) 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 June 2022, and conflicting national standards shall be withdrawn at the latest by June 2022.

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 14067-5:2006+A1:2010.

This document includes the corrigendum EN 14067-5:2021/AC:2023 which corrects some formulas.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags AC AC.

EN 14067, *Railway applications — Aerodynamics*, consists of the following parts:

- *Part 1: Symbols and units;*
- *Part 3: Aerodynamics in tunnels;*
- *Part 4: Requirements and test procedures for aerodynamics on open track;*
- *Part 5: Requirements and test procedures for aerodynamics in tunnels;*
- *Part 6: Requirements and test procedures for cross wind assessment.*

The results of the EU-funded research project “AeroTRAIN” (Grant Agreement No. 233985) have been used.

The contents of the previous edition of EN 14067-5 have been integrated in this document; they have been re-structured and extended to support the Technical Specifications for the Interoperability of the Trans-European rail system. Requirements on conformity assessment for rolling stock were added.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

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

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1 Scope

This document establishes aerodynamic requirements, test procedures, assessment methods and acceptance criteria for operating rolling stock in tunnels. Aerodynamic pressure variations, loads, micro pressure wave generation and further aerodynamic aspects to be expected in tunnel operation are addressed in this document. Requirements for the aerodynamic design of rolling stock and tunnels of the heavy rail system are provided. The requirements apply to heavy rail systems only.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 14067-4:2013+A1:2018, *Railway applications - Aerodynamics - Part 4: Requirements and test procedures for aerodynamics on open track*

EN 15273 series, *Railway applications — Gauges*

EN 17149-1:—,¹ *Railway applications — Strength assessment of railway vehicle structures — Part 1: General*

ISO 8756, *Air quality — Handling of temperature, pressure and humidity data*

3 Terms and definitions

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

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

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

3.1 compression wave

approximate step increase in pressure that travels at the speed of sound

3.2 expansion wave

approximate step decrease in pressure that travels at the speed of sound

3.3 computational fluid dynamics CFD

numerical methods of approximating and solving the formulae of fluid dynamics

¹ Under preparation. Stage at time of publication: prEN 17149:2021.

3.4**exceptional load**

infrequent load which represents the extremal load or combination of loads for the relevant operation conditions, including both steady and transient load

Note 1 to entry: Exceptional load is also described with the terms “static load”, “static design load” or “proof load”.

[SOURCE: EN 17149-1:—¹, 3.1.9; modified – “including both steady and transient load” added]

3.5**fatigue load**

frequent load or combination of loads which represents the normal relevant operation conditions

[SOURCE: EN 17149-1:—¹, 3.1.11]

3.6**steady load**

load that is constant or nearly constant with time

Note 1 to entry: These loads include the dynamic pressure due to the airflow acceleration around the front of the train and pressure changes caused by strong side winds.

3.7**transient load**

load that varies in time

Note 1 to entry: Transient loads can be divided into three kinds:

- a) loads caused by trains crossing with other trains in the open air or due to the pressure field around the train;
- b) loads caused by trains travelling alone or crossing with other trains in tunnels;
- c) loads that arise due to the turbulent nature of the flow around trains.

Note 2 to entry: Loads a) and b) are relevant for all train structures, but loads c) may be only relevant for some high speed train components and are not considered in this document.

3.8**tunnel**

excavation or a construction around the track provided to allow the railway to pass through, for example, higher land, buildings or water

3.9**tunnel length**

length of a tunnel is defined as the length of the fully enclosed section, measured centrally at rail level

3.10**tunnel cross-sectional area**

free cross-sectional area of a tunnel not including ballast, rail, sleepers, longitudinal piping, platform

3.11**vehicle cross-sectional area**

projected cross-sectional area in lengthwise direction of vehicle

3.12

critical crossing

crossing of two trains in a tunnel leading to maximum pressure changes

Note 1 to entry: The terms crossing and passing are used interchangeably in this document.

3.13

gauge pressure

amount by which the pressure measured in a fluid, such as air, exceeds that of the atmosphere

3.14

fixed formation

group of rail vehicles which can only be coupled/uncoupled or assembled/disassembled (e.g. articulated vehicles) in a workshop environment

[SOURCE: EN 17343:2020, 3.1.6.4]

3.15

load collective

pressure spectrum

table of loads and their frequency of occurrence

4 Symbols and abbreviations

For the purposes of this document, the symbols in Table 1 below apply.

Table 1 — Symbols

Symbol	Significance	Explanation or remark	Unit
A_S, A_T	area of integration	see Figure 12	sPa
B	train/tunnel blockage ratio	$B = \frac{S_{tr}}{S_{tu}}$	
b	width of vehicle	see Figure 2	m
C	load collective	see 7.7.4.1	
$C_{f,tr}$	train friction factor or coefficient	see Formula (15)	
$C_{f,tu}$	tunnel friction factor or coefficient		
$C_{lifecycle}$	total load collectives in open air and in tunnels	see Formula (34)	
$C_{lifecycle,front}$	total load collectives in open air and in tunnels at front of train	see 7.7.4.2	
$C_{lifecycle,tail}$	total load collectives in open air and in tunnels at tail of train	see 7.7.4.2	
C_n	factor depending on the shape of the train nose and the shape of the tunnel portal	see Formula (C.2)	
$C_{oa,cros}$	load collective for trains meeting on the open track	see Formula (30)	

Symbol	Significance	Explanation or remark	Unit
$C_{oa,cross,i}$	load collective for trains meeting in segment i		
$C_{tu,cross}$	load collective for passing with crossings in tunnels	see Formula (33)	
$C_{tu,cross,j}$	load collective for passing with crossings in tunnel j		
$C_{tu,solo}$	load collective for solo passages in the tunnel	see Formula (31)	
$C_{tu,solo,j}$	load collective for solo passages in tunnel j		
CFL	Courant-Friedrich-Levy number	see 7.6.2	
c	speed of sound		m/s
D_h	hydraulic diameter	see Formula (16)	m
d_x	measurement distance	see Formulae (21), (22), (23)	m
F_{max}	maximum measured force	see Figure D.4	N
g	gravity		m/s ²
h	height	see Figure 2	m
h_l	frequency corresponding to a class of amplitudes in a rainflow matrix	see 7.7.5	
h_0	distance from top of rail to the underside of the vehicle body	see Figure 2	m
h_c	height of tunnel centre above rail level	see Figure 1	m
$H, H1, H2$	relative humidity of air	see 7.3.2	%
k	S-N curve exponent	see 7.7.5	
k_r	vehicle structural rigidity factor	see 7.8.2	
k_1	factor	see Formula (12)	
k_2	factor	see Formula (12)	
k_s	train roughness parameter	see 7.3.3	m
L_n	nose length of train	see Figure 2	m
$L_{n,model}$	nose length of train model	see 7.2.7	m
$L_{section,i}$	length of the route section i	see 7.7.4.3	km
L_{tr}	length of train	Length overall	m
L_{tu}	length of tunnel		m
$L_{tu,crit}$	critical tunnel length	see 7.7.3.6	m
$L_{tu,min}$	minimum length of a tunnel measured in full-scale tests from entry portal	see Formula (4)	m

Symbol	Significance	Explanation or remark	Unit
$L_{virtun,j}$	virtual length of tunnel j	see Formula (37)	m
$L_{year,e}$	distance travelled per year on route section i	see 7.7.4.2	km/year
Ma	Mach number		
N_{oa}	number of sections of open track	see 7.7.4.2	1/a
N_c	number of cycles of reference value of the fatigue load	see 7.7.5	
$N_{trainsperhour}$	Number of trains passing a stationary point in one direction per hour	see 7.7.5	1/h
N_{tu}	total number of tunnels on a route	see 7.7.4.2	
$N_{\Delta te,j}$	calculated entry time gaps for j_{th} tunnel	see Formula (33)	
$n_{oa,cros,i}$	frequency for trains crossing on the open track in route section i	see Formula (36)	
$n_{tu,cros,j}$	frequency for trains crossing in the j_{th} double track tunnel	see Formula (38)	
$n_{tu,solo,j}$	frequency of single train passages without train encounter in the j_{th} double track tunnel	see Formula (31)	
Pe_{tr}	perimeter of train		m
Pe_{tu}	perimeter of tunnel		m
p	pressure	see Formula (40)	Pa
p_{eq}	damage-equivalent amplitude	see 7.7.5	Pa
p_l	classified pressure amplitude	see 7.7.5	Pa
p_L	pressure load	see Formula (24)	Pa
p_{atm}	atmospheric pressure		Pa
p_d	pressure difference between external and internal pressure	see 7.1	Pa
$p_e, p_e(t)$	external pressure outside of a vehicle, or generated by a train in a tunnel	see 7.1	Pa
$p_{fullscale}$	full-scale pressures determined from $p_{modelscale}$	see Formula (19)	Pa
$p_i, p_i(t)$	internal pressure in a vehicle, or in an enclosed air volume in a tunnel	see 7.1	Pa
$p_{modelscale}$	pressures measured at model scale	see Formula (19)	Pa
p_o	reference static pressure		Pa
p_{offset}	offset pressure	see Figure 10	Pa
$p(t)_{sim}$	pressure signal in tunnel from simulation software	see 7.3.4	Pa

Symbol	Significance	Explanation or remark	Unit
$p(t)_{\text{test}}$	pressure signal in tunnel from track test	see 7.3.4	Pa
r	radius	distance between tunnel exit portal centre and the point of interest, see Figure C.3	m
r_b	corner radius of the micro-pressure wave reference vehicle	see Figure 2	m
R	tunnel radius	see Figure 1	m
R_{model}	ratio of full-scale train to its model	see 7.6.3.2	
S_{eq}	equivalent leakage area		m ²
S_{tr}	vehicle cross-sectional area	see 3.11	m ²
S_{tu}	tunnel cross-sectional area	see 3.10	m ²
t, t_A, t_B, t_S, t_T	time	see Figures 9 and 11	s
t_e	difference in entry time	see 7.7.3.4	s
t_{life}	train service life	see 7.7.4.2	year
$t_{50 \%}$	time when pressure rise is 50 % of the value at time t_T	see Figure 12	s
T	absolute temperature		K
T_f	tunnel factor	see Formula (A.26)	
U	local dominant speed (train speed or pressure wave speed)	see 7.6.2	m/s
U_0	flow velocity in tunnel relative to train before train entry	see A.4	m/s
u_0	the measured air flow in a tunnel at the moment of train entry	see 7.3.2	m/s
v_{tr}	train speed		m/s
$v_{\text{tr},1}$	train speed	see 7.7.4.3	m/s
$v_{\text{tr},2}$	speed of the encountering train	see 7.7.4.3	m/s
$v_{\text{line,max}}$	design speed of a segment of line	Maximum permitted speed in a defined track segment. The segment may be a tunnel, a line or a segment of a line.	km/h
$v_{\text{tr,max}}$	maximum train speed or design speed of a train	Maximum train speed refers to train operation.	km/h

Symbol	Significance	Explanation or remark	Unit
		If limited by infrastructure, maximum train speed may be lower than design speed.	
$V_{tr,ref}$	train reference speed		km/h
$V_{tr,test}$	train test speed	see 7.3.2	m/s
V_{int}	internal volume of the vehicle	see 7.8.3	m ³
X_d, X_h, X_{fr}, X_t	dummy variables	see A.3	
X_p	distance between the entrance portal and the measuring position in the tunnel		m
x_1, x_2, x_3	longitudinal positions on the train	defined in 7.7.3.4	m
Y_{tr}	track distance	centre to centre	m
Δh	maximum altitude difference in a tunnel	see 7.2.5	m
ΔL_1	additional length	see 7.2.2.1	m
$\Delta p, \Delta p(t)$	differential pressure at time t		Pa
Δp_{alt}	natural pressure variation due to altitude	see Formula (9)	Pa
$\Delta p_{d,max}$	maximum difference between internal and external pressures	see Figure D.4	Pa
Δp_{exit}	amplitude of initial compression wave at the exit portal inside the tunnel	see Formula (C.4)	Pa
Δp_{fr}	pressure change due to friction effects caused by the entry of the main part of the train into the tunnel	see Figure 7	Pa
$\Delta p_{fr,o}$	pressure change due to friction effects caused by the entry of the main part of the train into the tunnel, measured on the exterior of a train	see 7.2.4	Pa
Δp_{HP}	pressure signature caused by the passing of the train nose at the measurement position in the tunnel	see Figure 7	Pa
$\Delta p_{i,limit}$	Pressure limit values, $i = N, N+fr, N+fr+T$	see Table 4	Pa
Δp_{max}	maximum peak-to-peak pressure change on outside of train		Pa
Δp_N	pressure change caused by the entry of the nose of the train into a tunnel	see Figure 6	Pa
$\Delta p_{N,o}$	pressure change caused by the entry of the nose of the train into a tunnel measured on a train on the exterior of the train	see 7.2.4	Pa

Symbol	Significance	Explanation or remark	Unit
Δp_T	pressure change caused by the entry of the tail of the train into a tunnel	see Figure 6	Pa
$\Delta p_{T,o}$	pressure change caused by the entry of the tail of the train into a tunnel measured on the exterior of a train	see 7.2.4	Pa
Δp_1	pressure after train tail entrance	see A.3.2	Pa
$\Delta p_{95\%,\max}$	maximum permissible pressure change	see Formulae (21), (22) and (23)	Pa
$\overline{\Delta p_N}$	average nose entry pressure change	see Table 4	Pa
$\overline{\Delta p_{fr}}$	average frictional pressure rise	see Table 4	Pa
$\overline{\Delta p_T}$	average tail entry pressure change	see Table 4	Pa
Δt	characteristic time interval for the pressure rise	see Formula (C.2)	s
Δt_e	time increment	see Formula (26)	s
Δx_1	additional distance to ensure a good temporal separation of individual pressure variations	see 7.2.2.2	m
$\varepsilon_{\Delta p}$	deviation between test and simulation	see 7.3.4	
ζ_E	loss coefficient for tunnel portal	see A.3	
ζ_h	loss coefficient of the train nose in the tunnel	see A.3	
ζ_{h0}	loss coefficient of the train nose in the open air	see A.3	
ζ_{h1}	coefficient for additional loss of the train nose in the tunnel	see A.3	
ζ_t	loss coefficient of the train tail in the tunnel	see A.3	
ζ_{t0}	loss coefficient of the train tail in the open air	see A.3	
ζ_{t1}	coefficient for additional loss of the train tail in the tunnel	see A.3	
ζ_1	loss coefficient for the train	see A.3	
ζ_N	train nose pressure loss coefficient	see A.4	
ζ_p	tunnel portal pressure loss coefficient	see A.4	
ζ_T	train tail pressure loss coefficient	see A.4	
θ_1, θ_2	temperature	see 7.3.2	°C
ρ_{amb}	ambient atmospheric air density	see Formula (12)	kg/m ³

Symbol	Significance	Explanation or remark	Unit
ρ_0	Reference air density	1,225 kg/m ³	kg/m ³
ρ, ρ_1, ρ_2	air density ρ_1 in test scenario ρ_2 in reference scenario	see 7.3.2 see 7.3.2	kg/m ³
τ_{dyn}	value of pressure tightness coefficient for moving rail vehicles	see 7.7.3.2	s
τ_{stat}	value of pressure tightness coefficient for static rail vehicles	see 7.8.1	s
Ω	solid angle representing the configuration around the tunnel exit portal	see C.4	
$\bar{}$, (overbar)	average of the value		

5 Requirements on locomotives and passenger rolling stock

5.1 Limitation of pressure variations inside tunnels

5.1.1 General

When a train enters and exits a tunnel, pressure variations are generated which propagate along the tunnel at sonic speed and are reflected back at portals into the tunnel. These pressure variations may cause aural discomfort or, in the worst case, aural damage to train passengers and train staff and will produce transient loads on the structure of trains and the infrastructure components.

To define a clear interface between the subsystems of rolling stock and infrastructure in the heavy rail system, the train-induced aerodynamic pressure variations inside tunnels need to be known and limited. In order to specify and to limit the train-induced aerodynamic pressure variations inside tunnels, two reference cases for rolling stock assessment are defined.

5.1.2 Requirements

5.1.2.1 Reference case

For track gauges from 1 435 mm to 1 668 mm inclusive, the pressure variations generated by a train entering a simple, non-inclined tube-like tunnel, (i.e. without any shafts, etc.), are defined by pressure signatures for two given combinations of train speed and tunnel cross-section. The latter are referred to as the reference cases.

The pressure signature consists of three characteristic pressure variations: Δp_N caused by the entry of the nose of the train into the tunnel, Δp_{fr} due to friction effects caused by the entry of the main part of the train into the tunnel, and Δp_T caused by the entry of the tail of the train into the tunnel (see Figure 6).

The assessment shall be made for standard meteorological conditions: atmospheric pressure $p_{\text{atm}} = 101\,325$ Pa, air density $\rho_{\text{amb}} = 1,225$ kg/m³, temperature $\theta = 15$ °C with no initial air flow in the tunnel.

Table 2 — Maximum tunnel characteristic pressure changes, Δp_N , Δp_{fr} and Δp_T for the reference case

Maximum design speed km/h	Reference case		Criteria for the reference case, Pa		
	Reference speed, $v_{tr,ref}$ km/h	S_{tu} m ²	Δp_N	$\Delta p_N + \Delta p_{fr}$	$\Delta p_N + \Delta p_{fr} + \Delta p_T$
$v_{tr,max} < 200$	No requirement				
$200 \leq v_{tr,max} \leq 230$	200	53,6	$\leq 1\,750$	$\leq 3\,000$	$\leq 3\,700$
$230 < v_{tr,max}$	250 or $v_{tr,max}$ ^a	63,0	$\leq 1\,600$	$\leq 3\,000$	$\leq 4\,100$
^a The lower value of $v_{tr,max}$ and 250 km/h shall be applied.					

5.1.2.2 Fixed or pre-defined train compositions

A fixed or pre-defined train composition, running at the reference speed in the reference case tunnel scenario without crossing other trains shall not cause the characteristic pressure variations at a fixed point in the tunnel to exceed the values set out in Table 2.

NOTE 1 Fixed and pre-defined train compositions are described in TSI LOC&PAS 2014, 2.2.1.

For train compositions that are non-symmetrical with respect to running direction, the requirement applies for both running directions. For assessment of symmetry see Table 4, column 1, row 1, excluding the differences that are beneficial.

For fixed or pre-defined train compositions consisting of more than one train unit, the full assessment shall be made for the maximum length of the train of coupled units, see 7.3.

NOTE 2 Full-scale tests provide input data for the assessment and can be carried out using shorter train configurations, see 7.2.2.3.

5.1.2.3 Single rolling stock units fitted with a driver's cab

A single unit fitted with a driver's cab running as the leading vehicle at the reference speed in the reference case tunnel scenario without crossing other trains shall not cause the characteristic pressure variations Δp_N and Δp_T to exceed the values set out in Table 2. The pressure variation Δp_{fr} shall be set to 1 250 Pa for trains with $200 \text{ km/h} \leq v_{tr,max} \leq 230 \text{ km/h}$ or, respectively to 1 400 Pa for trains with $v_{tr,max} > 230 \text{ km/h}$.

For single rolling stock units capable of bidirectional operation as a leading vehicle the requirement applies for both running directions.

5.1.2.4 Other passenger rolling stock

Other passenger rolling stock running at the reference speed in the reference case tunnel scenario shall not cause the characteristic pressure variations Δp_{fr} to exceed the values set out in Table 2. The pressure variation Δp_N shall be set to 1 750 Pa and Δp_T shall be set to 700 Pa for trains with $200 \text{ km/h} \leq v_{tr,max} \leq 230 \text{ km/h}$ or, respectively to 1 600 Pa and 1 100 Pa for trains with $v_{tr,max} > 230 \text{ km/h}$.

For passenger rolling stock that is not covered in 5.1.2.2 or 5.1.2.3, conformity shall be assessed for a possible real train configuration, including realistic end vehicles featuring a cab, as close as possible to 400 m train length. If the vehicle might be suitable for train compositions longer than 400 m, the maximum train length, (length of cabs plus rolling stock), shall be determined, which just meets the criterion in Table 2. This maximum train length shall be documented in the vehicle register. See 7.3.6 for scaling for the train length.

5.1.3 Full conformity assessment

A full conformity assessment of rolling stock² shall be undertaken according to Table 3.

Table 3 — Methods applicable for the full conformity assessment of rolling stock

Maximum design speed km/h	Methods
$v_{tr,max} < 200$	No assessment needed
$v_{tr,max} \geq 200$	Documentation of compliance according to 5.1.4 if applicable; or Full-scale tests according to 7.2.2 and Assessment according to 7.3

5.1.4 Simplified conformity assessment

A simplified conformity assessment may be carried out for rolling stock that is subject to minor design differences by comparison with rolling stock for which a full conformity assessment already exists.

With respect to pressure variations in tunnels, the only relevant design differences are changes in external geometry and differences in design speed and train length.

This simplified conformity assessment shall take one of the following forms in accordance with Table 4:

- a statement that the design differences have no impact on the pressure variations inside tunnels; or
- a comparative evaluation of the design differences relevant to the rolling stock for which a full conformity assessment already exists.

Table 4 — Methods and requirements applicable for simplified conformity assessment of rolling stock

Design differences	Methods and requirements
Differences in external geometry limited to: — reordering in a new consist examined coaches of the same type and/or cross-section; — minor differences in external geometry: — wipers, handles and antennae; — long isolated protruding objects or gaps that are not vertical or close to the front-side radius or edge smaller than 5 cm in the crosswise dimensions; — small isolated protruding objects and gaps smaller than 5 cm in each dimension; — pantographs, electrical wiring and pipes; — other roof and underfloor equipment changes smaller than 20 cm in each physical dimension;	Documentation of differences, statement of no impact and reference to an existing compliant full conformity assessment

² This assessment will comply with the Railway Interoperability Directive.

Design differences	Methods and requirements
— addition of equipment fairings greater than 10 m downstream from the tip of the nose; — fittings, seals, bonded joints, handle bars, rear view installations, surface roughness, doors, windows, changes in glazing, signal lights, pipes, cabling and plugs; — other parts with changes in lateral dimensions smaller than 5 cm. — differences that are beneficial: — increase of nose length; — decrease of cross-sectional area; — decrease of train length.	
Other differences in external geometry (e.g. in buffers, front couplers, snow ploughs, front or side windows) keeping the basic nose shape features, in particular the cross-sectional area and the nose length.	Documentation of differences and reference to an existing compliant full conformity assessment AND Assessment of the relative effect of differences by — reduced-scale moving model tests according to 7.2.7 or — three-dimensional CFD simulations according to EN 14067-4:2013+A1:2018, 6.1.2.4 AND evidence and documentation that i) The difference causes changes in each of $\overline{\Delta p_N}$, $\overline{\Delta p_N} + \overline{\Delta p_{fr}}$, and $\overline{\Delta p_N} + \overline{\Delta p_{fr}} + \overline{\Delta p_T}$, of less than 5 %. $\left \frac{\overline{\Delta p_{i,B}} - \overline{\Delta p_{i,A}}}{\overline{\Delta p_{i,A}}} \right < 0,05$ for $i = N, N + fr, N + fr + T$ NOTE Subscript <i>B</i> refers to the new train geometry and subscript <i>A</i> refers to the existing compliant train. and ii) The difference does not exceed 50 % of the margin available on the compliance with 5.1.2, i.e.: $\overline{\Delta p_{i,B}} - \overline{\Delta p_{i,A}} < 0,5 \cdot \left(\overline{\Delta p_{i,limit}} - \overline{\Delta p_{i,A}} \right)$ Where values of $\overline{\Delta p_{i,limit}}$, $i = N, N + fr, N + fr + T$, are given in Table 2.

Design differences	Methods and requirements
Increase of: — design speed; — train length.	— Documentation of differences AND — transfer to the reference case by re-scaling methods described in 7.3.2, 7.3.3 or 7.3.4; AND — evidence and documentation that the train still fulfils the requirements listed in 5.1.2.

5.2 Limitation of pressure gradient entering a tunnel (relative to micro-pressure wave generation)

5.2.1 General

When a high-speed train enters a tunnel a compression wave is generated by the piston effect. This compression wave propagates through the tunnel at the speed of sound in front of the train towards the opposite portal. At the opposite portal, the wave is partly reflected back into the tunnel and partly emitted into the environment. The emitted part is called a micro-pressure wave. If the pressure gradient of the compression wave inside the tunnel is sufficiently large, it can cause strong audible effects on people and the environment. Further information is to be found in Annex C.

Therefore, a definition of a reference scenario consisting of a reference train and a reference tunnel is introduced, and the performance of the assessed train is compared to that of the reference train.

5.2.2 Requirements

5.2.2.1 General

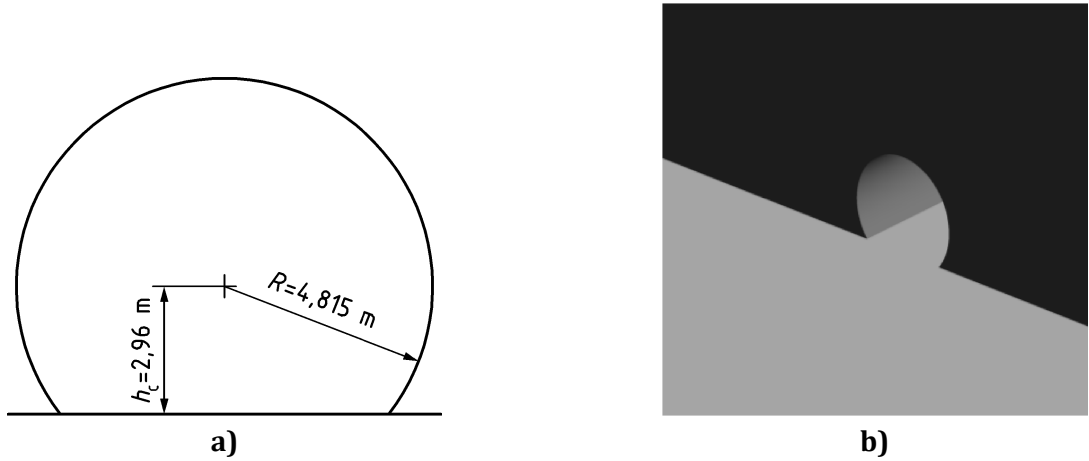
For heavy rail vehicles with track gauges from 1 435 mm to 1 668 mm inclusive it is required to assess the entry pressure gradient and to compare it to the one generated in the reference case.

NOTE The requirement is intended for operation on the European network. Its application to trains operating on limited networks (e.g. no tunnels) can be reassessed.

5.2.2.2 Reference case

The reference case for the tunnel and the train is defined as follows.

The reference tunnel has a free cross-sectional area of 63 m². It has a circular shape with a filled lower segment as shown in Figure 1. The portal is set in a vertical wall having at least a radius of 75 m around the tunnel centre. The train shall enter the tunnel centrally. The tunnel length shall be at least 300 m.



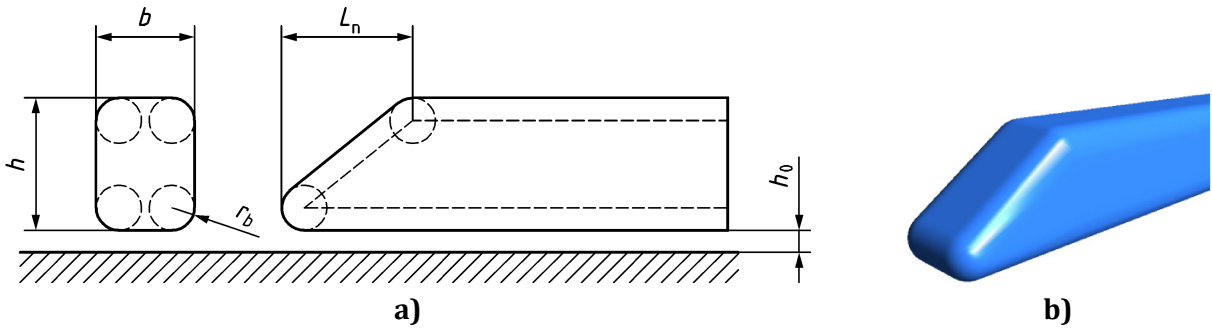
- Key**
- h_c height of tunnel centre above ground
 - R radius

NOTE The ground level in the reference case models the top of rail when assessing a train.

Figure 1 — Reference tunnel

The reference train is based on simple geometry parameters, as shown in Figure 2. All corners are smoothed by spheres with radius r_b . The body cross-section behind the train nose, with $S_{tr} = 11 \text{ m}^2$, remains constant up to the train end. There are no bogies, pantographs or inter-car gaps. The parameters to be used for the reference train geometry are:

$b = 3 \text{ m}$, $L_n = 4 \text{ m}$, $r_b = 0,75 \text{ m}$, $h_0 = 0,25 \text{ m}$, $h = 3,828 \text{ m}$



- Key**
- b width of train
 - h height
 - h_0 distance from top of rail to the underside of the vehicle body
 - L_n nose length
 - r_b Radius

Figure 2 — Reference vehicle

The reference train shall have the same length as the assessed train. It is sufficient to model just the first 100 m of the trains.

5.2.2.3 Rolling stock units fitted with a driver's cab

The requirement applies to any vehicle to be operated as a leading vehicle with design speed greater than or equal to 200 km/h, see Table 5.

The requirement applies for each possible running direction.

Table 5 — Methods applicable for the full conformity assessment of rolling stock

Maximum design speed km/h	Method
$v_{tr,max} < 200$	No assessment needed
$v_{tr,max} \geq 200$	Assessment by numerical simulation or reduced scale test according to 7.5.

5.2.3 Simplified conformity assessment

A simplified conformity assessment may be carried out for rolling stock units fitted with a driver's cab that are subject to minor design differences by comparison with rolling stock for which a full conformity assessment already exists. Changes in the basic nose shape features, in particular the cross-sectional area evolution, are generally not considered minor design changes.

With respect to pressure gradient entering a tunnel, the only relevant design differences are differences in external geometry, differences in design speed and equipment in the region of the nose influencing the nose pressure wave.

This simplified conformity assessment shall be made by a statement that the design differences have no impact on the pressure gradient in accordance with Table 6.

Table 6 — Methods and requirements applicable for simplified conformity assessment of rolling stock

Design differences	Methods and requirements
Differences in external geometry limited to: — increases in cross-sectional area less than 1 %; — reductions in nose length less than 2 %, — equipment in the region of the train nose not influencing the nose pressure wave stated as minor differences in external geometry in Table 4.	Documentation of differences, statement of no impact and reference to an existing compliant full conformity assessment having an entry pressure gradient at least 5 % lower than that of the reference vehicle assessment.

5.3 Resistance to aerodynamic loading

5.3.1 General

Aerodynamic loads are caused by the dynamic loads due to trains crossing in the open air, trains running in tunnels, and the steady loads due to the relative airflow over the trains, and include strong wind loads. The loads shall be considered in the construction of rail vehicle bodies, and may be used as aerodynamic loads for strength assessments according to EN 12663-1:2010+A1:2014. The methods to derive loads are suitable for rail vehicle bodies only. They need further adaptation to provide information for the design of smaller train elements such as windscreens, bodyside windows, doors, canopies, fairings or other mouldings attached to the vehicle body.

The most important relevant influencing parameters, not all of which apply to each reference case (see 5.3.2.4, 5.3.2.5 and 5.3.2.6), are as follows:

- natural wind speed;
- maximum line speed;
- train length;
- train cross-section;
- train leading and trailing end shapes;
- maximum train speed;
- comparable parameters of overtaking or crossing trains;
- track spacing (distance between track centres);
- tunnel cross-section;
- tunnel length;
- tunnel type, i.e. single or double track;
- relative entry times of trains entering a tunnel;
- ambient conditions:
 - air density;
 - speed of sound;
 - ambient pressure;
 - ambient temperature;
 - wind (including wind direction, front wind).

5.3.2 Requirements

5.3.2.1 General

For track gauges from 1 435 mm to 1 668 mm inclusive and heavy rail vehicles with design speed greater than 140 km/h, it is required to provide exceptional and fatigue aerodynamic loads for the design of rolling stock. Independently of design speed, this requirement shall also be fulfilled if the heavy rail vehicle is exposed to crossings in tunnels with vehicles running faster than 140 km/h in its standard train operation. The requirement is not applicable to freight wagons.

This document provides exceptional and fatigue aerodynamic loads for rolling stock design, and thereby provides an interface to structural strength assessments according to EN 12663-1:2010+A1:2014. As train parameters influence the loads, the loads shall be assessed individually for the reference cases by use of methods as stated below. For some trains, simplified load cases are provided and can be applied without further assessment steps, see 7.7.7. Furthermore, loads depend on the presence of strong winds, other trains passing on adjacent tracks, as well as the properties of the infrastructure and the train operations. National differences may arise due, for instance, to different vehicle and track gauges.

For vehicle bodies, the exceptional and fatigue aerodynamic load cases defined below are considered to sufficiently cover:

- running in strong winds;
- passing other trains in the open air;
- single train tunnel transit;
- crossing with one other train in a tunnel.

Occupancy of more than two trains may be possible in a very long tunnel. This case is not covered by this document.

The cases above result in an external pressure distribution on the vehicle body. The pressure inside the vehicle adapts to the outside pressure with a time delay dependent on the sealing properties of the vehicle. The difference between the internal pressure, p_i , and the external pressure, p_e , acts as a pressure load, p_L , on all components forming the exterior surface of the vehicle. The body structure of the vehicle shall resist these loads. Due to pressure variations in tunnel operation, the vehicle body is therefore exposed to positive and negative loads.

The following minimum requirements are specified for the determination of the loads. If other parameters are specified or are available from investigations, their use is permitted and shall be documented. The use of more detailed methods is permitted and shall be documented.

Unless otherwise defined, assessments shall be made in standard meteorological conditions, namely: atmospheric pressure $p_{\text{atm}} = 101\,325$ Pa, air density $\rho_{\text{amb}} = 1,225$ kg/m³, temperature $\theta = 15$ °C, with no initial air flow in any tunnels considered.

5.3.2.2 Exceptional load cases for vehicle bodies

Exceptional load cases result from operations in:

- the open air in a strong wind;
- in tunnels (worst case condition).

When travelling in the open air, the local load distribution due to strong wind is applied as a static load. It is derived using the reference case for running in strong winds, see 5.3.2.4. In tunnel operation, loads due to the tunnel air flow around the train are considered to be covered by loads in operation in open air with strong wind.

NOTE Although a gust (i.e. transient) wind speed is considered, the associated loading is considered as a static load.

Due to pressure variations caused by operation in tunnels, transient loads act on a train. All relevant operational tunnel scenarios shall be considered and the evaluated maximum load values taken into account in the design of the entire vehicle body. Transient loads due to pressure variation in tunnels are assessed using the reference cases for exceptional loads in tunnels, see 5.3.2.6.

The maximum aerodynamic loads (positive and negative values of p_L) are derived for each case separately. The maximum loads are applied to the vehicle body according to EN 12663-1:2010+A1:2014.

5.3.2.3 Fatigue load cases for vehicle bodies

Fatigue loads result from:

- frequent train passings in open air;
- general operations in tunnels (adverse, but typical scenario).

The basis for determining fatigue loads is an operational scenario with the following parameters which shall be taken into account: for the vehicle (train speed, other various vehicle parameters), for the train route system (tunnels, tunnel dimensions, open air segments, line speed limits, etc.) and for the oncoming traffic (type, speed, passing frequency).

Only transient loads are considered for fatigue loads. The effects caused by transient aerodynamic pressure loads on the vehicle body can, when appropriately combined for a defined operating scenario, represent the loads experienced over the entire life of the vehicle. Depending on the operating scenario under consideration, the load time histories for the following load cases shall be determined:

- Transient loads for passing on open track shall be assessed using the reference case for open air passings, see 5.3.2.5;
- Transient loads in tunnels shall be assessed using the reference case for fatigue loads in tunnels, see 5.3.2.7.

Trains passing in the open or operating in tunnels produce similar stress distributions and can therefore be considered in combination. The relevant effects on the body structure may be combined for instance by use of a rainflow analysis of the pressure curves, see 7.7.4.4. As long as the application meets the specified reference scenarios in accordance with this document, the loads may be regarded as conservative loads for strength assessments according to EN 12663-1:2010+A1:2014.

5.3.2.4 Reference case for running in strong winds (exceptional load case)

The local pressure distribution around the investigated vehicle travelling at maximum design speed in the open air with a steady and uniform wind speed of 30 m/s at wind angles of 0° and 90° causes imposed steady loads on the vehicle body that vary with location. These are referred to as the reference cases for running in strong winds. The loads shall be applied on the vehicle body. Assumptions regarding the position of the vehicle in the train and the properties of other vehicles in the train are allowed in the assessment.

NOTE The wind speed above is a chosen scenario for gust wind conditions considered sufficient for vehicle dimensioning and is not linked to cross wind stability.

5.3.2.5 Reference case for open air passings (fatigue load case)

The pressure field generated by a passing train travelling at maximum line speed on the investigated train in the open air and in the absence of embankments, cuttings and other significant trackside structures is referred to as the reference case.

The position of the investigated vehicle in a train has no influence on the pressure loads caused by the passing train. The imposed loads do depend on the distance between track centres as well as aerodynamic characteristics and speed of the passing train. Adverse aerodynamic characteristics are assumed for the passing train and shall be taken from EN 14067-4:2013+A1:2018, 4.1. The pressure variations generated by the passing train only apply loads on the adjacent side of the investigated train.

As loads from open air passings and tunnel operation are combined in fatigue assessments, the reference case of open air passings is included in the operational reference scenario defined in 5.3.2.7.

5.3.2.6 Reference cases for exceptional loads in tunnel transit

The reference scenario describes train operation in a series of tunnels, with some having other trains crossing. In the reference case, all trains are operated at a speed which is the lowest of i) the stated maximum tunnel speed, ii) the maximum design speed of the investigated vehicle or iii) a project specific speed limitation regarding the speed of crossing trains. The following scenarios with defined parameters for operation speed, tunnel dimensions and train properties are referred to as the reference case.

- a) Single track tunnels with cross-sectional tunnel area, S_{tu} , and maximum line speeds, $v_{line,max}$:
 - $v_{line,max} = 120 \text{ km/h}$, $S_{tu} = 32,4 \text{ m}^2$;
 - $v_{line,max} = 160 \text{ km/h}$, $S_{tu} = 46,7 \text{ m}^2$;
 - $v_{line,max} = 230 \text{ km/h}$, $S_{tu} = 52,0 \text{ m}^2$;
 - $v_{line,max} = 300 \text{ km/h}$, $S_{tu} = 59,7 \text{ m}^2$.
- b) Double track tunnels with a maximum speed, $v_{line,max}$, in the tunnel and cross-sectional tunnel area, S_{tu} , and a passing train class, making full use of the criteria defined in Table 2:
 - $v_{line,max} = 150 \text{ km/h}$, $S_{tu} = 51,0 \text{ m}^2$;
 - $v_{line,max} = 160 \text{ km/h}$, $S_{tu} = 74,2 \text{ m}^2$;
 - $v_{line,max} = 200 \text{ km/h}$, $S_{tu} = 79,2 \text{ m}^2$;
 - $v_{line,max} = 230 \text{ km/h}$, $S_{tu} = 79,2 \text{ m}^2$;
 - $v_{line,max} = 250 \text{ km/h}$, $S_{tu} = 82,1 \text{ m}^2$;
 - $v_{line,max} = 280 \text{ km/h}$, $S_{tu} = 82,1 \text{ m}^2$;
 - $v_{line,max} = 300 \text{ km/h}$, $S_{tu} = 92,0 \text{ m}^2$.

If the operation of the investigated vehicle is for a specific route, where some scenarios are not relevant, they shall be eliminated or replaced. For instance if there are no tunnels on the route, assessment of loads from tunnel scenarios may be ignored.

The above tunnel definitions are considered suitable for Germany. Figure 3 shows cross-sectional areas for single and double track tunnels typical of a number of European countries against the tunnel operating speeds. The reference cases above are shown as lines connecting the symbols. Unless there are reference cases defined on national or network level, reference cases may be derived to model the intended operation of the vehicle.

NOTE Information on tunnel length and cross sections can be found in the register of infrastructure according to "Commission Implementing regulation (EU) 2019/777 of 16 May 2019 on the common specifications for the register of railway infrastructure", see guide in [21].

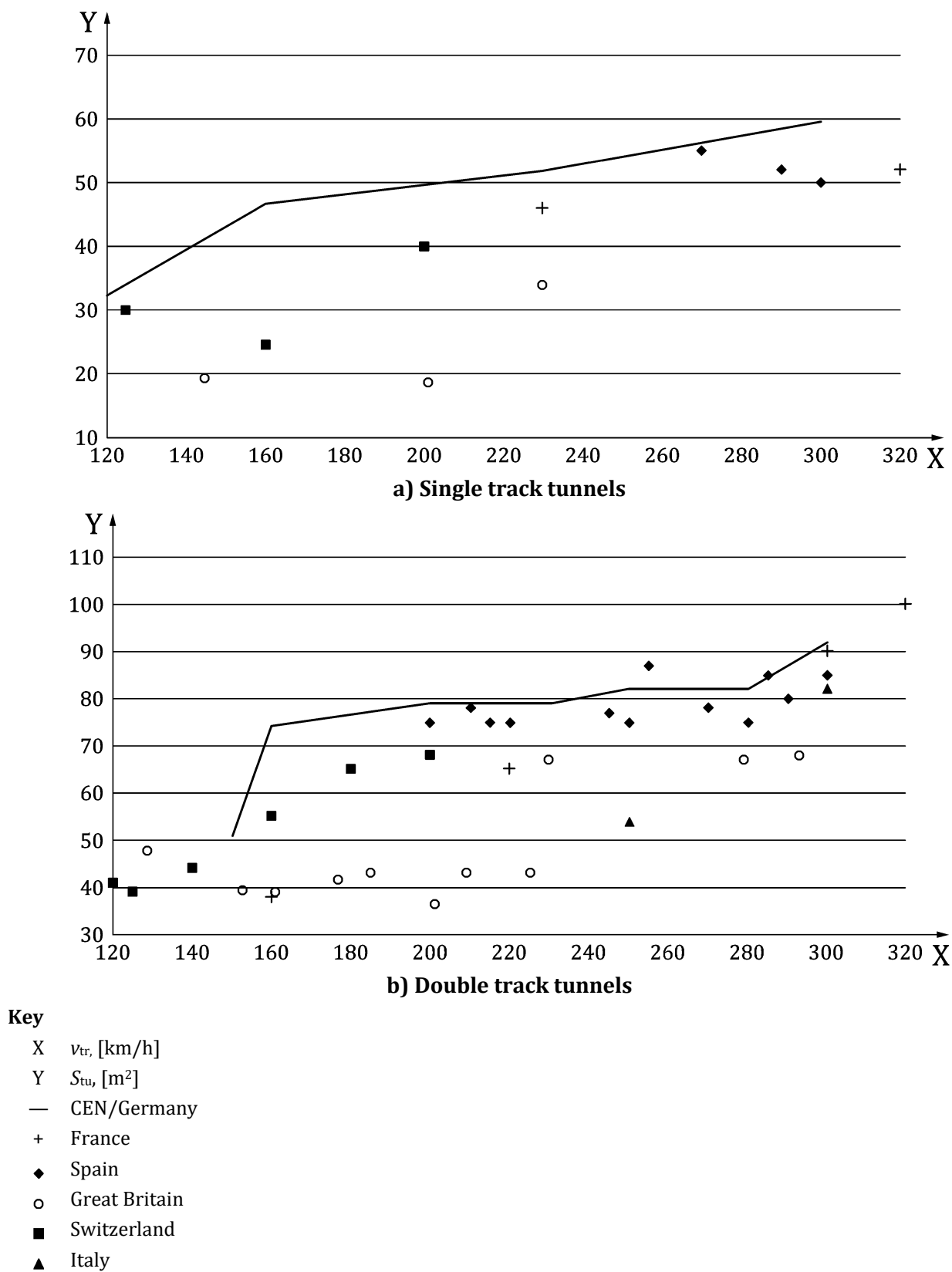


Figure 3 — Cross-sectional areas for single and double track European tunnels

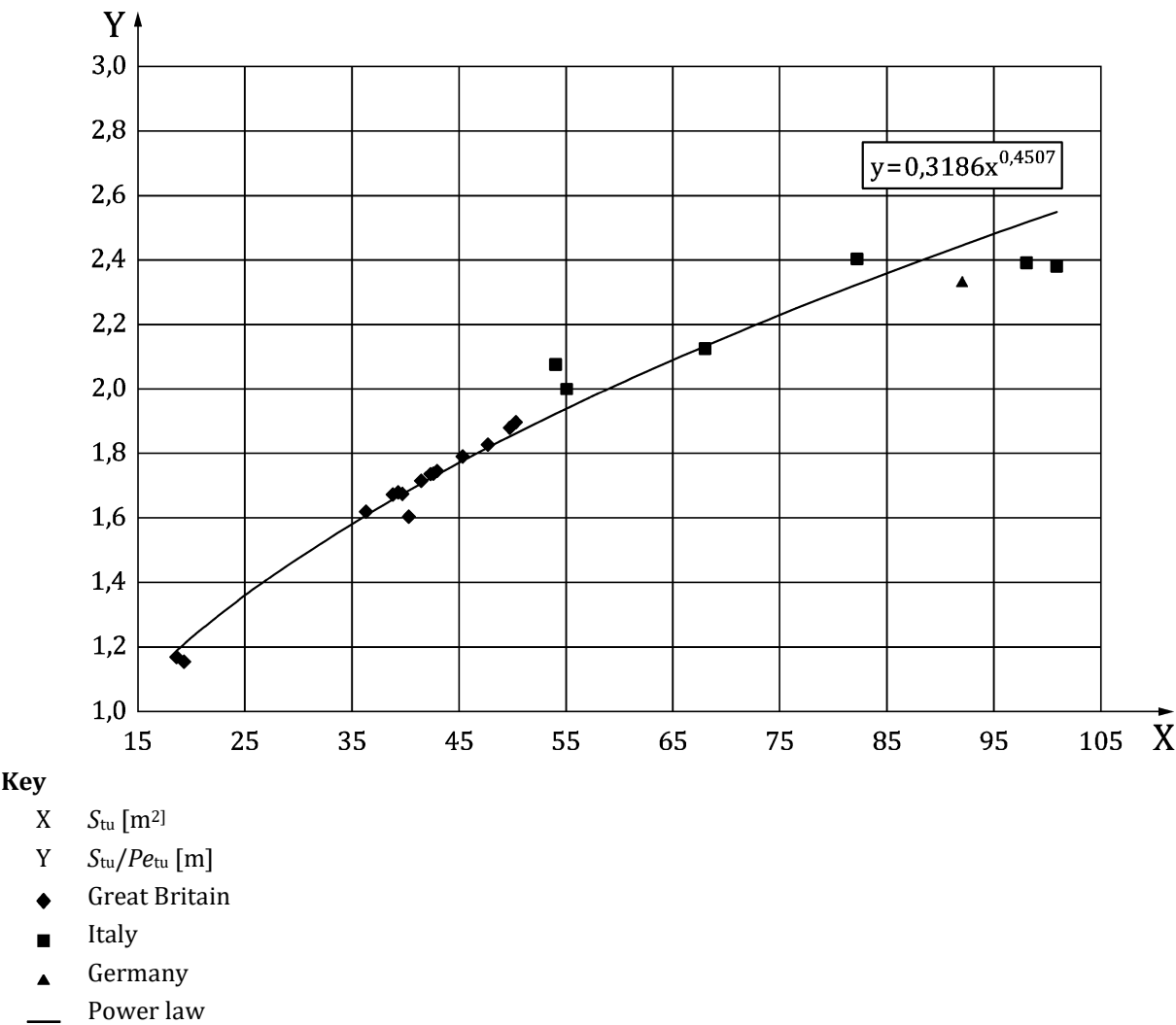


Figure 4 — Tunnel area to perimeter ratios

Figure 4 shows a plot of the tunnel area to perimeter ratio against tunnel area, based on national database values, which is useful when only tunnel area values are available.

Transient pressures in tunnels shall be assessed for the investigated vehicle running in a train. The tunnel length is chosen to be the critical length based on the maximum external pressure change according to 7.7.3.6.

5.3.2.7 Reference cases for fatigue loads in tunnel transit

A scenario with defined parameters for trains, operation and infrastructure as listed below is referred to as the reference case. The reference scenario describes a train operation on a railway line with tunnels and train crossings. In the reference case, the vehicle is assumed to operate for its full life-time solely on the railway line described by the reference scenario. In this operation, the vehicle's external surface is exposed to numerous pressure variations. Differences between the external and internal pressures act as transient loads on the vehicle body, and therefore depend on the degree of pressure sealing of the investigated vehicle.

The various pressure differences between the external and the internal pressures and their frequency of occurrence during the vehicle's life-time are represented by a load collective. The load collective representing a life-time operation according to the reference scenario shall be applied as a fatigue load to the vehicle body.

Until the development of standard reference scenarios, the scenarios should be specified in the vehicle specification. If a reference scenario is to be representative for a railway network and not just a specific line, justification shall be made to demonstrate that the chosen reference scenario contains sufficiently demanding fatigue loads to be representative of the different segments (i.e. tunnels, open air) of the network.

The generic reference scenario is defined by the following parameters describing operation of the investigated vehicle on a railway line for each segment of line:

- Infrastructure parameters (per segment):
 - length of a track segment, $L_{\text{section},i}$, and indicator whether it is open air or tunnel;
 - maximum line speed, $v_{\text{line,max}}$;
 - tunnel free cross-sectional area, S_{tu} ;
 - number of tracks and distance between track centres.
- Operational parameters:
 - operation in both directions on the defined infrastructure during the life-time of vehicle;
 - number of trains passing a stationary point in one direction per hour $N_{\text{trainsperhour}}$.
- Train parameters:
 - the speed of trains crossing is equivalent to maximum line speed, if not defined differently;
 - aerodynamic characteristics of trains crossing in tunnels, as defined by the limit values in Table 2 in 5.1.2.1;
 - aerodynamic characteristics of trains passing in the open air, as defined by EN 14067-4:2013+A1:2018, Table 2.

The required parameters of the investigated vehicle are introduced in 7.7.3.2.

NOTE A reference scenario for the German network is defined in [9] and [10].

5.3.3 Exceptional load assessment

A full exceptional load assessment of rolling stock shall be undertaken according to Table 7.

Table 7 — Methods applicable for the full exceptional load assessment of rolling stock

Criteria	Methods
Rail vehicles with — non-pressure tight design (see 7.7.3.2) and — $v_{tr,max} \leq 200$ km/h and — operation only on railway lines with $v_{line,max} \leq 200$ km/h.	Assessment of exceptional loads by — simplified load case according to 7.7.7.2
Any other rail vehicle	Assessment of — load due to operation in strong wind according to 7.7.1 and — exceptional transient loads in tunnel according to 7.7.3.
NOTE The term 'non-pressure tight' is used equivalently to 'unsealed', and 'pressure tight' equivalently to 'sealed' in this document.	

5.3.4 Fatigue load assessment

A full fatigue load assessment of rolling stock shall be undertaken according to Table 8.

Table 8 — Methods applicable for the full fatigue load assessment of rolling stock

Criteria	Methods
Rail vehicles with — non-pressure tight design and, — $v_{tr,max} \leq 200$ km/h and — operation only on railway lines with $v_{line,max} \leq 200$ km/h.	Assessment of fatigue loads by — simplified load case according to 7.7.7.3
Any other rail vehicle	Assessment of — fatigue loads due to trains crossing in open air according to 7.7.2 and — fatigue loads due to operation in tunnels according to 7.7.4.

5.3.5 Assessment in case of modification

A simplified load assessment may be carried out for rolling stock that is subject to minor design differences when compared to rolling stock for which a full load assessment already exists.

The only relevant design differences are differences in train design speed, changes in the route characteristics, and changes in the pressure tightness of the investigated train, which will only be significant if they impact on the aerodynamic load collective or on the strength analysis.

This simplified conformity assessment shall take one of the following forms:

- a statement that the differences have no impact on the load collective or strength analysis;
- a comparative evaluation of the design differences from the rolling stock for which a full conformity assessment already exists.