



BSI Standards Publication

Railway applications - Ballastless track systems

Part 2: System design, subsystems and components

National foreword

This British Standard is the UK implementation of EN 16432-2:2017. BSI, as a member of CEN, is obliged to publish EN 16432-2:2017 as a British Standard.

Attention is drawn to the fact that during the development of this European Standard, the UK committee identified several issues relevant to the UK implementation of the Standard.

It is the view of the UK committee that further clarity is necessary for designers and practitioners within the UK. The areas for clarification are:

- 1) This standard makes reference to a "Finite Element Method (FEM)" for analysis of ballastless track. FEM may be considered a generic term for validated numerical methods involving discretisation of the problem using shell, beam, brick or similar elements, and also incorporating the ground or substrate below, either explicitly using finite elements or using grounded springs with equivalent properties, so as to allow an appropriately accurate simulation of the track system structure together with its support medium. The emphasis here is that use of the most current, validated and industry-accepted numerical analysis methods is allowed according to this standard and such alternatives may represent the best, or acceptable, approaches for a specific project.
- 2) Regarding the use of the modulus of deformation (E_{v2}), there is no standardized methodology in the UK for determining this parameter from a static plate loading test. Reference can be made to other nations' Standards.
- 3) Recommendations concerning CEM I shall not be considered mandatory.
- 4) This standard makes reference to a track structure designed using the concept of a reinforced concrete road pavement, with reinforcement located at or near the neutral axis of the concrete section. Alternative design concepts may be considered, particularly where required for extended design life or other project requirements. These include reinforced concrete beams or slabs (continuous or otherwise) with reinforcement away from the neutral axis and designed using the concept of a reinforced concrete structure. These should follow guidance given in the relevant structures codes for reinforced concrete, covering aspects including exposure conditions, design life, reinforcement, concrete mix, cover to the reinforcement, maximum crack widths and other strength and durability requirements.

The UK participation in its preparation was entrusted to Technical Committee RAE/2, Railway Applications - Track. Membership of the subcommittee Ballastless Track included representation from: HS2, Network Rail, London Underground, UK Tram, Balfour Beatty, Amey, Rhomborg Sersa UK, Carillion, Beazley Sharp, Arup, Mott MacDonald, Schwihag, ERT, Pandrol, WSP, Tiflex and RSSB.

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

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systèmes et composants

Bahnanwendungen - Feste Fahrbahn-Systeme - Teil 2:
Systementwurf, Untersysteme und Komponenten

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European foreword

This document (EN 16432-2:2017) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2018, and conflicting national standards shall be withdrawn at the latest by February 2018.

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

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

This European Standard is one of the series EN 16432 “*Railway applications — Ballastless track systems*” as listed below:

- *Part 1: General requirements;*
- *Part 2: System design, subsystems and components;*
- *Part 3: Acceptance (in preparation).*

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

Introduction

This part of the series EN 16432 covers the design of the ballastless track system, subsystems and components and is used in conjunction with the following parts:

- Part 1: General requirements;
- Part 3: Acceptance.

A ballastless track system may consist of, but is not limited to, subsystems and components shown in 5.1, Figure 1. Those items are designed in accordance with the requirements defined in this standard, or if applicable, other existing European standards.

NOTE Typical examples are rails defined in EN 13674-1, EN 13674-2 and EN 13674-3 or rail fastenings for ballastless track system defined in EN 13481-5.

1 Scope

This part of EN 16432 specifies system and subsystem design and component configuration for ballastless track system.

The system and subsystem design requirements are assigned from the general requirements of EN 16432-1. Where applicable, existing subsystem or component requirements from other standards are to be referenced.

2 Normative references

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

prEN 197-1:2014, *Cement — Part 1: Composition, specifications and conformity criteria for common cements*

EN 206:2013+A1:2016, *Concrete — Specification, performance, production and conformity*

EN 1097-6:2013, *Tests for mechanical and physical properties of aggregates — Part 6: Determination of particle density and water absorption*

EN 1992 series, *Eurocodes*

EN 1992-1-1:2004, *Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings*

EN 1992-2:2005, *Eurocode 2 — Design of concrete structures — Concrete bridges — Design and detailing rules*

prEN 13043:2015, *Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas*

EN 13108-1:2016, *Bituminous mixtures — Material specifications — Part 1: Asphalt Concrete*

EN 13108-5:2016, *Bituminous mixtures — Material specifications — Part 5: Stone Mastic Asphalt*

EN 13230-1:2016, *Railway applications — Track — Concrete sleepers and bearers — Part 1: General requirements*

EN 13230-2:2016, *Railway applications — Track — Concrete sleepers and bearers — Part 2: Prestressed monoblock sleepers*

EN 13230-3:2016, *Railway applications — Track — Concrete sleepers and bearers — Part 3: Twin-block reinforced sleepers*

EN 13230-4:2016, *Railway applications — Track — Concrete sleepers and bearers — Part 4: Prestressed bearers for switches and crossings*

EN 13230-5:2016, *Railway applications — Track — Concrete sleepers and bearers — Part 5: Special elements*

prEN 13230-6:2015, *Railway applications — Track — Concrete sleepers and bearers — Part 6: Design*

EN 13242:2002+A1:2007, *Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction*

EN 13286-47:2012, *Unbound and hydraulically bound mixtures — Part 47: Test method for the determination of California bearing ratio, immediate bearing index and linear swelling*

EN 13481 (all parts), *Railway applications — Track — Performance requirements for fastening systems*

EN 13674-1:2011+A1:2017, *Railway applications — Track — Rail — Part 1: Vignole railway rails 46 kg/m and above*

EN 13674-2:2006+A1:2010, *Railway applications — Track — Rail — Part 2: Switch and crossing rails used in conjunction with Vignole railway rails 46 kg/m and above*

EN 13674-3:2006+A1:2010, *Railway applications — Track — Rail — Part 3: Check rails*

EN 13877-1:2013, *Concrete pavements — Part 1: Materials*

EN 13877-2:2013, *Concrete pavements — Part 2: Functional requirements for concrete pavements*

EN 13877-3:2004, *Concrete pavements — Part 3: Specifications for dowels to be used in concrete pavements*

EN 14227-1:2013, *Hydraulically bound mixtures — Specifications — Part 1: Cement bound granular mixtures*

EN 16432-1:2017, *Railway applications — Ballastless track systems — Part 1: General requirements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply as well as terms and definitions according to EN 16432-1.

3.1

filling layer

monolithic structure connecting prefabricated elements or subsystems of a ballastless track system and establishing load transfer to the pavement or any supporting structure

3.2

pavement

continuous, layered structure that forms a hard and durable surface and it is designed to provide bearing capacity

3.3

system design

process of applying a systematic approach to ensure that all elements specified will work together to fulfil the performance requirements

Note 1 to entry: This process involves dealing with the general requirements for ballastless track systems as defined in EN 16432-1 and combining these into a set of scenarios to analyse and resolve in order to provide final dimensioning and a satisfactory specification.

3.4

track stiffness

resistance of the entire track structure to deformation in relation to the applied force

4 Symbols and abbreviations

Symbol	Definition	Unit
AC	Asphalt Concrete	
CRCP	Continuously Reinforced Concrete Pavement	
CTB	Cement Treated Base layer	
FEM	Finite Element Method	
FST	Floating Slab Track	
JPCP	Jointed Plain Concrete Pavement	
PmB	Polymer modified Bitumen	
RAMS	Reliability, Availability, Maintainability, Safety	
SLS	Serviceability Limit State	
SMA	Stone Mastic Asphalt	
ULS	Ultimate Limit State	
A	Axle load	N
A_i	Layer cross-section area calculated based on 1 mm width of the first layer	mm ²
A_{LS}	Contact area or area of the loading surface	mm ²
a	Rail seat spacing or reference length of embedded rail section	mm
a_s	Total cross-section area of steel reinforcement calculated based on 1 mm slab width	mm ²
α_t	Coefficient of thermal expansion	1/K
B	Width of the slab or pavement	mm
B_{crit}	Critical width of slab or pavement	mm
B_1 and B_2	Width of the layers 1 and 2, respectively	mm
b	Reference radius of contact area	mm
b_B	Half of slab width or width of beam	mm
b_h	Width of beam	mm
b_1	Width of upper layer (1st layer)	mm
b_2	Width of 2nd layer	mm
c	Material correction factor for concrete layers or hydraulically bonded layers, e.g. $c = 0,83$	
c_{tot}	Total system stiffness	N/mm
c_1	Stiffness of the fastening system specified for dynamic loading and low temperature	N/mm
c_2	Stiffness of an additional elastic element (e.g. booted block)	N/mm

Symbol	Definition	Unit
	supporting rail seat (if applicable)	
D_{pr}	Proctor Density	g/mm^3
d	Diameter of the steel bars Joint/crack width	mm
E	Young's Modulus	N/mm^2
E_{conc}	Young's modulus of concrete	N/mm^2
E_{dyn}	Dynamic Young's modulus	N/mm^2
E_R	Young's modulus [N/mm^2] of the rail, (typically $E_R = 210\,000\, \text{N/mm}^2$)	N/mm^2
E_S	Young's modulus of steel	N/mm^2
E_{V2}	Modulus of deformation obtained on 2 nd loading in the plate bearing test	N/mm^2
E_1	Young's modulus of the 1st layer of a beam or a slab/pavement	N/mm^2
E_2	Young's modulus of the unbound granular material or substructure	N/mm^2
E_1, E_2, E_3	Young's modulus of the concrete, unbound base layer and the substructure, respectively	N/mm^2
e_a	Distance between pavement surface and neutral axis	mm
e_b	Distance between bottom of pavement and neutral axis	mm
f_{ck}	Characteristic concrete compressive strength (cylinder or cube) after 28 days	N/mm^2
f_{ctk}	Characteristic concrete tensile strength	N/mm^2
h	Equivalent thickness	mm
h	h_I or h_{II} or h_{III} thickness of Winkler slab/pavement thickness of system h_I or h_{II} or h_{III} the thickness of the slab/pavement [mm] or h_I or h_{II} or h_{III}	mm
h^*	Reference thickness of the layer based on the normalized Young's modulus	mm
h_i	Layer thickness	mm
h_1	Thickness of the 1st layer of a beam or a slab/pavement	mm
h_1^*	Equivalent height of the beam or slab/pavement having same Young's modulus as the half-space beneath	mm
h_2^*	Equivalent height of the unbound base layer having same Young's as the half-space beneath	mm

Symbol	Definition	Unit
h_2	Thickness of the unbound base layer	mm
h_I	Thickness Variant I (single layer)	mm
h_{II}	Half-space equivalent thickness Variant II (unbonded multiple layer)	mm
h_{III}	Half-space equivalent thickness Variant III (bonded multiple layer)	mm
I	Vertical Moment of inertia of a T-beam	mm ⁴
I_B	Vertical Moment of inertia of the beam	mm ⁴
I_R	Vertical moment of inertia of the rail	mm ⁴
I_1	Moment of inertia of upper layer (1st layer)	mm ⁴
k	Bedding modulus	N/mm ³
k	Permeability	m/s
k_d	Dynamic load factor	
k_q	Factor to increase the static wheel loads by additional vertical load (additional quasi static wheel load acting on outside rail along curves)	
L	Slab length / crack or joint spacing	mm
L_{el}	Elastic length	mm
l	Joint or crack spacing	mm
l_b	Length of full bond between steel bar and concrete	mm
l_e	Strain length of steel bar	mm
$M_{lat,neigh}$	Lateral bending moment activated by neighbouring loads	Nmm
$M_{lat I,II,III}$	Lateral bending moment	Nmm
$M_{lat I}$	Lateral bending moment activated in system I	Nmm
$M_{lat II}$	Lateral bending moment activated in system II (unbonded multiple layers)	Nmm
$M_{lat,1}$	Lateral bending moment activated by neighbouring load P_1	Nmm
$M_{long,neigh}$	Additional longitudinal bending moment activated by neighbouring loads	Nmm
$M_{long,I}$	Longitudinal bending moment activated in system I (single layer on substructure)	Nmm
$M_{long,II}$	Longitudinal bending moment activated in system II (unbonded multiple layers)	Nmm
$M_{long,1}$	Longitudinal bending moment activated by neighbouring load P_1	Nmm

Symbol	Definition	Unit
$M_{\text{long II}}$ and $M_{\text{lat II}}$	Longitudinal and lateral bending moments activated in system II (unbonded multiple layers)	Nmm
$M_{\text{long III}}$ and $M_{\text{lat III}}$	Longitudinal and lateral bending moments activated in system III (bonded multiple layers)	Nmm
$M_{\text{long I,II,III}}$	Longitudinal bending moment	Nmm
$M_{j-r,t}$	Radial and tangential bending moment	Nmm
$M_{r,t}$	Radial and tangential bending moment	Nmm
M_0	Rail bending moment	Nmm
$M_0 \text{ I, II, III}$	Bending moment	Nmm
n	Number of trains Number of load cycles, usually the number of axles	
P_j	Rail seat load due to wheel loads Q_i	N
p	Load contact pressure	N/mm ²
Q_i	Wheel load	N
r	Radius for circular contact area A_{LS} ; $r = \sqrt{\frac{A_{LS}}{\pi}}$	mm
s	Distance between rail axis (1,5 m for normal gauge)	mm
W_F	Rail section modulus at underside of rail foot	mm ³
x_i	Distance between rail seat and position of wheel	mm
x_j	Distance between the rail seat 0 and the rail seat j	mm
$X_{S,i}$	Distance between centre of layer cross-section area A_i and neutral axis of the T-beam model	mm
y	Vertical deflection of slab or pavement in	mm
y_i	Vertical displacement due to Q_i	mm
y_0	Rail deflection	mm
α_s	Total cross-section area of steel reinforcement calculated based on 1mm slab width	mm ² /mm
β_{fs}	Bending tensile strength of concrete	N/mm ²
β_j, β_1	Angle between longitudinal track direction and line between P_0 and neighbouring rail seat load	°
Δd	Change of crack or joint width	mm
ΔT	Difference between top and bottom temperature	K
Δt	Temperature gradient according to the thickness h_1 of the	K/mm

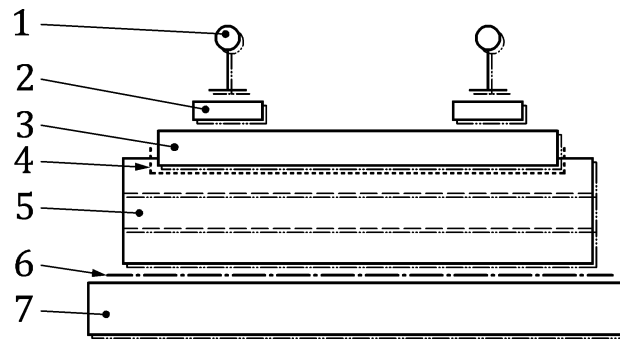
Symbol	Definition	Unit
	concrete slab/pavement	
Δz	Measured change of deflection due to $\Delta\sigma_z$	mm
ζ	Normalized distance to neighbouring load based on elastic length L_{el}	radian measure
ζ_i	$\zeta_i = \frac{x_i}{L_{el}}$	
η_i	Influence factor of rail deflection activated by additional wheel loads $\eta_i = \frac{\sin \zeta_i + \cos \zeta_i}{e^{\zeta_i}}$	radian measure
$\lambda_{r,j}$	Radial influence factor of additional rail seat loads	
$\lambda_{r,t}$	Radial or tangential influence factor of additional rail seat loads	
$\lambda_{r,1}$	Radial influence factor of rail seat load P_1	
$\lambda_{t,j}$	Tangential influence factor of additional rail seat loads	
$\lambda_{t,1}$	Tangential influence factor of rail seat load P_1	
κ	Strain length [mm] of steel l_e per joint or crack spacing l [mm] $\kappa = l_e/l$	
μ	Poisson's ratio	
μ_i	Influence factor of rail bending moment activated by additional wheel loads	radian measure
μ_j	Influence factor of slab/pavement bending moment activated by additional rail seat loads	
μ_1	Poisson's ratio of slab/pavement – 1st layer	
ξ_i	Normalized distance to neighbouring load based on elastic length L_{el} in	
ξ_j	$\xi_j = x_j / L_{el}$	
σ_c	Constant stress Longitudinal tensile stress in winter (calculated using max ΔT).	N/mm ²
σ_e	Residual stress	N/mm ²
σ_{lat}	Lateral bending stress	N/mm ²
$\sigma_{lat1,bottom}$	Lateral bending stress at bottom of first layer	N/mm ²
$\sigma_{lat1,top}$	Lateral bending stress at top of first layer	N/mm ²

Symbol	Definition	Unit
σ_{long}	Longitudinal bending tensile stress	N/mm ²
$\sigma_{\text{long1,bottom}}$	Longitudinal bending stress at bottom of first layer	N/mm ²
$\sigma_{\text{long1,top}}$	Longitudinal bending stress at top of first layer	N/mm ²
σ_Q	Maximum allowable flexural fatigue stress due to vehicle load	N/mm ²
max σ_Q lat	Maximum allowable lateral flexural stress	N/mm ²
max σ_Q long	Maximum allowable longitudinal flexural stress	N/mm ²
σ_{r1}	Bending stress in layer 1	N/mm ²
σ_{r2}	Bending stress in layer 2	N/mm ²
σ_w	Linear stress Lateral flexural tensile stress in winter (calculated using max Δt) or the reduced lateral flexural tensile stress σ_w in case of slabs/pavements with width $B < 0,9 B_{\text{crit}}$	N/mm ²
σ_z	Vertical stress in	N/mm ²
$\Delta\sigma$	Applied change of vertical stress	N/mm ²
Δz	Measured change of deflection due to $\Delta\sigma_z$	mm
max σ_z	Maximum allowable vertical stress	N/mm ²
σ_0	Bending stress at the rail foot	N/mm ²

5 General

5.1 Ballastless track system, subsystems and components

A ballastless track system may consist of (but is not limited to) following levels of subsystems and components shown in Figure 1.



Key	Item	Type
1	rail/switch and crossing	Subsystem
2	fastening system /system for embedded rail	Subsystem
-	clip, clamp, rail pad etc.	Component
-	adhesive	Component
3	prefabricated element	Subsystem
-	seeper, block	Component
-	slab, frame	Component
4	intermediate layer, boot, fixation	Subsystem
-	concrete filling layer	Component
5	pavement	Subsystem
-	single-, multi-layered pavement	Component
-	base layer	Component
6	intermediate layer	Subsystem
-	foil, sheeting	Component
-	compensation layer	Component
7	substructure	System

Figure 1 — Ballastless track system - subsystems and components

Figure 1 shows the structure of ballastless track system according to the subsystem and component levels. The sequence of subsystems in vertical direction as well as the presence or absence of subsystems and components within the ballastless track is up to the individual design. Intermediate layers may be used at different subsystem interfaces (levels).

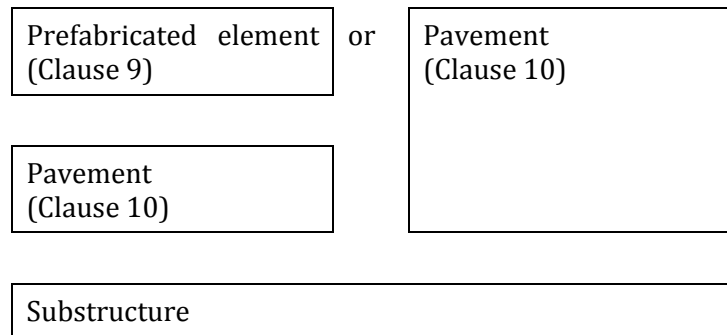
5.2 Subsystems configuration

5.2.1 Ballastless track system with continuous support and embedded rails

The rails are buried in, coated or covered by an elastomeric material, but leaving an exposed rail head. Coating or covering may offer first level of elasticity according to stiffness design.

The supporting structure (prefabricated element or pavement) may be equipped with channels or other components designed to control the geometry of the rails and to handle the loads.

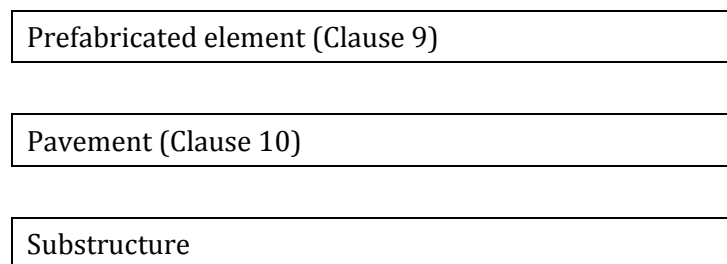
The following diagram illustrates the subsystem configuration.



5.2.2 Ballastless track system with discrete rail seats

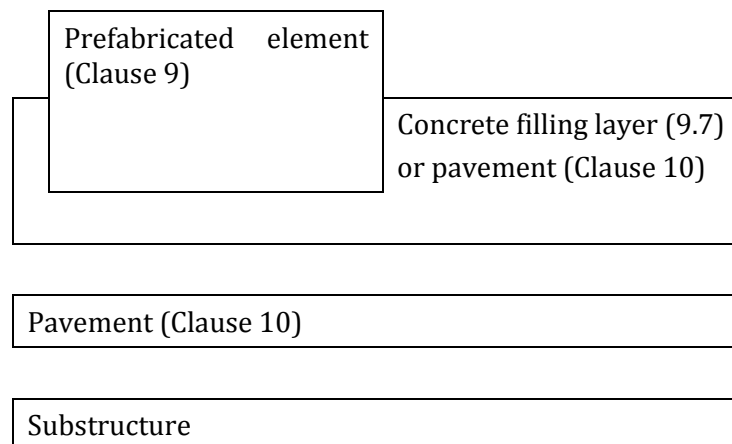
5.2.2.1 Ballastless track system with discrete rail seats on prefabricated element supported by a pavement

The following diagram illustrates the subsystem configuration.



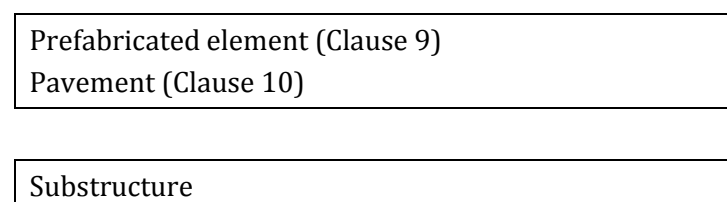
5.2.2.2 Ballastless track system with discrete rail seats on prefabricated element, independent from the surrounding concrete filling layer or pavement

The following diagram illustrates the subsystem configuration.



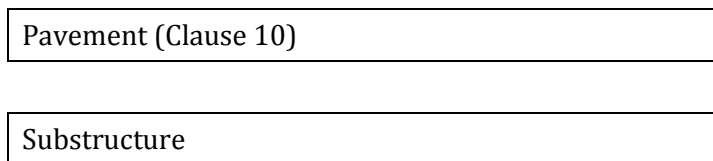
5.2.2.3 Ballastless track system with discrete rail seats on prefabricated element, monolithically integrated in a pavement

The following diagram illustrates the subsystem configuration.



5.2.2.4 Ballastless track system with discrete rail seats on a concrete pavement

The following diagram illustrates the subsystem configuration.



6 System design

6.1 Establishing the system criteria

The overall system design shall ensure that the ballastless track system integrates safely, and effectively into the interfacing elements of the railway system throughout its specified life. This includes impact on and from following:

- signalling system (including induction effects, interference from reinforcement etc.);
- supporting structures (e.g. earthworks, foundations, tunnels, bridges, viaducts etc.);
- electrical power system (e.g. stray current requirements, cable access etc.);
- other electrical systems (e.g. telecommunications);
- operational needs (e.g. drainage, maintainability and accessibility).

This requires an initial high level design to be outlined to enable understanding of the applicable general requirements, including:

- understanding the interaction of the system with the supporting substructure(s) presented and interpreting the necessary parameters influencing them, such as settlement, flexure etc.;
- dealing with the requisite live and exceptional loads;
- dealing with other environmental actions (including drainage etc.);
- risk factors affecting durability, such as shrinkage, water ingress temperature etc.;
- understanding the interfaces such as those that arise with transitions in and between substructures and track components, such as switches and crossings;
- parameters influencing environmental performance (e.g. vibration emissions);
- combination with either assumptions or nominations in respect of:
 - construction methodology;
 - track stability in the vertical, lateral and longitudinal directions, accounting also for dynamic effects;
 - rail and components for its fixation.

6.2 System assurance plan

The system assurance plan sets out how a system will demonstrate that it complies with the performance requirements and defines the acceptance criteria by which the performance will be verified.

The system assurance plan should be developed and reviewed throughout the design process.

Acceptance criteria should be defined on the basis of risk and may include physical testing and/or simulation methods.

6.3 System integration

System integration ensures that compatibility between subsystems of the track and external interfaces are suitably considered. This shall include consideration of failure/deterioration modes of the ballastless track system, subsystems and components.

The process of detailed design shall then be structured to ensure all the components (e.g. layers, etc.) are accounted for and the interactions, internal loads and load distribution effects are dealt with.

Various approaches can be used to ensure all aspects are considered, including:

- risk management;
- FMEA;
- RAMS;
- limit state analysis.

6.4 Vertical track stiffness

The value of track stiffness is not specified by this standard. It is only an input parameter for the calculations. The numbers which are given in the Annex D are only intended to illustrate the calculation method. They are not to be treated as recommended values. The required value should be specified by the purchaser of the ballastless track system taking into account the permissible bending tensile rail foot stress and the proposed operating conditions.

The track stiffness is the result of the combination of the stiffness of the different constituents. Different combinations can produce the same global result. Changes of track stiffness should be applied gradually along a pre-determined transition length.

6.5 Track stability

Track stability in the lateral direction shall be demonstrated according to EN 16432-1 by:

- fixations introduced at the interfaces between subsystems and components designed to handle horizontal forces;
- application of the lateral and longitudinal resistance force between prefabricated element and substructure, see Table 1, shall result in a lateral displacement not exceeding 2 mm.

Table 1 — Example for minimum lateral and longitudinal resistance depending on rail temperature ranges by solar radiation (other effects e.g. by eddy current brake not included)

Kind of resistance	Rail temperature range ΔT (K) (difference between the neutral/stress free temperature and the maximum rail temperature due to solar radiation)	Track resistance (kN/m)
Lateral	≤ 45	≥ 25
Longitudinal	≤ 45	≥ 14

6.6 Load distribution and load transfer by subsystems and components

6.6.1 Principles

The rail assembled, on prefabricated element or pavement shall be considered as a beam on a continuous or discrete resilient support loaded according to EN 16432-1. The moment of inertia of the rail profile, the spacing of the support points as well as the elasticity of the whole assembly on its support, have an influence on the longitudinal distribution of the vertical and horizontal loads applied on the rail.

The rail supporting structure which is formed of prefabricated elements and/or a pavement (single/multi layered) shall be designed to distribute the load by bending (beams and frames mainly in longitudinal direction; slabs in the longitudinal and transverse directions) into the substructure. Bending behaviour shall be elastic with or without limited plastic deformation according to the individual design characteristics (e.g. asphalt layers used as an intermediate or levelling layer on tunnel floor).

The design shall be undertaken based on the selected subsystems and/or components and using the relevant respective material properties (e.g. fatigue strength, thermal coefficient etc.). The final design (cross section design, dimensioning, descriptions of components, materials used and construction procedures) as well as the applied design procedure(s) shall be documented.

The design calculations for the ballastless track system shall be undertaken using one of the following approaches:

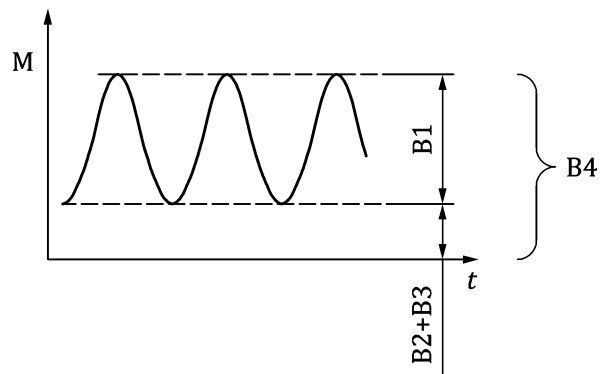
- analytical calculations;
- validated numerical tools.

NOTE 1 Examples of analytical calculations are given in Annex F, Figure F.1 and in informative Annexes A, B and C.

NOTE 2 Example for validated numerical tool: FEM.

The bending moments and the resulting bending tensile stresses due to different load cases may be determined separately and the total effects obtained from superposition of the individual load effects (see Figure 2).

The tensile fatigue strength for oscillating traffic load calculated on the basis of the constant stress level (e.g. due to temperature load) shall be higher than the stresses due to a given traffic load (including static and dynamic factors).

**Key**

- B1** determination of bending moment (bending tensile stress) due to rail seat loads
- B2** determination of bending moment activated by temperature gradient Δt [K/mm] of rail supporting subsystems like slabs, pavements, frames or beams caused by surface heating
- B3** determination of tensile force activated by cooling ΔT [K] of rail supporting subsystems like slabs pavements, frames or beams
- B4** superposition of bending moments from traffic and thermal impact
- M** bending moment

Figure 2 — Fatigue modelling – Superposition of constant and oscillating loads

6.6.2 Calculation steps

6.6.2.1 Determination of bending moment (bending tensile stress) due to rail seat loads

The analytical models are:

Slab on Winkler foundation (Westergaard) to determine longitudinal and lateral bending moments and beam on Winkler foundation (Zimmermann) to determine longitudinal bending moment. The higher longitudinal stress level shall be used as B1.

Alternative, numerical methods are:

- FEM for system design calculation including subsystems and/or components;
- multi layer theory applicable for asphalt pavements only.

6.6.2.2 Determination of bending moment activated by temperature gradient Δt [K/mm] of rail supporting subsystems like slabs, pavements, frames or beams caused by surface heating

The analytical models are edge supported beam or slab. An alternative numerical method is FEM.

6.6.2.3 Determination of tensile force activated by cooling ΔT [K] of rail supporting subsystems like slabs, pavements, frames or beams

The analytical model is friction model or CRCP model according to B.2.1. An alternative method is FEM.

6.6.2.4 Superposition of bending moments from traffic and thermal impact

The load combination may be done according to fatigue model (Smith), see B.3. An alternative method is FEM.

6.6.3 Determination of forces (rail seat loads) between subsystems fastening system and supporting structure (prefabricated element or pavement)

6.6.3.1 Vertical rail seat loads

To determine the vertical loads acting between rail and supporting structure (prefabricated element/pavement) the following procedure shall be applied:

- characteristic (static) load scheme acting on rail plus quasi-static and dynamic effects selected according to EN 16432-1;
- rail held by fastening system/embedded rail modelled as an infinite beam with discrete or continuous elastic support (Winkler) to calculate rail seat loads acting between rail and supporting structure, see Annex A or FEM calibrated by Annex A.

The rail seat loads shall be given by combination of following parameters: Force [N], contact area [mm²] or vertical stress [N/mm²].

In case prefabricated elements (e.g. blocks, sleepers) are used to further distribute the load into the supporting substructure the respective increase of contact area should be taken into account, see Annex B.

6.6.3.2 Lateral rail seat loads

The lateral loads according to EN 16432-1 shall be longitudinally distributed in accordance with the lateral stiffness of the ballastless track system.

If the lateral stiffness of the ballastless track system is not defined the horizontal force may be distributed as follows:

- 60 % horizontal wheel loading acting on rail seat below wheel;
- each 20 % horizontal wheel loading acting on rail seats before and after wheel.

6.6.4 Prefabricated element loading and load distribution

6.6.4.1 General

Vertical and horizontal loading of prefabricated elements differs dependent on contribution to overall bearing capacity by:

- mainly load spreading by increasing the contact area (blocks);
- mainly load distribution by transverse (sleepers) bending or longitudinal bending (beams or frames) or combination of both (slabs/pavements).

6.6.4.2 Transverse elements (sleepers) loading and transverse load distribution

Loading of the sleepers acting as a self-standing subsystem (sleeper supported by a pavement) shall follow the procedures of prEN 13230-6:2015. Eurocodes are not applicable.

The positive and negative bending moments may be calculated from rail seat loads according to prEN 13230-6:2015, 9.5.

prEN 13230-6:2015 is also applicable for all prefabricated structures which are designed to follow the function and design principles of the sleepers.

6.6.4.3 Loading and load distribution of longitudinal beams and frames

Design criteria for longitudinal structures distributing the loading by bending (flexural resistance) are the maximum tensile flexural stresses acting in the structure. The longitudinal beam with continuous elastic support (Winkler foundation) may be used as design model, see Annex B or FEM calibrated by Annex A.

Decisive combination of rail seat loads (vertical/horizontal) shall be used to determine the maximum bending moment acting in the structure. Rail seat loads which cause a reduction in bending moment shall be removed from the model. Consequently an iterative approach is needed to determine the decisive number and arrangement of rail seat loads.

Longitudinal beams supporting the rails shall be connected to each other (-frames) or connected to the supporting structure to handle all lateral loading, see 6.6.3.2. and to control track geometry and gauge.

6.6.4.4 Slabs or frames loading and longitudinal and transverse load distribution

Pavement models may be applied, see 6.6.5, Annex B or FEM calibrated by Annex B. Limited dimensions (width and length) of the prefabricated element shall be accounted for a reduction of bending moments but for an increase in vertical stresses.

FEM should be applied using validated models.

6.6.5 Pavement design

6.6.5.1 Calculation models and limits

Design criteria for all layered structures/pavements as well as prefabricated slabs following the design principles of pavements and distributing the loading by bending (flexural resistance) are the maximum flexural tensile stresses acting in the layer(s). Loading of supporting layers (base layers) made by unbound materials shall be evaluated using vertical compressive stresses. Safety factors applied for traffic loads to calculate vertical stresses acting on unbound granular materials may be reduced.

The following models may be applied for pavement design:

- slab and beam with continuous elastic support (Winkler foundation) applicable for concrete pavements and other layers with high flexural resistance and high material strength, see Annex B or FEM;
- multi layer theory (half space) may be applied for asphalt pavement design and for unbound layers.

For optimization of design (mainly individual layer thickness and width) it is highly recommended to apply Finite-Element-Models which should be calibrated and verified using the design procedures covered by Annex B.

The decisive combination of rail seat loads shall be used to determine the maximum bending moment acting in the pavement structure, see Annex B.

The decisive tensile flexural stresses (bending tensile stresses) of all layers of a multi-layered system shall be calculated. Stresses shall not exceed tensile flexural fatigue strength, see Annex B.

6.6.5.2 Continuously reinforced concrete pavement (CRCP)

The design of CRCP-layers is based on cracking behaviour which is either random cracking (non jointed) or controlled cracking (jointed CRCP). Average crack width and crack distance of CRCP with random cracking or controlled cracking is mainly influenced by amount of reinforcement and tensile strength of the concrete. Calculations on amount of reinforcement and crack/joint distance may be done according to B.2.2 or using FEM.

Flexural fatigue strength may be calculated according to Annex B. The higher stress calculated according to B.2.3 (temperature gradient Δt [K/mm]) and according to B.2.2 (temperature drop ΔT [K]) shall be taken as time constant stress for determination of flexural fatigue strength.

NOTE 1 Unless other specified input parameters for CRCP design and pavement materials according to 10.2.3.2 are:

- concrete Young's Modulus $E = 34\,000\text{ N/mm}^2$;
- concrete Poisson's ratio $\mu = 0,15$;
- concrete Coefficient of thermal expansion $\alpha_t = 1,0 \times 10^{-5}\text{ 1/K}$;
- steel reinforcement Young's Modulus $E = 210\,000\text{ N/mm}^2$;
- steel reinforcement; coefficient of thermal expansion $\alpha_t = 1,2 \times 10^{-5}\text{ 1/K}$.

NOTE 2 Acceptable flexural fatigue stress for CRCP with random cracking according to 10.2.3.2 activated by traffic loading is typically $0,85\text{ N/mm}^2$ in longitudinal and $2,1\text{ N/mm}^2$ in transverse direction. Acceptable flexural fatigue stress for jointed CRCP with controlled cracking according to 10.2.3.2 activated by traffic is typically $1,8\text{ N/mm}^2$ (joint spacing 2,60 m) up to $2,0\text{ N/mm}^2$ (joint spacing 1,95 m) in longitudinal direction and $2,1\text{ N/mm}^2$ in transverse direction.

6.6.5.3 Jointed plain concrete pavements (JPCP)

The design of JPCP concrete pavement is based on controlled cracking by transverse joints. Maximum allowable flexural fatigue stress due to vehicle load σ_Q should be calculated using procedures according to 6.6.1.

NOTE Unless other specified input parameters for JPCP design and concrete pavement materials according to 10.2.2 are:

- concrete Young's Modulus $E = 34\,000\text{ N/mm}^2$;
- concrete Poisson's ratio $\mu = 0,15$;
- concrete; coefficient of thermal expansion $\alpha_t = 1,0 \times 10^{-5}\text{ 1/K}$.

6.6.5.4 Asphalt pavements

The maximum allowable flexural fatigue stress activated by vehicle load B1, see Figure 2, should be calculated using procedures according to 6.6.1.

Unless otherwise specified the Young's modulus should be set equal to $E = 5\,000\text{ N/mm}^2$ (annual average value) and the mean flexural fatigue strength equal to $0,80\text{ N/mm}^2$.

6.6.5.5 Base layers

6.6.5.5.1 Cement treated or bituminous base layers

The maximum allowable flexural fatigue stress due to vehicle load σ_Q should be calculated using procedures according to 6.6.1.

For cement treated base layer:

- Unless otherwise specified the Young's modulus should be set equal to a range of $E = 5\,000\text{ N/mm}^2$ up to $E = 15\,000\text{ N/mm}^2$. In case the compressive strength is $\geq 15\text{ N/mm}^2$ the maximum allowable flexural fatigue stress can be set to $0,80\text{ N/mm}^2$.

For bituminous (asphalt) base layer:

- Unless otherwise specified the Young's modulus should be set equal to $E = 5\,000\text{ N/mm}^2$ (annual average value) and the mean flexural fatigue strength equal to $0,80\text{ N/mm}^2$.

6.6.5.5.2 Unbound base layers

Vertical stresses due to static, quasi-static and dynamic traffic load acting on unbound base layers may be calculated based on the deflection of the slab or pavement.

$$\sigma_z = k \times y \quad (1)$$

where

- σ_z is vertical stress in $[\text{N/mm}^2]$;
- k is the bedding modulus in $[\text{N/mm}^3]$, see Annex B;
- y is the vertical deflection of slab or pavement in $[\text{mm}]$.

Alternatively vertical stress may be calculated by load distribution according to procedure Annex C.

Unless otherwise specified a dynamic factor 1,17 (DAF₂) equivalent to confidence level 68,7 % (standard deviation = 1) shall be applied to determine dynamic stress level.

Unbound layers, subgrade and subsoil are not affected by risk of cracking or other sudden failures. The decisive failure mode is uneven plastic deformation along slab/pavement support. Consequently the confidence level used to determine dynamic factors may be reduced to 68,7 % for the design of such subsystems.

Unless otherwise specified vertical stresses due to traffic load acting on unbound granular material (determination according to Annex B and Annex C) shall not exceed $\sigma_z = 0,050\text{ N/mm}^2$.

or

maximum allowable stress due to traffic load (vertical compressive strength of unbound materials) can be calculated according to fatigue models (Heukelom and Klomp) as follows:

$$\max \sigma_z = \frac{0,006 \times E_{\text{dyn}}}{1 + 0,7 \log(n)} \quad (2)$$

where

- $\max \sigma_z$ is maximum allowable vertical stress in $[\text{N/mm}^2]$;
- n is the number of trains; Unless otherwise specified $n = 2 \times 10^6$;
- E_{dyn} dynamic Young's modulus in $[\text{N/mm}^2]$ specified by the customer, if not specified and if E_{V2} is applied then $E_{\text{dyn}} = E_{V2}$ according to 10.4.6.

6.7 Loading of substructure

Unless otherwise specified vertical stresses activated by traffic load acting on subsoil or subgrade as well as maximum allowable vertical stress (vertical compressive strength) should be determined according to 6.6, Annex C or FEM.

6.8 Transitions

A special construction is required between:

- ballastless track and ballasted track;
- different types of ballastless tracks (for stiffness transitions).

At the transition between ballastless track and ballasted track, different vertical deflections at the rail can occur. These different deflections can result in similar load distributions as for a sudden change in stiffness, leading to increased settlement of the ballasted track and an increased degradation risk at the ballasted track supports.

Therefore the transition zone should be designed to limit the differential settlement to a minimum:

- no sudden change in track stiffness should occur at the transition. For this reason elastic rail pads, under sleeper pads or ballast mats may be applied;
- the bound base layers according to 10.4 may continue under the ballast over a certain length;
- the ballast may be glued;
- additional rails may be installed to increase the load distribution.

At the transition between different ballastless track systems and for different vertical deflections, it is recommended that every stiffness zone should have a minimum length of $V \text{ [m/s]} \times 0,5 \text{ [s]}$.

For High speed application the difference in rail deflection under design loads according to EN 16432-1:2017, 5.1.2 over any intermediate transition length should not exceed 0,5 mm.

7 Rails

The rail profile taken into account shall be according to EN 13674-1, EN 13674-2 and EN 13674-3. If other rail profiles are used the comparability in function shall be demonstrated.

8 Rail fastening systems

8.1 General

The requirements for rail fastening systems are defined in EN 13481-5.

8.2 Rail fastening spacing

If not supported continuously, rail is typically supported at a spacing range of 0,6 m to 0,75 m. The effects of spacings outside this range need to be determined individually based on the traffic conditions, track geometry and the line speed. This should be supported by appropriate test data.

8.3 Adjustment

Adjustments of the rail geometry may be provided by the fastening systems.

9 Prefabricated elements

9.1 General

Integrated prefabricated elements form ballastless track systems in combination with in situ construction components like filling layer, pavements, hydraulic base layers etc. Characteristics of the prefabricated elements, in situ construction components and their connection properties determine the

system performance with regard to the track rigidity and the support stiffness. The characteristics of a rigid or resilient track shall be included in the system design and in the calculation of the track model. Two groups of prefabricated elements are established. The first is formed by small size or linear elements like sleepers, blocks and bearers. The second is formed by two-dimensional elements like slabs, frames etc.

9.2 General design considerations

9.2.1 Data to be supplied for the general system design

- Geometrical and mechanical data of each element. If nonlinear method of calculation is intended in the general system design, the reinforcement details and constitutive equations of the materials should be given;
- connection conditions to the “in-situ” or other prefabricated elements of the system. Topics like discrete or continuous, elastic or rigid, bonded or unbonded connection are relevant. The particular load- displacement behaviour should be specified;
- general construction process including precast process, manipulation, transport and construction stages, so the loadings associated with these particular steps are taken into account.

9.2.2 Individual precast element design

9.2.2.1 Load distribution and internal forces

As a result of the system design process the load distribution and the forces acting on each prefabricated concrete element of the ballastless track system, also the forces and stresses for the connecting system and devices are given.

The transfer of loads shall be done within a contact area which offers acceptable stresses, applicable by the precast element and the structure supporting the element.

9.2.2.2 Design

The most general method is the application of existing standards to elements like sleepers, blocks and bearers. This is covered in EN 13230 series and EN 13481 series. The element designer shall provide those tolerances of the prefabricated track component which are necessary to ensure the required track quality of the entire ballastless track system.

For elements like frames, slabs which are not covered by previous standards the general methods of design of continuous media may be applied, e.g. EN 1992 series.

9.3 Manufacturing process

9.3.1 General requirements

Details of production plant and equipment are part of the design of the prefabrication. The processes for curing, formwork removal and handling conditions of the prefabricated concrete elements are part of the manufacturing process. Any change in the manufacturing process shall be verified and documented.

The concrete and air temperature shall be monitored at least in the testing phase of the production. When the relationship between concrete and air temperature is evident at all stages throughout the curing cycle, it is permissible for the air temperature within the immediate curing environment to be measured instead of the concrete temperature.

When the temperature is measured in the concrete, it shall be measured as near as possible at the mid depth and at the mid width of the element.

9.3.2 Curing

Curing and protection should start as soon as possible after the compaction of the concrete and continue according to EN 13230-1:2016, 6.2, Figures 4 and 5 to ensure durability.

The curing procedure applied to the element shall be chosen in accordance with required interface conditions, e.g. bond, defined by system design.

9.3.3 Surface finish

For the specification of the surface characteristics of a precast element, reference should be made to EN 13230-1:2016 for concrete sleepers and bearers and EN 13369:2013, J.4 for the surface items to be described of other precast elements.

9.3.4 Marking

It is recommended to identify each element with permanent marking to ensure traceability.

9.4 Quality control

9.4.1 General

A quality management system shall be operated, which is defined and maintained in a quality manual. This manual shall address all actions, functions and resources, procedures and practices concerned with achieving and providing documentary evidence that the quality of the delivered concrete element and services are in line with the requirements.

The quality manual shall include a quality plan for the production of concrete elements, which defines and details at least the following:

- the organization, structure and responsibilities;
- all the materials, processes and procedures for manufacturing, storing and transporting of the concrete elements;
- all testing requirements including definition of testing equipment, method of testing, frequency of tests, etc.;
- all other quality control procedures to ensure and verify that the concrete elements and services provided are to the requirements.

9.4.2 Quality control during design approval tests

The quality documents in relation with the pre-fabricated elements which shall be submitted for design approval are at least:

- detailed drawings of the element and components included;
- detailed information of the reinforcing system (including anchoring system for pre-stressed elements), if applicable;
- detailed information about material composition;
- procedure showing how all requirements are fulfilled. This includes:
 - geometrical tests with description of the gauge and measurement method for each dimension;
- calculations and optionally load tests on concrete elements with the description of the measurement means and method;

- general description of the manufacturing process;
- test report showing compliance of the elements with the dimensions and maximum specified tolerances.

9.4.3 Quality control during manufacturing

Prior to start of manufacturing a quality plan including all quality documents in relation with the acceptance of materials and manufacturing of the concrete elements shall be established.

For routine tests, alternative test arrangements can be used if evidence of results complying with approved test arrangements is provided.

The quality plan shall detail at least:

- frequency of testing for each dimensional requirement;
- if part of the quality control frequency for load tests on concrete elements;
- mechanism used to increase the testing frequency when defects are identified;
- actions to be taken in the case of defects being found to ensure remedial works and recheck for compliance or not acceptance for delivery.

NOTE For prefabricated slabs, see Annex E, Table E.2.

9.5 Concrete sleepers, bearers and blocks

- a) Concrete sleepers, bearers and blocks which are supported by pavements are defined in EN 13230 series;
- b) concrete sleepers bearers and blocks which are independent from the surrounding concrete linked by rigid or stiff intermediate layers or interfaces are defined in EN 13230 series;
- c) concrete sleepers, bearers and blocks which are independent from the surrounding concrete linked by elastic intermediate layers or interfaces are defined in EN 13230 series and EN 13481-5;
- d) concrete sleepers, bearers and blocks which are integrated into the slab or the pavement (monolithic systems) and designed to withstand the loading together a durable bond with the slab shall be demonstrated. Except for design EN 13230-1:2016, EN 13230-2:2016, EN 13230-3:2016, EN 13230-4:2016 and EN 13230-5:2016 define the relevant procedures. For design, production and acceptance of precast elements, which fulfil their bearing function only in composite action with the *in situ* slab concrete, only EN 13230-1:2016 applies, except for the clauses for sleeper and bearer testing, 7.1 to 7.3.

NOTE In case of a), b) and c) the design by test method explained in prEN 13230-6:2015 can be useful.

The design load may be obtained according to prEN 13230-6:2015, Annex A. For this purpose the stiffness of the ballast shall be replaced by those of the elastic support. Also the irregularity support condition on the ballast parameters, k_r , $k_{i,r}$ and $k_{i,c}$ shall be adapted according to prEN 13230-6:2015.

9.6 Prefabricated slabs and frames

9.6.1 Classification

9.6.1.1 Classification in longitudinal sense

Continuous in longitudinal sense (connected slabs):

Prefabricated slabs are installed on-site and connected by steel and concrete filling of the joints to a monolithic, track system.

Independent in longitudinal sense:

Open joints between adjacent slabs enable length compensation of these slabs. The transverse and longitudinal displacement resistance should be controlled e.g. by tapered grouting openings or other types of restraints.

9.6.1.2 Classification according to the support conditions on the supporting layer

After installing and adjusting the slabs the gap between the supporting structure and the underneath layer of the slabs shall be grouted, so that the slabs are solidly connected with the supporting structure, e.g. concrete base layer, tunnel invert, bridge construction, hydraulically bonded base layer or mass spring system. For grouting a self-compacting concrete or mortar may be used to avoid vibrating because of the exactly adjusted track. Alternatively bituminous or low strength material may be used for grouting. It shall be ensured that the grouting material shows low shrinkage performance and does not deform plastically. The pourable concrete or mortar joins the slab to the support structure and is levelling the slabs. Concerning the thickness there are different possibilities:

- slim: compact lay-out, no reinforcement,

or

- thick: reinforced in order to limit wide cracks.

To attenuate vibrations and structure-borne noise and for distribution of load peaks or to avoid steep load transmission an elastic layer may be affixed on the underneath of the slabs or in general on all surfaces which adjoin the base structure. As a consequence the slabs perform like a light-weight mass spring system.

9.6.1.3 Classification according to the kind of reinforcement

- Reinforced concrete slabs with un-tensioned reinforcement;
- pre-stressed reinforced concrete slab (in longitudinal and lateral or in lateral direction only);
- combined solutions for reinforcement, e.g. use of steel fibre reinforced concrete to support reinforcement in areas of supporting points and to avoid influences on electro-magnetic track equipment;
- fibres.

9.6.1.4 Classification according to the function and load distribution characteristic

Classification of a prefabricated element is dependent on its function and load distribution characteristic. Beside a two-dimensional load distribution element a slab may also be designed as a set of concrete sleepers connected to each other.

9.6.2 Design

9.6.2.1 General

EN 1992 design principles can be applied, see e.g 9.6.2.2. In case a slab acts as a set of concrete sleepers the design principles according to EN 13230 series, see 9.5. and pavement design according to Clause 10 may be applied instead of 9.6.2.

9.6.2.2 Design of active and passive reinforcement, limit states, fatigue checking

For the application of EN 1992-1-1, the following requirements should be fulfilled:

- Ultimate Limit States (ULS) according to EN 1992-2:2005, Clause 6 and EN 1992-1-1;
- Serviceability Limit States (SLS) according to EN 1992-2:2005, Clause 7 and EN 1992-1-1;
- fatigue checking according to EN 1992-2:2005, 6.8.

For fatigue compression of concrete no verification is necessary if the maximum stresses under frequent loads are below $0,5 f_{ck}$ (fatigue tensile strength of $0,5 f_{ctk}$ may also be accepted).

f_{ck} characteristic concrete compressive strength (cylinder) after 28 days;

f_{ctk} characteristic concrete tensile strength.

NOTE Checking of the tensile stress in pre-stressed solutions can be according to prEN 13230-6:2015. Furthermore:

- damage equivalent stresses for fatigue checking according to EN 1992-2:2005, Annex N;
- detailing of reinforcement and pre-stressing tendons according to EN 1992-2:2005, Clause 8;
- detailing of members and particular rules according to EN 1992-2:2005, Clause 9;
- design of reinforcement according to EN 1992-2:2005, Clause 6 (Ultimate Limit States) and EN 1992-2:2005, Clause 7 (Serviceability Limit States).

9.6.2.3 Durability, cover, environmental conditions, material characteristics, crack control

- Durability and concrete cover of reinforcement shall be according to EN 1992-2:2005, Clause 4, including the national application document that normally improves the general requirements introducing the benefits of high quality cement or detailing the case of pretensioned prestressing tendons;
- exposure classes related to environmental actions shall be in accordance with EN 206:2013+A1:2016, 4.1 or EN 1992-1-1:2004, Table 4.1;
- mechanical properties of concrete and steel shall be in accordance with EN 1992-2:2005, Clause 3 or EN 206;
- crack control shall be according to EN 1992-2:2005, 7.3;
- additional functional crack control in accordance with EN 1992-1-1:2004, 7.3 can be included as well as precise specified experimental methods to check real cracking as an alternative to calculation.

9.6.3 Materials

Specific materials and elements are:

- Concrete, steel fibre concrete, polypropylene fibre concrete;
- reinforcement steel B 500 A/B minimum, pre-stressing steel;
- rail fastening for pre-assembly in factory;
- distance pieces for concreting, plastic anchors;
- possibly resilient layer fixed with adhesive, hydro waxing;

- earthing connectors.

Pre-stressing:

- Directly bonded according to EN 1992-1 and EN 1992-2;
- post-tensioned slabs according to EN 1992-1 and EN 1992-2.

NOTE For raw materials requirements, see also Annex E, Table E.1.

9.6.4 Geometrical tolerances

A quality system shall be provided, which is defined and maintained in a quality manual. This manual shall address all testing requirements including definition of testing equipment, method of testing, frequency of test etc. The geometrical tolerances shall be fixed in this quality manual.

In particular the following quality characteristics shall be checked:

- length;
- width;
- thickness;
- rail seat distance;
- vertical and lateral alignment of rail support points;
- dimension of grouting openings;
- exterior and inner rail support point distance;
- depth gauge;
- inclination;
- surface and planarity.

NOTE For example of quality plan, see Annex E, Table E.3

9.6.5 Storage, handling, transport and on-site installation

9.6.5.1 General

The outstanding performance of a ballastless track system requires a high level of accuracy and quality during storage, handling, transport and on-site installation of the slabs. This clause defines the minimum requirements. Each slab shall be permanently marked with details of type, production batch number and date of manufacture.

9.6.5.2 Storage, handling and transport

Unacceptable and unforeseen loads, stresses and deflections in the slabs shall be avoided at any stage and under any circumstance. A method statement shall be provided in order to ensure that the slabs are stored, handled and transported safely. This method statement includes:

- maximum number of slabs mounted on top of each other;
- method for the slab storage (3-point-mounting, 4-point-mounting, etc.);