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Translation

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Recommendations for the design of joist-in-concrete railway bridges

*Recommandations pour une méthode de calculs des ponts-rails à poutrelles enrobées
Empfehlungen für die Berechnung von Eisenbahnbrücken aus Walzträgern in Beton*



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Summary

UIC Leaflet 773 (electronic version of the 4th edition dated 01.01.1997 without any change of content) sets out recommendations on the determination of a calculation method for joist-in-concrete railway bridges.

The regulations on materials and the definition of railway activities in the present leaflet refer to European standards and Eurocodes.

The calculation rules are only applicable to joist-in-concrete decks constructed in accordance with the construction provisions indicated in the leaflet.

1 - General - Field of application - Regulations

1.1 - General

These rules relate to European Standards or Eurocodes, for definition of the effects of rail traffic and of the materials used. Other standards or rules for the materials may be used if the safety factors are validated.

NB : This applies particularly to *EN 1994-2, Appendix K* concerning the filler beam decks. The principle rules of this appendix, which are consistent with the present rules, were worked out in concert with the UIC working group

Joist-in-concrete decks consist of rolled steel beams encased in concrete.

The following calculation rules are only appropriate for decks with filler beams encased in concrete, which are constructed according to the requirements given in point [1.3 - page 3](#).

The calculations for the transverse bending and the torsion of slabs with encased filler beams should be based on the rules applicable to reinforced concrete railway bridges supplemented by the specific rules given in this document.

1.2 - Field of utilisation

Steel joist-in-concrete decks may be used for railway bridges with a span of up to roughly 30 m for simply supported beams and roughly 35 m for continuous beams.

They are of shallow depth and are well suited for spans where the construction depth is limited.

The prefabrication of small decks is possible.

1.3 - Requirements

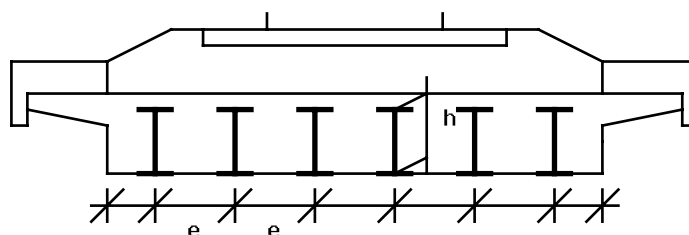


Fig. 1 - Requirements

1.3.1 - Steel beams

The decks are constructed using plain, unstrengthened **rolled beams**. Specific mechanical shear connection means need not be provided. The steel must be cleaned to remove mill scale.

The web of the beam must be drilled to accommodate the transverse reinforcement and the fixing of spacers.

The clear distance between the flanges of adjacent beams must not be less than 15 cm. The distance e between the centre-lines of the beams should not exceed the following values:

$$e \leq 75 \text{ cm}$$

$$e \leq h/3 + 60 \text{ cm}$$

with: h = nominal beam in [cm]

The use of **welded beams** is allowed, when their dimensions are not different from the dimensions of the equivalent rolled beams.

1.3.2 - Concrete cover

The thickness of concrete above the upper flanges must be 7 cm minimum; it must not exceed one-third of beam depth, with a maximum of 15 cm.

The concrete cover must also satisfy the rule concerning the position of the neutral plastic axis given in point [5.1.2 - page 14](#).

1.3.3 - Stability of beams during construction

Spacers should be provided between the beams in order to facilitate their setting up.

Bracing is provided to prevent beams from lateral - torsional buckling during concreting. It consists of transverse bracing at supports which maintains beams in a vertical position. Additional intermediate transverse bracing and plan bracing may be needed. In order to reduce the number of braces, the concreting may be carried out in more than one stage. Appropriate checks must be made at the calculation stage to ensure the safety of such staged construction.

Welding must not be used for attachments in order to avoid any risk of fatigue.

1.3.4 - Permanent formwork

Shutter plates placed on the lower flanges of the beams and bedded on cement mortar or on a rubber strip may be used as permanent formwork. The thickness of this formwork depends on its span and the depth of the concrete. Its ability to carry the weight of the wet concrete must be verified.

The detailing and fixing of this formwork must be carefully considered in order to reduce the risk of corrosion between the plate and the flange of the beam.

The formwork does not contribute to the resistance or to the stiffness of the structure.

1.3.5 - Reinforcing steel

1.3.5.1 - Transverse reinforcement in the lower part of the slab

In order to resist torsion and transverse bending transverse reinforcement should be provided in the lower part of the slab over the whole width of the deck.

This reinforcement, which passes through the web above the root radius between the web and the lower flange, must be fully anchored in the concrete, beyond the edge beams, (anchorage by hooks) or by bolting to the webs of the beams.

1.3.5.2 - Transverse reinforcement in the upper part of the slab

For this reinforcement, which must also be provided over the whole width of the deck, the cross sectional area shall be equal to at least half that of the lower transverse reinforcement, and shall, in any case, be not less than 5 $\varnothing$ 10 mm diameter high bond bar per meter.

This reinforcement shall be prevented from contact with the upper flanges of the beams. Spacers or longitudinal reinforcement can be used to ensure this.

The vertical reinforcement of the free ends should be extended in order to encircle efficiently the whole slab, together with the upper and lower transverse reinforcement.

1.3.5.3 - Longitudinal upper reinforcement

Where the concrete is in tension in the upper part of the slab, reinforcement shall be provided longitudinally in order to limit crack width (see point 4.4 - page 13). This reinforcement can be taken into account in determining the resisting bending moment at the intermediate supports of continuous bridges (see point 5.1 - page 14).

1.3.5.4 - Longitudinal lower reinforcement

In order to limit the width of cracks in the concrete tension zone, longitudinal lower reinforcement may be provided if the spacing of the beams is large. This reinforcement shall be not less than 5 $\varnothing$ 10 mm diameter high bond bar per metre.

1.3.6 - Skew

The effects of the skew angle of the decks must be taken into account in the calculations when the skew angle of the supports is lower than 70 gon.

1.3.7 - Beam supports

Each rolled beam should be supported individually on bearings, on bearing blocks at the piers or abutments. This facilitates the concreting and ensures a direct transfer of the deck loads to the supports.

If other support modes are considered, the transfer of the loads shall be carefully studied and justified in the calculations.

2 - Materials

2.1 - Steel of the beams

The grades and qualities of the steel for the beams shall be conforming to European Standard *EN 10025* and *EN 10113, part 1 to 3* (see Bibliography - page 45).

The recommended¹ grades and qualities for rolled beams used in railway bridges if not spliced by welding are underlined in the following table. The recommended grades and qualities for rolled beams used in railway bridges with welded joints, are indicated in bold type in the following table.

The grades and qualities indicated in italics in the following table may be used experimentally, in particular for large spans. The bond between concrete and steel shall be checked beforehand under repeated loading, by tests or calculations².

	European Standard <i>EN 10025: 1993</i>		European Standard <i>EN 10113-1: 1993</i> <i>EN 10113-2: 1993</i> <i>EN 10113-3: 1993</i>	
	Grade	Quality	Grade	Quality
Nominal yield strength				
240 Mpa	S 235	JR, JO		
275 Mpa	<u>S 275</u>	<u>JO</u>	S 275	N, M NL, ML
355 Mpa	<u>S 355</u>	<u>JO, J2G3,</u> <u>K2G3</u>	S 355	N, M NL, ML
420 Mpa			S 420	N, M NL, ML
460 Mpa			S 460	N, M NL, ML

The values for the yield strength to be adopted as a function of the thickness are given in the above mentioned two European Standards.

1. These recommendations assume that the price differences between different grades and qualities are small and marginal with respect to the cost of the construction of railway bridges on lines open to traffic. For the same reason, the use of steel of lower quality is not recommended, when steel with higher grade is chosen.
2. Within the scope of the studies for the elaboration of EN 1994, tests have been carried out on composite beams with encased webs. They have shown good bending performance up to the ultimate limit state, with or without shear connectors and using steel with a yield strength close to 450 N/mm².

2.2 - Reinforcing steel

Concrete reinforcement must be in accordance with the requirements of *EN 1992-2, Chapter 3.2* (see [Bibliography - page 45](#)).

Only steels with high ductility B500H are to be used¹.

2.3 - Concrete

Concrete must be in accordance with the requirements of *EN 1992-3, chapter 1* which are summarised as follows.

Strength class of concrete	C 20/25	C 25/30	C 30/37	C 35/45	C 40/50
f_{ck} (N/mm ²)	20	25	30	35	40
f_{ctm} (N/mm ²)	2,2	2,6	2,9	3,2	3,5

f_{ck} : characteristic value of the concrete compressive strength measured on a cylinder
 f_{ctm} : mean value of the tensile strength

According to *EN 1992, point 7.3.1.1* the classification of concrete involves two values, for example, C 20/25; the first value refers to the characteristic cylinder strength, (20N/mm² in the example), the second to the cube strength (25 N/mm² in the example).

For reasons of durability of the bridges, the recommended concretes for railway bridges with beams or rolled girders encased in concrete are from class C30/37.

In the case of exceptional use of lightweight concrete the complementary recommendations of [Appendix E - page 44](#) are applicable.

2.4 - Modular ratio

2.4.1 - The modular ratio steel-concrete for short-term loading is defined as the ratio:

$$n_i = \frac{E_a}{E_i}$$

where:

E_a = modulus of longitudinal elasticity of the beam steel,

E_i = secant modulus of elasticity of the concrete, for short- term loading.

For normal weight concrete the following value should be adopted:

$$n_i = 6$$

1. According to *EN 10080*.

2.4.2 - The long term modular ratio, which takes into account the shrinkage of the concrete, is defined by the expression:

$$n_v = \frac{E_a}{E_i} (1 + K_{f1})$$

If the value of the coefficient K_{f1} is not otherwise specified, K_{f1} shall be taken as equal to 2 in the case of normal weight concrete and the long term modular ratio is then equal to 3 times the short term modular ratio:

$$\text{Thus: } n_v = 18$$

2.5 - Shrinkage of concrete

Shrinkage of the concrete is not considered.

2.6 - Poisson's ratio

The effective Poisson's ratio (or average) shall be taken equal to 0 for the calculations for ultimate limit states and 0,2 for the calculations for serviceability limit states.

The same value may be used for both orthogonal directions of filler beam slabs.

2.7 - Properties of filler beam decks for dynamic calculations

2.7.1 - Dynamic calculations

The stiffness and the mass of the deck change during the life of the bridge. For each of the different parameters, which determine the dynamic behaviour of filler beam slabs, two values have to be taken into account in the calculations, the highest and the lowest value, applying the appropriate value in each situation in order to take into account the most unfavourable case.

The minimum flexural stiffness is evaluated by assuming that concrete in tension is cracked for all the cross sections under the action of the permanent loads and variable traffic loads and by taking into account the short term modulus of elasticity of the concrete (short term modular ratio given in point [2.4.1 - page 7](#)).

The maximum stiffness is determined by assuming that the whole concrete in tension is uncracked. The stiffness may be considered as constant along the beam.

The mass of the deck, as well as the rotational inertia of mass should be evaluated using both the maximum and minimum values, for the depth of ballast on the deck.

The damping of the structure may be taken as equal to 2 % of the critical damping¹.

2.7.2 - Simplified calculations

In view of the application of *EN 1991-3, point 6.4.3* (see [Bibliography - page 45](#)) the first natural frequency of the flexural vibration of the structure may be calculated using the following assumption: a constant moment of inertia determined as indicated in point [3.4.2 - page 10](#), the modular ratio corresponding to the short-term loading and the mass taken as equal to the minimum nominal value given above.

1. The corresponding logarithmic decrement is equal to 0,126.

3 - Loads and other factors

3.1 - Constant loads

The constant loads comprise the following:

1. the weight of the steel beams, the permanent formwork, the reinforcement, the cross bracing, windbracing and spacers, and encasing concrete,
2. the weight of the protective layer, waterproofing, the track and its components. This weight can vary during use. For these loads, reference should be made to *EN 1991-2-1, sections 3.4.3 and 3.4.4* (see Bibliography - page 45).
3. the imposed permanent deformations, induced settlements and/or support settlements.

Where this is not the case, the loads listed under 1. should be applied to the steel beams alone, whilst the actions 2. and 3. should always be applied on the composite structure.

The load 1. can be applied to the composite structure, after hardening of concrete, provided that the beams are supported along their whole length during concreting and the supports remain in place control the concrete has set.

The weight of the elements constituting the deck is calculated using the nominal dimensions assuming a unit mass of 7,85 ton per m³ for the steel (beams, reinforcement, spacers,...), of 2,4 ton per m³ for the normal weight encasing concrete, and of 2,5 ton per m³ for the normal weight reinforced concrete (parts in cantilever...).

3.2 - Railway loads

The railway loads are given in *EN 1991-3, section 6*.

3.3 - Other variable loads

The loads due to wind action are given in the *EN 1991-2-4* (see Bibliography - page 45). The combination with the railway loads are defined in *EN 1991-3 (1994 edition)*.

The loads due to aerodynamic effects from passing trains are given in *EN 1991-3, part 6 (1994 edition)*.

The effects due to the temperature do not need to be taken into account in designing the deck, (but they must be considered for the bearings). The effects due to snow also do not have to be considered.

3.4 - Calculation of internal forces and deformations

3.4.1 - Calculation models

The internal forces and the deformations of the structure are calculated by considering a linear elastic model.

The deck may be modelled as a thin orthotropic plate possibly skewed. The calculation of the internal forces can then be made using the tables of Guyon-Massonnet-Barès or with the help of finite element software. The utilisation of software is necessary in the case of decks with a skew angle less than 70 degrees.

Deformations and transverse forces on the deck are to be measured using the same linear elastic two-dimensional calculation model.

The modelling of the deck as single beams which may be calculated by classical theory of bending is allowable, if the transverse bending or the torsion of the structure can be taken into account by means of the transverse reinforcement. This is the case for the decks carrying only one track and with a skew angle higher than 70 gon, where the transverse lower reinforcement consists of high bond steel bars with a spacing of 300 mm, and with a diameter of 16 mm, when the span is greater than 5 m, and with a diameter of 20 mm, when the span is lower than 5 m.

3.4.2 - Calculation of internal forces and deformations under longitudinal bending

The check of the longitudinal bending should determine first the beams with the highest internal forces and then calculate the most unfavourable bending moments in the cross sections subjected to the highest internal forces.

Internal forces and deflections may be determined assuming a moment of inertia with a constant value along the structure.

For loads applied after complete hardening of concrete, the moment of inertia I is determined from the following assumptions:

- I is equal to the mean value:

$$I = \frac{I' + I''}{2}$$

Where:

I' = moment of inertia of the composite cross-section (equivalent section) subjected to sagging bending, calculated neglecting concrete in tension.

I'' = moment of inertia of the composite cross-section (equivalent section) subjected to sagging bending, calculated assuming that concrete is uncracked and participates in resistance.

- The width of the concrete associated with each steel beam is equal to their spacing e .
- The longitudinal reinforcement must not be taken into account.
- The modular ratios to be used are those indicated above.

The deflections, which are used in determining the fabrication camber must be calculated in accordance with the above-mentioned rules.

4 - Serviceability limit states

4.1 - General

The serviceability limit states to be considered are given in *EN 1991-3, section 6*.

In addition to the deformation limit states following limit states should be checked: limitation of stresses in the materials and of crack width.

The combination of actions to be considered for the serviceability limit states are given in *EN 1991-1 and EN 1991-3 (1994 edition)*.

4.2 - Deformations

To check the serviceability limit states of deformations, these must be evaluated by using the rules given above in point [3.4 - page 10](#).

4.3 - Limitation of stresses

4.3.1 - Verification principle

This limit state is aimed at verifying by calculation of the stresses in the materials, that neither the concrete in compression, nor the structural steel suffers irreversible deformations under any possible load combination.

The maximum total stresses for each construction phase and in service shall not exceed, at any point in the structure, the limit stresses of the materials given hereafter in point [4.3.3 - page 12](#).

The stresses due to the permanent loads applied before the concrete has fully hardened must be calculated considering that only the steel beams are carrying the loads.

The stresses due to the permanent loads acting on the structure after all concrete has fully hardened must be calculated considering the resistance of the composite section with the long term modular ratio given in point [2.4.2 - page 8](#).

The stresses due to the variable loads are calculated also considering the resistance of the composite section but with the short term modular ratio given in point [2.4.1 - page 7](#).