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Railway applications – Wheelsets and bogies – Powered and non-powered axles with inboard bearings – Design method

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Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 August 2011. It was prepared by Technical Committee RAE/3, *Railway rolling stock material*. A list of organizations represented on this committee can be obtained on request to its secretary.

Information about this document

The start and finish of text introduced or altered by Corrigendum No. 1 is indicated in the text by tags C1 C1.

Test laboratory accreditation. Users of this British Standard are advised to consider the desirability of selecting test laboratories that are accredited to BS EN ISO/IEC 17025 by a national or international accreditation body.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is “shall”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

Railway axles were among the first train components to give rise to fatigue problems.

Many years ago, specific methods were developed in order to design these axles. They were based on a feedback process from the service behaviour of axles combined with the examination of failures and on fatigue tests conducted in the laboratory, so as to characterize and optimize the design and materials used for axles.

A European working group under the aegis of UIC (Union International des Chemins de fer) started to harmonize these methods at the beginning of the 1970s. This led to an ORE (Office de Recherches et d'Essais de l'UIC) document applicable to the design of trailer stock axles [1], which was subsequently incorporated into national standards (French, German, and Italian).

This method was successfully extrapolated in France for the design of powered axles and the French standard also applies to such axles. Consequently this method was converted into an UIC leaflet [2].

Work continued in Europe and standards were prepared under a mandate given to CEN/CENELEC/ETSI by the European Commission and the European Free Trade Association, which supports the essential requirements of Directives 96/48/EC [3] and 2001/16/EC [4] amended by Directive 2004/50/EC [5]. These Directives have now been superseded by Directive 2008/57/EC [6].

The resulting European standards BS EN 13103 and BS EN 13104 for the design methods for outboard bearing axles were derived based largely on the UIC leaflet [2].

This British Standard takes these considerations into account and they have been adopted and amended accordingly, for the axle configurations having inboard journal bearings. UK practice, including TM/TC0001 *Design guide for the calculation of stresses in axles with inboard journals* [7], BASS 503 *Design guide for the calculation of stresses in axles driven by axle hung traction motors* [8] and BASS 504 *Design guide for the calculation of stresses in non-driving axles* [9], has also been used in the preparation of this document.

The method described in these reference documents is largely based on conventional loadings for axles and applies the beam theory for the stress calculation. The shape and stress recommendations are derived from design verification, and the outcome is validated by many years' experience on the UK mainline railway system.

1 Scope

This British Standard specifies a design method for powered and non-powered axles with inboard bearings for railway applications.

This standard:

- specifies the forces and moments to be taken into account with reference to masses, traction and braking conditions;
- specifies the stress calculation method for axles with inboard axle journals;

- specifies the maximum permissible stresses to be assumed in calculations for steel grades EA1N, EA1T and EA4T as defined in BS EN 13261 and steel grades A1N and A1T as specified in BS 5892-1;
- specifies a method for determining the diameters for the various sections of the axle. It also gives recommendations for the preferred shapes and transitions to ensure adequate service performance.

This standard is applicable to:

- solid and hollow powered axles for railway rolling stock;
- solid and hollow non-powered axles of motor bogies;
- solid and hollow non-powered axles of locomotives;
- axles defined in BS EN 13261 and in BS 5892-1;
- UK standard gauge.

This standard is applicable to axles fitted to rolling stock intended to run under normal UK mainline conditions. Before using this standard, if there is any doubt as to whether the railway operating conditions are normal, it is necessary to determine whether an additional design factor has to be applied to the maximum permissible stresses. The calculation of wheelsets for special applications (e.g. tamping/lining/levelling machines) may be made according to this standard only for the load cases of free-running and running in train formation. This standard does not apply to workload cases. They are calculated separately.

2 Normative references

The following referenced documents are indispensable for the application 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.

BS 5892-1, *Railway rolling stock materials – Part 1: Specification for axles for traction and trailing stock*

BS EN 13261, *Railway applications – Wheelsets and bogies – Axles – Product requirements*

3 Symbols

For the purposes of this British Standard, the following symbols apply.

m_1	Mass on journals (including bearings and axle boxes), in kilograms (kg)
m_2	Wheelset mass and masses on the wheelset between running surfaces (brake disc, etc.), in kilograms (kg)
$m_1 + m_2$	For the wheelset considered, portion of the mass of the vehicle on the rails, in kilograms (kg)
g	Acceleration due to gravity, in metres per second squared (m/s^2)
P	Half the vertical force per wheelset on the rail, $\frac{(m_1 + m_2)g}{2}$, in newtons (N)

P_0	Vertical static force per journal when the wheelset is loaded symmetrically, $\frac{m_1 g}{2}$, in newtons (N)
P_1	Vertical force on the more heavily-loaded journal, in newtons (N)
P_2	Vertical force on the less heavily-loaded journal, in newtons (N)
P'	Portion of P braked by any mechanical braking system, in newtons (N)
Y_1	Wheel/rail horizontal force perpendicular to the rail on the side of the more heavily-loaded journal, in newtons (N)
Y_2	Wheel/rail horizontal force perpendicular to the rail on the side of the less heavily-loaded journal, in newtons (N)
H	Force balancing the forces Y_1 and Y_2 , in newtons (N)
Q_1	Vertical reaction on the wheel situated on the side of the more heavily-loaded journal, in newtons (N)
Q_2	Vertical reaction on the wheel situated on the side of the less heavily-loaded journal, in newtons (N)
F_i	Forces exerted by the masses of the unsprung elements situated between the two wheels [brake disc(s), pinion, etc.], in newtons (N)
F_f	Maximum force input of the brake shoes of the same shoe holder on one wheel or interface force of the brake pads on one brake disc, in newtons (N)
M_x	Bending moment due to the masses in motion, in newton millimetres (N·mm)
M'_x, M'_z	Bending moments due to braking, in newton millimetres (N·mm)
M'_y	Torsional moment due to braking, in newton millimetres (N·mm)
M''_x, M''_z	Bending moments due to traction, in newton millimetres (N·mm)
M''_y	Torsional moment due to traction, in newton millimetres (N·mm)
MX, MZ	Sum of bending moments, in newton millimetres (N·mm)
MY	Sum of torsional moments, in newton millimetres (N·mm)
MR	Resultant moment, in newton millimetres (N·mm)
$2b$	Distance between vertical force input points on axle journals, in millimetres (mm)
$2s$	Distance between wheel treads, in millimetres (mm)
h_1	Distance between the centre of the axle and the centre of gravity of the vehicle, in millimetres (mm)
y_i	Distance between the tread of one wheel and force F_i , in millimetres (mm)
y	Abscissa for any section of the axle calculated from the section subject to force P_1 , in millimetres (mm)

Γ	Average friction coefficient between the wheel and the brake shoe or between the brake pads and the brake disc
σ	Stress calculated in one section, in newtons per square millimetre (N/mm ²)
$\sigma_{\max}$	Maximum stress calculated in one section, due to the masses in motion plus braking or masses in motion plus traction, whichever is the greater, in newtons per square millimetre (N/mm ²)
K	Fatigue stress concentration factor
R	Nominal radius of the tread of a wheel, in millimetres (mm)
R_b	Radius of circle on brake disc at which brake force is applied, in millimetres (mm)
d	Diameter for one section of the axle, in millimetres (mm)
d'	Bore diameter of a hollow axle, in millimetres (mm)
D	Diameter used for determining K , in millimetres (mm)
r	Radius of transition fillet or groove used to determine K , in millimetres (mm)

4 General

The major phases for the design of an axle shall be undertaken as follows:

- a) definition of the forces to be taken into account and calculation of the moments on the various sections of the axle;
- b) selection of the diameters of the axle body and journals and, on the basis of these diameters, calculation of the diameters for the other parts;
- c) verification of the options taken by:
 - stress calculation for each section;
 - comparison of these stresses with the maximum permissible stresses.

NOTE A sample axle calculation sheet template is given in Annex A and some example calculations are given in Annex B to Annex H.

5 Forces and moments to be taken into consideration

5.1 Types of forces

Three types of forces shall be taken into consideration as a function of:

- the masses in motion;
- the braking system;
- the traction.

5.2 Influence of masses in motion

NOTE 1 The forces generated by masses in motion are concentrated along the vertical plane of symmetry (y, z) (see Figure 1) intersecting the axle centreline.

Unless otherwise specified (for example by the customer), the masses ($m_1 + m_2$) to be taken into account for the main types of rolling stock shall be as specified in Table 1.

NOTE 2 For particular applications, e.g. suburban vehicles, other masses might be necessary in accordance with the specific operating requirements (see Table 1 Footnotes ^{A)} and ^{B)}).

Figure 1 Influence of masses in motion

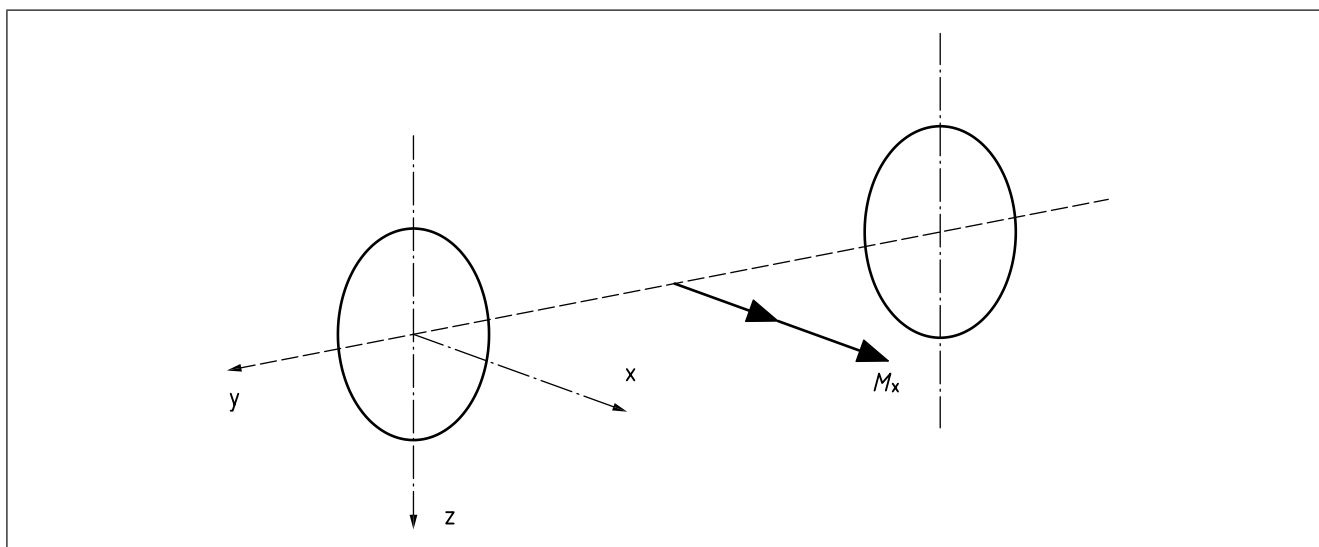


Table 1 Masses to be taken into account for the main types of rolling stock

Type of rolling stock units	Mass ($m_1 + m_2$)
Freight wagons	For the axle considered, portion of the wagon mass under maximum permissible loading in service
Traction units with no passenger accommodation, luggage areas and postal vans	For the axle considered, portion of the vehicle mass under maximum permissible loading in service
Traction units including passenger accommodation, luggage areas and postal vans	For the axle considered, portion of the vehicle mass under maximum permissible loading in service
1 – Main line vehicles ^{A)}	Total mass = Mass in service + $1.2 \times$ payload Where: Mass in service is the vehicle mass without passengers, tanks full (of water, sand, fuel, etc.) Payload is the mass of passengers^{B)} and luggage, taking the mass of a passenger with hand luggage as 80 kg and assuming: • 1 passenger per seat; • 2 passengers/m² in corridors and vestibules; • 2 passengers per attendant compartment; • 300 kg/m² in luggage compartments.
2 – Suburban vehicles ^{A) C)}	Total mass = Mass in service + $1.2 \times$ payload Where: Mass in service is the vehicle mass without passengers, tanks full (of water, sand, fuel, etc.) Payload is the mass of passengers^{B)} and luggage, taking the mass of a passenger, with little or no hand luggage, as 70 kg, and assuming: • 1 passenger per seat; • 3 passengers/m² in corridor areas; • 4 or 5 passengers/m² in vestibule areas^{C)}; • 300 kg/m² in luggage compartments.

^{A)} The payloads to be taken into account to determine the mass of the mainline and suburban vehicles broadly reflect the normal operating conditions of the member railways of the International Union of Railways (UIC). If the operating conditions differ significantly, these masses may be modified, for example, by increasing or decreasing the number of passengers per square metre in corridors and vestibules.

^{B)} The standing passenger loadings in this table have been derived for UK application using the options available in BS EN 15663.

^{C)} These vehicles are sometimes associated with different classes of passenger travel, i.e. 1st or 2nd class, in which there are different densities of passenger seating, and different numbers of standing passengers.

5.3 Load cases

5.3.1 General

The following load cases 1 and 2 shall be used to ensure that axles are not under designed.

NOTE It is important that these two load cases are considered independently and that the worst load case is used for the axle design against the permissible limits given in this standard.

5.3.2 Load case 1: Straight track case

COMMENTARY ON 5.3.2

If the lateral loads ordinarily applied for outboard journal axles in the high speed curving case were to be applied to inboard journal bearing axles, then it will reduce the overall bending moment when applied to that of the bending moment due to vertical load. Additionally, the vertical forces from the sinusoidal running on straight track should also not be applied.

Parameters for load case 1:

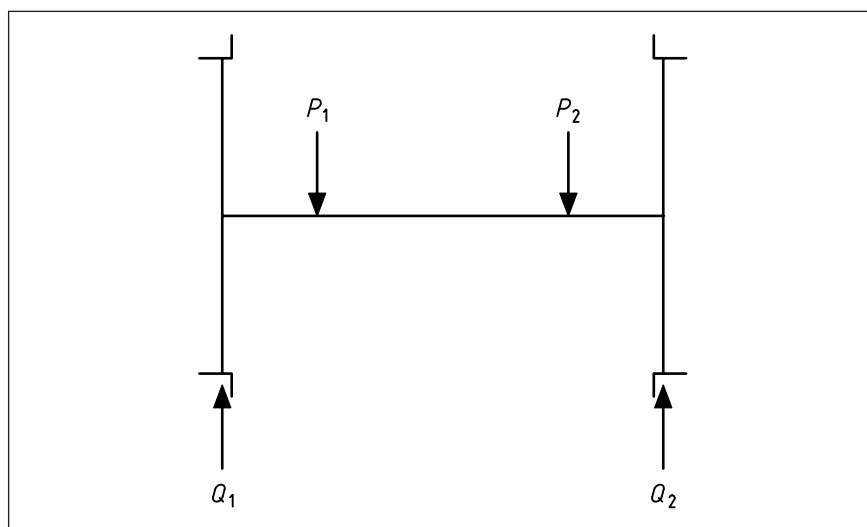
Vertical acceleration:

- Quasi static 1g
- Dynamic 0.6g
- Total 1.6g

Lateral acceleration: not applied.

$P_1 = P_2 = 0.8m_1g$ (for load balance see Figure 2)

Figure 2 Load balance for load case 1



The bending moment M_x in any section shall be calculated from forces P_1 , P_2 , Q_1 , Q_2 and F_i as shown in Figure 3.

The value of the forces F_i shall be determined from multiplying the mass of each unsprung component by an appropriate acceleration level. This will be significantly greater than $1g$ and the level shall be defined in the design.

NOTE 1 This represents the most adverse condition for the axle, i.e.:

- asymmetric distribution of forces;
- the direction of the forces F_i due to the masses of the unsprung components selected in such a manner that their effect on bending is added to that due to the vertical forces.

Figure 3 Forces for calculating bending moment M_x

