AS 7508:2017

Australian STANDARD

Track Forces and Stresses

RISSB
RAIL INDUSTRY SAFETY AND STANDARDS BOARD

Rolling Stock Standard

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Development of the Standard was undertaken in accordance with RISSB's accredited process. As part of the approval process, the Standing Committee verified that proper process was followed in developing the Standard.

RISSB wishes to acknowledge the positive contribution of subject matter experts in the development of this Standard. Their efforts ranged from membership of the Development Group through to individuals providing comment on a draft of the Standard during the open review.

I commend this Standard to the Australasian rail industry as it represents industry good practice and has been developed through a rigorous process.

Paul Daly
Chief Executive Officer
Rail Industry Safety and Standards Board

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Track Forces and Stresses

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Contents

Appendix Contents

1 Introduction

1.1 Purpose

This document describes requirements to limit the forces and contact stresses exerted on the track by rolling stock.

The main purpose of the requirements is to contain the degradation of the track to economically sustainable levels.

1.2 Scope

This document applies to the following types of new and modified rolling stock, or existing rolling stock previously captive to a particular operation which is to be operated in a new area:

(a) locomotive rolling stock.

(b) freight rolling stock.

(c) passenger rolling stock; and

(d) infrastructure maintenance rolling stock.

The document covers the design, construction and maintenance of rolling stock.

Operation of rolling stock is not covered.

Rolling stock used on light rail, cane railway and/or monorail networks are not covered.

1.3 Compliance

There are two types of control contained within Australian Standards developed by RISSB:

(a) mandatory requirements

(b) recommended requirements.

Each of these types of control address hazards that are deemed to require controls on the basis of existing Australian and international Codes of Practice and Standards.

A **mandatory** requirement is a requirement that the Standard provides as the only way of treating the hazard.

Mandatory requirements are identified within the text by the term ‘shall’.

A **recommended** requirement is one where the standard recognises that there are limitations to the universal application of the requirement and that there may be circumstances where the control cannot be applied or that other controls may be appropriate or satisfactory, subject to agreement with the Rail Infrastructure Manager (RIM), Rolling Stock Operator (RSO), and/or Rail Safety Regulator.

Recommended clauses are mandatory unless the RIM or RSO can demonstrate a better method of controlling the risk.

Recommended requirements are to be considered when compliance with the Standard is being assessed.

Recommended requirements are identified within the text by the term ‘should’.

Hazards addressed by this Standard are included in an appendix. Refer to the RISSB website for the latest Hazard Register Guideline: www.rissb.com.au.

Refer to AS 7501 for details on the compliance assessment process.

1.4 Referenced documents

1.4.1 Normative references

The following referenced documents are cited in this Standard for information only:

(a) AS 4292 Railway safety management;

(b) AS 5100.2 Bridge design - Part 2: Design loads;

(c) AS 7501 Railway rolling stock - Rolling stock acceptance;

(d) AS 7509 Railway rolling stock - Dynamic behaviour;

(e) AS 7514 Railway rolling stock - Wheels;

(f) ANZRC Railway Bridge Design Manual, 1974;

(g) Australian Bridge Design Code HB77.8 - Railway Supplement, 1996;

(h) Elkins, J.A. & Gostling, R.J. "A General Quasi-Static Curving Theory for Railway Vehicles", IUTAM Symposium, 1977;

(i) Koffman, J.L. technical paper in Rail Engineering International, 1971.

1.4.2 Informative references

The following referenced documents are used by this Standard for information only:

1.5 Definitions

Axle Load: The weight force exerted on the rail by the two wheels on any axle of a vehicle when stationary on level track.

Bogie Side L/V: Total sum of the lateral forces between the wheels and the rails on one side of a bogie divided by the total sum of the vertical forces on the same wheels of the bogie. Used as an indicator of rail rollover.

Cane Railway Network: A railway system dedicated to hauling harvested sugar cane from farms to a raw sugar factory. Typically 610mm gauge.

Constrained Curving: Condition where the trailing wheelset of a bogie or rigid vehicle wheelbase is in flange contact with the low rail of a curve, in addition to the leading wheelset of the same bogie or rigid vehicle wheelbase being in flange contact with the high rail. See also Free Curving.

Free Curving: Condition where only the leading wheelset of a bogie or rigid vehicle wheelbase is in flange contact in a curve. See also constrained curving.

Freight Rolling Stock: Hauled rolling stock used to transport goods, materials, etc.

Gross Mass: Nominal total mass of rolling stock including maximum payload, provisioning, maximum service capacity of crew and passengers, and wheels at nominal new diameter.

Infrastructure Maintenance Rolling Stock: Track machines and road-rail vehicles. Also, known as on track vehicles.

Interstate Standard Gauge Network: Standard gauge track, mostly under control of ARTC, connecting the mainland Australian state capital cities.

Lateral: The direction across the track, perpendicular to the track centreline and parallel to the line joining the top of the rail heads.

Lateral Track Shifting Force: The lateral force exerted by each wheelset, tending to shift the rails and sleepers laterally in the ballast.

Lateral Wheel To Rail Force: The lateral force between an individual wheel and the rail, including force components at the wheel tread and/or flange, depending on the contact conditions.

Light Rail Network: A passenger-carrying railway system operating with trams or other similar shorter length, lower speed and lower axle-load self-propelled vehicles. Typically used in urban areas and often having a shared right-of-way with road traffic.

Locomotive Rolling Stock: Self-propelled, non-passenger-carrying railway vehicles used for hauling other (typically freight or passenger) rolling stock.

Modified Rolling Stock: Rolling stock that has been altered in such a way as to affect its compliance with the requirements in the standard.

Monorail Network: A passenger-carrying system in which vehicles travel over a single broad beam (rather than two narrow rails connected by sleepers as with conventional railway rolling stock).

Non-conformal Contact: Contact between the wheel throat and rail gauge corner giving a gap of more than 0.4mm between their undeformed shapes.

Operator: The person or body responsible by reason of ownership, control or management, for the provision, maintenance or operation of trains, or a combination of these, or a person or body acting on its behalf.

Passenger Rolling Stock: Rolling stock carrying people and facilities for these people. Excludes dedicated motive power units containing only a driving crew (i.e. locomotives).

P2 Force: Total vertical force (static plus 'low frequency' dynamic forces) per wheel when the rolling stock operates over a defined angular discontinuity (dip) in the rail vertical profile, representing an idealised dipped rail joint. The dynamic component of P2 force is directly proportional to speed.

Rail Contact Stress: Stress in the rail head from local deformation in the region of the contact with the wheel. The magnitude and depth of the maximum stress is dependent on the tangential and normal forces and also the curvature of the wheel and rail surfaces. High rail contact stresses will accelerate the deterioration of the rail through a mechanism termed rolling contact fatigue.

Rail Gauge Corner: The section of the crown of the rail on the side towards the track centreline which has a slope of between 10 degrees and 50 degrees to the line joining the highest points on the two rails.

Rail Infrastructure Manager (RIM): The person or body responsible by reason of ownership, control or management, for the construction and maintenance of track, civil and electric traction infrastructure, or the construction, operation or maintenance of train control and communication systems, or a combination of these; or a person or body acting on its behalf.

Regulator: A government body responsible for ensuring compliance with particular laws, acts, regulations etc., e.g. a rail safety regulator.

Residual Imbalance: Abbreviation of "Residual Dynamic Imbalance Forces" that are the net out-of-balance forces where balance weights have been fitted to partially balance reciprocating masses, such as connecting rods and pistons of steam locomotives.

Road-Rail Vehicle: A vehicle that can travel on a road and can also travel on rail by use of a rail wheel guidance system.

Routine Test: A test conducted on every vehicle that will be registered to operate. See also Type Test.

Shall: The word "shall" indicates that a statement is mandatory for the applicable vehicles.

Should: The word "should" indicates that a statement is a recommendation for the applicable vehicles.

Simulated Service Worn Condition: Rolling stock featuring bogies with worn damping devices and a Worn Wheel Test Profile on all wheelsets.

Tare Mass: The mass of the vehicle in the lightest condition under which it will be operated.

Track Machine: A flange wheeled vehicle used for infrastructure maintenance, construction and inspections. Separate from Freight Rolling Stock (e.g. wagons used for carrying rail, sleepers, spoil, ballast, etc.) and Road-Rail Vehicles.

Type Test: A test conducted on one vehicle which is typical of all vehicles constructed to the same specifications. See also Routine Test.

Unsprung Mass: The mass of a wheel, or wheelset, and other associated components which are not dynamically isolated from the track by vehicle suspension arrangements. See Appendix B.

Vertical: The direction perpendicular to the plane of the rail heads.

Worn Wheel Test Profile: A wheel profile that is a valid representation of the geometry that is expected to develop in service and intended to be used when assessing rolling stock dynamic behaviour.

2 Evaluation and testing

If the rolling stock being assessed is similar to rolling stock that is currently approved to operate on a railway network, then the extent of physical testing necessary to demonstrate compliance with this standard may be reduced following a formal assessment of the possible changes to the forces exerted on the track.
Table A1 provides guidance on the extent of assessment required to ensure that track forces are no worse than the currently operating rolling stock.
The acceptance criteria are given in the following clauses together with acceptable methods for determining whether the track force criteria are met.
With the exception of static axle load and overall vehicle mass, all other requirements may be demonstrated by calculations or type tests rather than routine tests on each vehicle.

3 Axle load and overall vehicle mass

3.1 General

The maximum axle load and overall vehicle mass determined by a static weigh test described in the following clauses shall not exceed limits set by the Rail Infrastructure Manager for the routes over which approval is sought for the rolling stock to operate. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

Unless testing of the first vehicle demonstrates a margin of at least 10% to the acceptance criteria then this test shall be conducted as a routine test (not applicable to freight rolling stock). 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

Note: that the Rail Infrastructure Manager's nominal axle load limits are generally applicable to commonly used axle spacings, however Rail Infrastructure Managers may reduce these limits for unusual axle spacings depending on the designs of bridges along the route.

Note that it is considered good practice to design rolling stock, wherever possible, for symmetric side-side and end-end wheel loads.

Note that variations in side-side or end-end mass of freight rolling stock due to loading, and whether or not such variations are safe for operation, is outside of the scope of this standard.

3.2 Vehicle and test conditions

Weighing for all locomotive rolling stock and infrastructure maintenance rolling stock shall be carried out with the vehicle in the gross mass condition. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

Routine test weighing for freight rolling stock and passenger rolling stock shall be carried out with the vehicle in the tare condition. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

All suspension components shall be fitted and adjusted to their normal operating heights and bump stop clearances. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

Rolling stock with semi-permanent couplers should remain coupled throughout the weighing operation. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

A weighbridge that may be approached from either direction is the preferred equipment for carrying out this test, however other methods may be used if the repeatability of measurements is checked on the vehicle being weighed. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

The weighing equipment shall have a current calibration certificate(s), from an organisation accredited by NATA or an equivalent signatory to the international laboratory accreditation cooperation, covering the measurement range applicable to the test. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

All brakes shall be released on the vehicle being weighed. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

Brakes shall not be applied on any vehicle being weighed, at any time during the weighing operation, including shunting on and off the weighing equipment. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

The vehicle should be run on to the weighing equipment at a speed no greater than 10km/h. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

It is recommended that check rails or similar devices be fitted at either end of the weighing equipment to guide the wheel flanges to a central location between the rails. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

The additional wheel loads on freight rolling stock from the payload shall be calculated and added to the loads measured at tare mass during the routine test weighing, taking into account the likely longitudinal and lateral offsets in the centres of gravity of the proposed loading. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

Bulk commodity freight rolling stock shall also undergo a type test weighing loaded to the full volumetric capacity with the highest density commodity proposed to be carried in the vehicle. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

Any additional wheel loads on passenger rolling stock from the passengers, luggage and provisioning shall be calculated and added to the loads measured at tare mass, taking into account the positioning of these additional masses. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

Passenger rolling stock should also undergo a type test weighing loaded to the equivalent of the maximum passenger, luggage and provisioning capacity. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

3.3 Weighing procedure

The weighing procedure should consist of four independent weighings. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

If a weighbridge is used, then it is recommended that the direction the vehicle approaches the weighbridge be alternated between weighings. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

If individual scales under each wheel are used instead of a weighbridge, then the vehicle should be lifted far enough to unload the suspension before lowering evenly until the full vehicle weight is on the scales. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

If a weighbridge is used, then the track shall be plain track that is straight and level under the whole length of the vehicle being measured. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

If individual scales under each wheel are used instead of a weighbridge, then the scales shall be straight and level under the whole length of the vehicle being measured. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

3.4 Calculations

The total vehicle mass for each weighing, M1, M2, M3 and M4, is calculated by summing the individual wheel load measurements from each weighing.

The average total vehicle mass, Ma, is calculated by averaging the total vehicle masses, as per equation 1.

$$Ma = 0.25\,[M1 + M2 + M3 + M4]$$

Equation 1: Average total vehicle mass

For each wheel in turn, the average wheel load P is determined by averaging that wheel's individual load from each of the weighings, as per Equation 2.

$$P = 0.25\,[P1 + P2 + P3 + P4]$$

Equation 2: Average wheel load

The weight imbalance is defined as the difference between the weight on each individual wheel on a wheelset and the average weight over both wheels as a percentage of the average weight according to Equation 3.

$$\text{Weight imbalance (\%)} = (PL - PR) / (PL + PR)$$

where -

PL, PR = Average wheel load P on left and right side of the same axle.

Equation 3: Weight imbalance on an axle

The average axle load is defined as the average total vehicle mass, Ma, divided by the number of axles according to Equation 4.

$$A = Ma / N$$

where -

N = Total number of axles on vehicle being weighed.

Equation 4: Average axle load

Measurement results obtained at each weighing (i.e. M1-4 and P1-4) should be recorded for completeness.

3.5 Acceptance criteria

The average total vehicle mass, Ma, shall not exceed any maximum mass specified by the Rail Infrastructure Manager. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

The sum of the two wheel loads P at each axle in turn, shall not exceed 102% of the maximum axle load specified by the Rail Infrastructure Manager. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

No individual wheel load P shall exceed 52.5% of the maximum axle load specified by the Rail Infrastructure Manager. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

It is recommended that the weight imbalance between wheels on any axle, calculated in Equation 3, is not greater than 10%.5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

For locomotives with driving axles intended to exert the same tractive effort, in order to maximise tractive effort and minimise wheel spin, it is recommended that the sum of the two wheel loads P at each driving axle in turn, does not deviate by more than + 2% from the average axle load calculated by Equation 4, unless it can be shown that the locomotive design can accommodate a higher deviation. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

In addition to the above criteria, it is recommended that the user asks the Rail Infrastructure Manager if there are additional acceptance limits for their Network, for example:

(a) a lower permitted weight imbalance between wheels on any axle of not greater than 4%.

(b) ±2% for overall vehicle side to side imbalance.

(c) ±6% for trailer axle to axle variation.

(d) weighing uncertainty for average vehicle mass.

4 Rail contact stresses

4.1 Wheel profile

Wheel profiles approved by Rail Infrastructure Managers are listed in AS 7514.

4.2 Wheel diameter

In addition to its effect on contact stresses, wheel diameter affects dissipation of energy from tread braking which also needs to be considered in accordance with AS 7514 Section 5.

Unless otherwise approved by the Rail Infrastructure Manager, the minimum wheel diameter shall be determined by the P/D ratio according to equation 5. 5.26.1.36, 5.2.1.54, 5.2.1.55

4.3 Acceptance criteria

Maximum P/D ratio = 125 kN/m

where -

P = Static load on wheel (kN)

D = Minimum [worn] wheel diameter (m)

Equation 5: Maximum P/D ratio for non-conformal contact

The limit in equation 5 generally applies to conventional rolling stock for conventional rail operations, but the advice of the Rail Infrastructure Manager should be sought, as higher P/D levels may be allowed by Rail Infrastructure Managers based on annual tonnages, consistency of loading, rail and wheel profile characteristics and maintenance practices, and other factors specific to the application.

5 P2 Forces

5.1 General

The P2 force exerted by rolling stock travelling at its nominal maximum speed and nominal gross mass over a dipped weld in one rail shall not exceed the limits specified by the Rail Infrastructure Manager. 5.1.1.4, 5.23.1.22, 5.23.1.23, 5.23.1.24

Table 1 shows typical P2 force limits.

See tab Table 1 - P2 force limits' to see proposed new table.

Network	Rail size	P2 force limit (kN)			
		Locomotives		Any other rolling stock	
	kg/m	0.010 rad dip	0.014 rad dip	0.010 rad dip	0.014 rad dip
Interstate Corridor	<53	(175)	200	(175)	200
	≥53	(250)	295	(192)	230
Hunter Valley	≥53	(250)	295	(192)	230
Sydney	<53	(192)	230	(192)	230
	≥53	(250)	295	(192)	230
Queensland narrow gauge	>41	200		200	
Typical value for all other routes, but check with RIM	≥53	200		200	
Note: Figures in brackets are approximate figures scaled for 0.010 radian dip.					

Table 1: Typical P2 force limited
(but check with RIM for all networks)"

The included angle between the rails at the dipped weld (nominally 0.010 or 0.014 radians) is defined in Figure A1.

When the effective unsprung mass of the rolling stock cannot be calculated readily, or if the P2 force calculated in accordance with Section 5.2 is greater than 90% of the limit for the respective track, physical type testing in accordance with Section 5.3 is recommended. 5.1.1.4, 5.23.1.22, 5.23.1.23, 5.23.1.24

An assessment of the P2 force exerted by the rail guiding wheels of a road-rail vehicle would only be warranted if the static load exerted on any of these wheels exceeds 100kN.

It is not necessary to assess the P2 force exerted by a pneumatic tyred driving wheel of a road-rail vehicle.

5.2 P2 force calculation

The P2 force is to be calculated for the case of the vehicle operating at its nominal maximum speed and nominal gross mass in accordance with Equation 6.

Refer to Appendix B for guidance on how to calculate the effective unsprung mass of the wheel(set).

where -

P_2 = force (kN)

P_0 = vehicle static wheel load (kN)

M_u = vehicle unsprung mass per wheel (kg)

2_a = included angle of dip, nominally 0.01 or 0.014 radians

V = vehicle velocity (m/s)

K_t = equivalent track stiffness (MN/m)

C_t = equivalent track damping (kNS/m)

M_t = equivalent track mass (kg)

Equation 6: P2 Force Calculation

Track parameter	Symbol	Value	Units
Equivalent track stiffness per wheel	K_t	107	MN/m
Equivalent track damping per wheel	C_t	52000	kNS/m
Equivalent track mass per wheel	M_t	200	kg

Table 2: Typical track parameters for equation 6
(but check with RIM for all networks)

5.3 P2 force measurement

A dipped joint having an included angle of nominally 0.010 radians should be located between sleepers as shown in Figure 1 to enable strain gauges to capture the P2 force. 5.1.1.4, 5.23.1.22, 5.23.1.23, 5.23.1.24

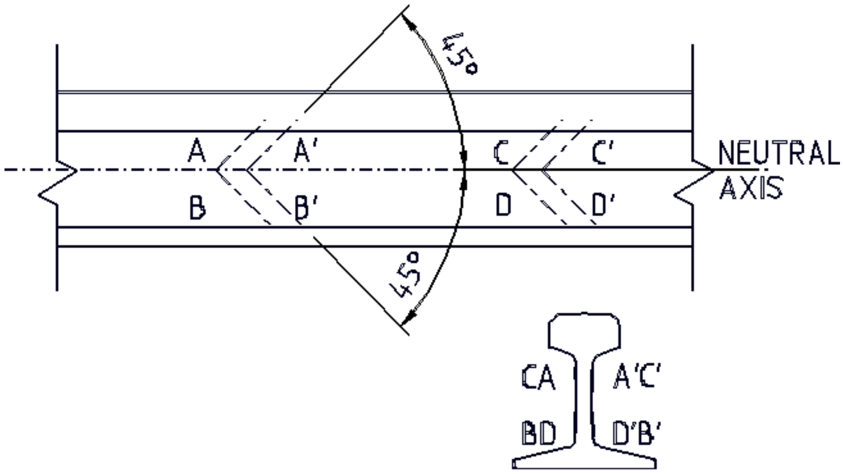

Figure 2: Strain gauge arrangement for P2 force test

A set of strain gauges should be attached to the rail web either side of the dip as shown in Figure 2 and connected in a bridge circuit to measure the P2 force by the difference in vertical shear force between the two measurement planes as shown in Figure 3. 5.1.1.4, 5.23.1.22, 5.23.1.23, 5.23.1.24

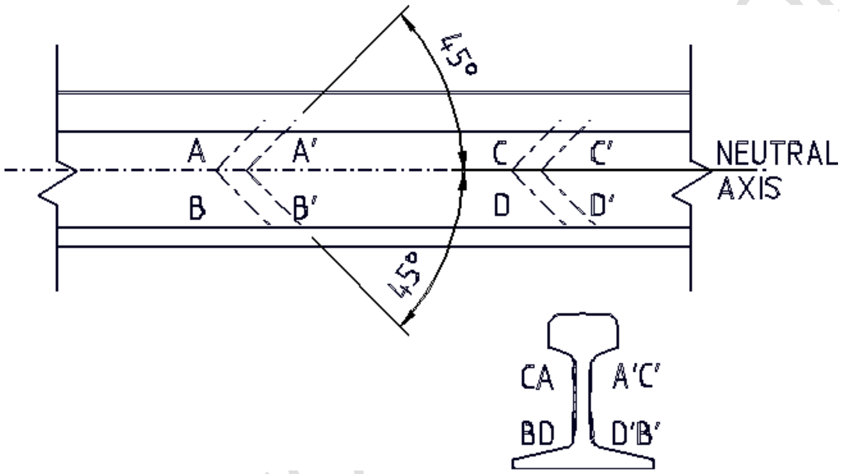

Figure 3: Arrangement of strain gauge bridge

The adjacent sleepers should be far enough away from the measurement planes so that the strains are not distorted (refer to 45 degree lines from end of rail pad on Figure 1. 5.1.1.4, 5.23.1.22, 5.23.1.23, 5.23.1.24

The distance between the dipped joint and the trailing set of strain gauges (length Wq in Figure 1) should be greater than a quarter of a cycle of the resonance of the unsprung mass on the track stiffness. 5.1.1.4, 5.23.1.22, 5.23.1.23, 5.23.1.24

The cycle wavelength can be predicted using Equations 7 and 8.

$$f = \frac{1}{2.\pi}\frac{\sqrt{k}}{m}$$

Where -

f = wave frequency (Hz)

k = effective spring constant (N/m) of the track

m = unsprung mass (kg)

Equation 7: Wave frequency for P2 force

$$L = \frac{v}{f}$$

Where –

L = wavelength (m)

v = vehicle velocity (m/s)

f = wave frequency (Hz)

Wave Frequency (Hz)	Velocity (km/h)	
	50	140
20	0.694	1.944
30	0.463	1.296
40	0.347	0.972
50	0.278	0.778
60	0.231	0.648
70	0.198	0.556

Table 3: Wavelengths (m) for wave frequency vs speed

The distance between the dipped joint and the leading set of strain gauges (length L in Figure 1) is typically minimised to be as close to the dipped joint as possible, in order to fit the strain gauges between the 45 degree lines to the rail pads as shown in Figure 1.

If an existing weld is being used then the joint may lie almost anywhere between the sleepers initially, however its location relative to the strain gauges is determined by Wq and may require the sleepers to be moved to achieve the necessary dimensions.

Calibration of the load bridge may be carried out before testing by rolling the test vehicle, or another vehicle with similar but known axle loading, over the site at a crawl speed allowing the output signal to be calibrated against the axle-loadings.

The calibration test vehicle is to be weighed as accurately as possible.

Strain gauge data should be band pass filtered between 20 and 70 Hz before analysis. 5.1.1.4, 5.23.1.22, 5.23.1.23, 5.23.1.24

The static wheel load is to be added to the measured result to obtain the P2 force.

Provided that the ramp angle is between 0.008 and 0.014 radians, the dynamic component of the P2 force may be scaled linearly by the ratio of the nominal to actual ramp angles.

6 Lateral track shifting forces

6.1 General

Lateral track shifting force shall be determined for all rolling stock that negotiates curves with an unbalanced lateral acceleration of greater than 0.6m/s^2 for 1067mm gauge track or 0.72m/s^2 for 1435mm and 1600mm gauge track. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30, 5.23.1.47, 5.23.1.48, 5.23.1.49

A lateral acceleration of 0.6m/s^2 corresponds to 70mm cant deficiency for 1067mm gauge track, and a lateral acceleration of 0.72m/s^2 corresponds to 110mm cant deficiency for 1435mm gauge track or 123mm for 1600mm gauge track.
Vehicles that do not exceed the indicated line speed for conventional trains typically will not exceed the unbalanced lateral acceleration limit given in 6.1.1 and therefore will not need to be assessed for Lateral Track Shifting Force.
The maximum Lateral Track Shifting Force (S) shall comply with Equation 9. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30, 5.23.1.47, 5.23.1.48, 5.23.1.49

$$Smax = 0.85\ x\ (10 + \frac{A}{3})$$

Where –

Smax = track shifting force limit in kN

A = static axle load in kN

Equation 9 – Track shifting force limit

The lateral track shifting force limit applies to the resultant lateral force derived from the sum of the lateral wheel-rail forces at both wheels of any wheelset of the rolling stock.
The lateral track shifting force limit applies to the maximum sustained force acting over the time interval taken for the rolling stock to travel 2 metres.
Lateral track shifting force assessment may need to include consideration of the new condition as well as any degradation in performance due to wear of suspension components prior to maintenance.
Whilst wear of components can degrade performance in certain areas, the new condition can be worse in others.
Rolling stock being tested for lateral track shifting force in a simulated service worn condition should have damping devices replicated to be worn to within 10% of condemning limits. 5.5.1.52

6.2 Lateral track shifting force determination

Recommended method for determining track shifting force is one or a combination of the following: 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30, 5.23.1.47, 5.23.1.48, 5.23.1.49

(a) instrumented wheelsets which are equipped with strain gauges and processing electronics such that the lateral and vertical forces between each wheel and rail can be measured while the rolling stock is in motion. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30, 5.23.1.47, 5.23.1.48, 5.23.1.49

(b) instrumented track where rails are equipped with strain gauges and processing electronics such that the lateral and vertical forces between each wheel and rail can be measured during the passage of a train. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30, 5.23.1.47, 5.23.1.48, 5.23.1.49

(c) measurement of lateral acceleration of the wheelset and lateral deflection of the primary suspension to determine the force as per Equation 10, provided that the force versus deflection characteristics of the suspension are accurately known. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30, 5.23.1.47, 5.23.1.48, 5.23.1.49.

(d) dynamic computer simulation programs that use numerical integration techniques and that cater for wheel to rail interaction non-linearities and rail vehicle body and suspension non-linearities, provided physical tests have been done to validate the methods used in the modelling and any input data that is not accurately known. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30, 5.23.1.47, 5.23.1.48, 5.23.1.49.

$$Total\ lateral\ force\ per\ wheelset = (m.y + k.y$$

where -

m = effective lateral mass of wheelset

k = lateral stiffness of wheelset relative to bogie frame

ÿ = lateral acceleration of wheelset

y = lateral displacement of wheelset relative to bogie frame

Equation 10: Total lateral force from primary suspension measurements

Dynamic computer simulations should include the case of a vehicle curving at maximum cant deficiency with a superimposed track irregularity that includes longer wavelength irregularities that excite the body yaw and sway modes of the vehicle. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30, 5.23.1.47, 5.23.1.48, 5.23.1.49

Dynamic behaviour simulation software shall be an industry-recognised kinematic tool, shall include the validated modelling of the behaviour of the wheel-rail interface (as evidenced by peer review in technical publications) and shall have been validated as being suitable for simulation of railway vehicle dynamic performance. 5.2.1.3, 5.2.1.4, 5.4.1.2, 5.5.1.52, 5.53.1.9

7 Lateral wheel to rail force

7.1 General

The maximum lateral wheel to rail force shall not exceed the following limits: 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

(a) 84kN for the interstate standard gauge network; 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

(b) 84kN for track with rail sizes of greater than 41 kg/m and resilient rail fastenings, excluding Queensland 1067mm gauge track; 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

(c) 50kN for all other track. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

The lateral wheel to rail force limit applies to the maximum lateral force exerted by any wheel.

The lateral wheel to rail force limit applies to the maximum sustained force acting over the time interval taken for the rolling stock to travel 2 metres.

The maximum bogie side L/V shall not exceed 0.6. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

The maximum bogie side L/V limit of 0.6 applies to the maximum sustained force ratio acting over the time interval taken for the rolling stock to travel 2 metres.

Lateral wheel to rail force assessment may need to include consideration of the new condition as well as any degradation in performance due to wear of suspension components prior to maintenance.

Whilst wear of components can degrade performance in certain areas, the new condition can be worse in others.

Rolling stock being tested for lateral wheel to rail force in a simulated service worn condition should have damping devices replicated to be worn to within 10% of condemning limits. 5.5.1.52

7.2 Lateral wheel to rail force determination

The lateral wheel to rail force should be considered for each wheel of the vehicle. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

The lateral wheel to rail forces should be evaluated over the range of curve radii that will be encountered in service, both at the vehicle’s maximum design cant deficiency and with a cant excess corresponding to a lateral acceleration of 0.73m/s^2 (85mm for 1067mm gauge track, 112mm for 1435mm gauge track, 124mm for 1600mm gauge track). 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

It is suggested that the curves used for evaluating the lateral wheel to rail forces include the entry and exit transitions as well as the body of the curve, with irregularities representative of the most severe likely to be encountered in service such as defined in Sections 6 and 8.2.5 of AS 7509.

It is suggested that evaluations also include the case of a vehicle running over straight and level track that is gauge-widened by 25mm with a superimposed sinusoidal lateral irregularity of the track centreline of amplitude 32mm peak-peak and 12m wavelength.

The recommended method for determining lateral wheel to rail force is one or a combination of the following: 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

(a) instrumented wheelsets which are equipped with strain gauges and processing electronics such that the lateral and vertical forces between each wheel and rail can be measured while the rolling stock is in motion. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

(b) instrumented track where rails are equipped with strain gauges and processing electronics such that the lateral and vertical forces between each wheel and rail can be measured during the passage of a train. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

(c) dynamic computer simulation programs that use numerical integration techniques and that cater for wheel to rail interaction non-linearities and rail vehicle body and suspension non-linearities, provided physical tests have been done to validate the methods used in the modelling and any input data that is not accurately known. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

(d) calculations assuming cylindrical wheel treads with fully saturated creep forces (sliding friction) such as presented by Porter (1935) and Heumann (1954) are suitable for sharp curves where constrained curving conditions occur, e.g. rigid frame or 3-piece bogies on curves in the order of 200m radius or less. 5.23.1.19, 5.23.1.20, 5.23.1.21, 5.23.1.25, 5.23.1.26, 5.23.1.27, 5.23.1.28, 5.23.1.29, 5.23.1.30

8 Rail stress during track work

If Infrastructure maintenance rolling stock during work is capable of inducing stresses in the rail that exceed 90% of the rail yield stress, then an instruction shall be clearly displayed in the operator's manual and near the appropriate controls indicating the correct operating procedure to minimise damage to the rail. 5.23.1.46

9 Residual dynamic imbalance forces

To alleviate vibration at speed on locomotive rolling stock and infrastructure maintenance Rolling Stock, partial balancing of reciprocating masses (such as connecting rods and pistons of steam locomotives) is normally provided using rotating balance weights on the driving wheels. These balance weights cause a dynamic force to be exerted on the track in the vertical direction due to the residual imbalance.

For steam locomotives, and other vehicles having a connecting rod directly coupled to a crankpin on a wheelset, with maximum speeds less than 100km/h, the dynamic force exerted on the track in the vertical direction by any wheels due to residual imbalance shall not be greater than the limit calculated by Equation 11, unless otherwise approved by the Rail Infrastructure Manager. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

$$\text{Permissible Imbalance Force per wheel (N)} = 1.4 \text{ x (Maximum Speed in km/h)}^2$$

Equation 11: Permissible imbalance force for speeds less than 100km/h

For steam locomotives, and other vehicles having a connecting rod directly coupled to a crankpin on a wheelset, with maximum speeds of 100km/h or greater, the vertical imbalance force per wheel shall not exceed 14kN, unless otherwise approved by the Rail Infrastructure Manager. 5.1.1.3, 5.2.1.17, 5.2.1.18, 5.23.1.10, 5.23.1.11, 5.23.1.12, 5.23.1.13

Appendix A Large tables and figures

A.1 Track forces and stresses assessment requirements

Parameter change	Track force criteria to be re-assessed					
	Static axle load and overall vehicle mass	P2 force	Residual imbalance	Rail contact stress	Lateral track shifting force	Lateral wheel to rail force
Increased overall vehicle mass	Yes	Yes	-	Yes	Yes	Yes
Altered mass distribution	Yes	Yes	-	Yes	Yes	Yes
Increased unsprung mass	-	Yes	-	-	-	-
Increased operating speed	-	Yes	Yes	-	Yes	Yes
Increased cant deficiency	-	-	-	-	Yes	Yes
Modified bogie or suspension components	Yes	Yes	-	-	Yes	Yes

Table A1: Requirements for re-assessing rack forces and stresses criteria when comparing against current rollingstock

A.2 Dipped Weld

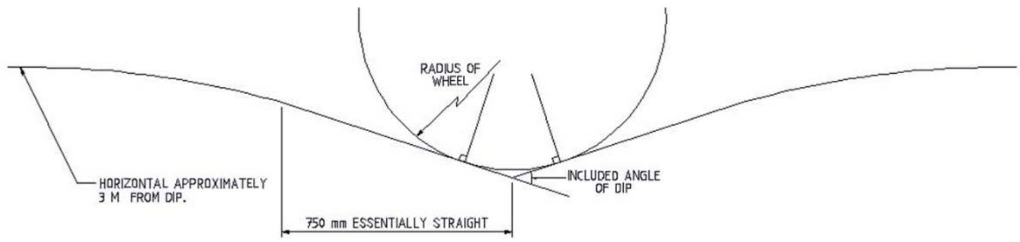

Figure A1: Included angle between rails at dipped weld

Appendix B Unsprung mass

B.1 General

The following items have 100% of their mass included I the wheelset unsprung mass:

(a) Axle;

(b) Wheels;

(c) axle-mounted brake discs;

(d) axle bearings;

(e) non-"swing arm type" axle boxes;

(f) miscellaneous axle-mounted equipment (tachos, earth brush assemblies);

(g) crank pins, eccentrics, crank axles and balance weights on steam locomotives and other vehicles having a connecting rod directly coupled to a crankpin on a wheelset.

The following items are apportioned at 50% of their mass as being unsprung:

(a) primary suspension springs;

(b) primary suspension dampers;

(c) miscellaneous items of symmetrical geometry connecting from the wheelset to the bogie or body (e.g. rods, links, cables).

Swing arm type axle boxes are apportioned based on their centre of gravity distance along the line connecting the axle and pinned joint centrelines.

Axle-mounted components that are off-centre (e.g. gearboxes) are apportioned to each wheel based on their centre of gravity position along the axle centreline.

B.2 Axle-hung traction motors

Equation B1 gives a method for calculating the effective unsprung mass of a wheelset and traction motor assembly, where the traction motor is "axle-hung" (i.e. predominantly supported off the axle).

Axle-hung arrangements are the norm for conventional locomotives in Australia.

The equation takes into consideration motor rotational inertia which increases the effective unsprung mass.

$$m_{\mathrm{u}} \frac{[\{(m_1 = m_3).(I_3 = [4.r]I_2.)\} + m_1.m_3.(L_1)^2]}{[I_3 + m_3.(L_{-1})^2 + (4.r)^2.I_2]}$$

where -

m_u = unsprung mass per wheelset (kg)

m_1 = wheelset mass (kg)

m_3 = motor mass (kg)

I_2 = armature mass moment of inertia (kg.m2)

I_3 = motor case mass moment of inertia (kg.m2)

r = gear ratio (pinion/gear teeth)

L_1 = wheelset to motor centreline distance (m)

Equation B1 – Unsprung mass for axle-hung motors

The effective unsprung mass will be less than that calculated by equation B1 if there is torsional flexibility in the drivetrain between the axle and the motor, e.g. as provided by elastomer isolation.

B.3 Wheelsets with gearbox

Wheelsets with an axle-mounted gearbox, driven via a flexible joint to a bogie or body mounted drive (e.g. traction motor or hydraulic transmission), are another form of driven wheelset arrangement. This type of arrangement is common on higher speed passenger stock and locomotives.

For these arrangements, proportioning the gearbox mass ranges from being 100% unsprung where the gearbox is supported vertically by the axle (and rotational resistance is provided by a reaction link), to proportioning based on the gearbox centre of gravity position relative to the line between the axle centreline and frame connection point where the gearbox is supported vertically at both the axle and at the bogie frame.

The flexible joint (e.g. cardan shaft, flexible blade drive etc.) along with any reaction links to a 100% unsprung gearbox are 50% unsprung.

B.4 Three-piece bogie

Where conventional AAR-based three-piece freight bogies are used, the effective unsprung mass per wheel includes half the mass of the sideframe and one quarter of the mass of sideframe-mounted bogie brake equipment.

Any reduction in the apportioning of sideframe and brake equipment mass through the use of resilient pads between the bearing adaptors and sideframes would require verification by physical testing.

B.5 Rigid frame bogie

A rigid frame undriven bogie with primary suspension would have the unsprung mass determined as per Section B1.

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