



Bridge design

Part 9: Timber



This Australian Standard® was prepared by Committee BD-090, Bridge Design. It was approved on behalf of the Council of Standards Australia on 17 March 2017. This Standard was published on 31 March 2017.

The following are represented on Committee BD-090:

- Australian Industry Group
 - Australian Steel Institute
 - Austroads
 - Bureau of Steel Manufacturers of Australia
 - Cement and Concrete Association of New Zealand
 - Cement Concrete & Aggregates Australia—Cement
 - Concrete Institute of Australia
 - Consult Australia
 - Engineers Australia
 - New Zealand Heavy Engineering Research Association
 - Rail Industry Safety and Standards Board
 - Steel Construction New Zealand
 - Steel Reinforcement Institute of Australia
 - Sydney Trains
-

This Standard was issued in draft form for comment as DR AS 5100.9:2014.

Standards Australia wishes to acknowledge the participation of the expert individuals that contributed to the development of this Standard through their representation on the Committee and through the public comment period.

Keeping Standards up-to-date

Australian Standards® are living documents that reflect progress in science, technology and systems. To maintain their currency, all Standards are periodically reviewed, and new editions are published. Between editions, amendments may be issued.

Standards may also be withdrawn. It is important that readers assure themselves they are using a current Standard, which should include any amendments that may have been published since the Standard was published.

Detailed information about Australian Standards, drafts, amendments and new projects can be found by visiting **www.standards.org.au**

Standards Australia welcomes suggestions for improvements, and encourages readers to notify us immediately of any apparent inaccuracies or ambiguities. Contact us via email at **mail@standards.org.au**, or write to Standards Australia, GPO Box 476, Sydney, NSW 2001.

Australian Standard[®]

Bridge design

Part 9: Timber

First published as AS 5100.9:2017.

COPYRIGHT

© Standards Australia Limited

All rights are reserved. No part of this work may be reproduced or copied in any form or by any means, electronic or mechanical, including photocopying, without the written permission of the publisher, unless otherwise permitted under the Copyright Act 1968.

Published by SAI Global Limited under licence from Standards Australia Limited, GPO Box 476, Sydney, NSW 2001, Australia

ISBN 978 1 76035 722 1

PREFACE

This Standard was prepared by the Standards Australia Committee BD-090, Bridge Design, in response to numerous requests from industry, designers and representatives in the field of Bridge Design, especially those involved with timber bridges.

This Standard is also designated as Austroads publication AP-G51.9-17.

The objectives of the AS(AS/NZS) 5100 series are to provide nationally acceptable requirements for—

- (a) the design of road, rail, pedestrian and bicycle-path bridges;
- (b) the specific application of concrete, steel, composite and timber construction, which embodies principles that may be applied to other materials in association with relevant Standards; and
- (c) the assessment of the load capacity of existing bridges.

The requirements of the AS(AS/NZS) 5100 series are based on the principles of structural mechanics and knowledge of material properties, for both the conceptual and detailed design, to achieve acceptable probabilities that the bridge or associated structure being designed will not become unfit for use during its design life.

The objective of this Standard (AS 5100.9) is to provide engineers with the requirements for the design and construction of timber bridges and associated structures including members that contain steel connections. In addition, the Standard applies to the design of stress laminated timber decks for bridges.

Whereas earlier editions of the Australian Bridge design were essentially administered by the infrastructure owners and applied to their own inventory, an increasing number of bridges are being built under the design-construct-operate principle and being handed over to the relevant statutory authority after several years of operation. This Standard includes clauses intended to facilitate the specification to the designer of the functional requirements of the owner to ensure the long-term performance and serviceability of the bridge or associated structure.

In line with Standards Australia policy, the words ‘shall’ and ‘may’ are used consistently throughout this Standard to indicate respectively, a mandatory provision and an acceptable or permissible alternative.

Statements expressed in mandatory terms in Notes to tables are deemed to be requirements of this Standard.

The term ‘normative’ has been used in this Standard to define the application of the appendix to which it applies. A ‘normative’ appendix is an integral part of a Standard.

CONTENTS

	<i>Page</i>
FOREWORD.....	5
 SECTION 1 SCOPE AND GENERAL	
1.1 SCOPE.....	6
1.2 APPLICATION	6
1.3 NORMATIVE REFERENCES	6
1.4 DEFINITIONS.....	7
1.5 NOTATION.....	11
 SECTION 2 MATERIALS	
2.1 TIMBER.....	16
2.2 CONNECTORS.....	17
2.3 PRESTRESSING TENDONS.....	17
 SECTION 3 DESIGN FOR STRENGTH AND STABILITY	
3.1 DESIGN REQUIREMENTS.....	20
3.2 STRENGTH	20
3.3 STABILITY.....	21
3.4 DURABILITY	21
3.5 DEFLECTION.....	21
3.6 VIBRATION	22
3.7 MODIFICATION FACTORS.....	22
 SECTION 4 DESIGN FOR DURABILITY	
4.1 DURABILITY OF TIMBER	26
4.2 NATURAL DURABILITY AND PRESERVATIVE TREATMENTS	27
4.3 FABRICATION.....	29
4.4 DURABILITY OF STEEL COMPONENTS	29
 SECTION 5 STRESS-LAMINATED TIMBER (SLT)	
5.1 SCOPE OF SECTION	30
5.2 TYPES OF SLT DECKS	30
5.3 DURABILITY REQUIREMENTS	32
5.4 DESIGN REQUIREMENTS.....	33
5.5 METHODS OF STRUCTURAL ANALYSIS.....	34
5.6 SERVICEABILITY—CONTROL OF DEFLECTION	36
5.7 DESIGN CAPACITY	37
5.8 DESIGN OF PRESTRESSING ELEMENTS.....	40
5.9 DESIGN OF ANCHORAGE SYSTEMS.....	42
 SECTION 6 TIMBER MEMBERS	
6.1 SCOPE OF SECTION	45
6.2 METHODS OF STRUCTURAL ANALYSIS.....	45
6.3 DESIGN CAPACITY	46

SECTION 7	CONNECTIONS	
7.1	SCOPE OF SECTION	51
7.2	JOINT GROUPS AND JOINT TYPES.....	51
7.3	REQUIREMENTS FOR CONNECTIONS	52
7.4	DESIGN OF BOLTED JOINTS	54
7.5	DESIGN OF COACH SCREWED JOINTS.....	64
7.6	DESIGN OF DOWELLED FIN PLATE JOINTS.....	67
APPENDIX A	DESIGN PROPERTIES FOR TIMBER	76
BIBLIOGRAPHY		83

FOREWORD

Bridges built in timber are enjoying a significant revival around the world for both pedestrian and vehicular bridges. There are several reasons for this. The growing interest in environmental questions of reducing CO₂ emissions and increasing sustainability has paved the way in part. New and innovative use of timber such as stress-laminated timber (SLT) decks, better connections and engineered materials have played an important role. The fact that reinforced concrete did not turn out to be as durable as first thought is another factor, as many countries experience serious issues with concrete bridges less than 50 years old.

Timber's high strength-to-weight ratio, its environmental sustainability, its ability to capture and store carbon, and its aesthetic appeal, combined with the ease and speed of construction inherent in the off-site prefabrication methods used, make the modern timber bridge an option worth considering. Centuries of experience in the use of timber for bridges coupled with extensive research over the past 25 years has provided the knowledge required to design and construct safe, strong, durable and beautiful modern timber bridges.

Although a girder in a traditional timber girder bridge built in Australia in the past may have had an average life expectancy in the order of 30 years, and may not have been suitable to carry even T44 vehicular loadings when assessed with limit state design methods, bridges designed in accordance with this Standard are designed for the full 100 year design life and for the full vehicular loadings as outlined in AS 5100.2. In order to achieve this, some materials are excluded from use (e.g. unseasoned timber) and timber is excluded from some locations (e.g. in contact with ground).

STANDARDS AUSTRALIA

Australian Standard
Bridge design

Part 9: Timber

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard sets out requirements for the design and construction of timber bridges and associated structures including members that contain steel connections. Requirements are also given for the design of stress-laminated timber (SLT) decks for bridges.

This Standard applies to timber structures made using the following materials:

- (a) Seasoned kiln-dried sawn timber.
- (b) Glued-laminated timber (glulam).
- (c) Structural laminated veneer lumber (LVL).

NOTE: The use of unseasoned timber is not permitted in this Standard.

This Standard applies to structures where timber members are not in contact with the ground or water.

NOTE: For rehabilitation or strengthening of existing timber bridges using other materials (such as round timbers or unseasoned timbers), refer to AS 5100.8.

1.2 APPLICATION

The general requirements of AS 5100.5 pertaining to the design of concrete and of AS/NZS 5100.6 pertaining to the design of steel shall apply, where relevant, in addition to the requirements of this Standard.

1.3 NORMATIVE REFERENCES

The following are the normative documents referenced in this Standard:

NOTE: Documents referenced for informative purposes are listed in the Bibliography.

AS

1110	ISO metric hexagon bolts and screws—Product grades A and B
1110.1	Part 1: Bolts
1111	ISO metric hexagon bolts and screws—Product grade C
1111.1	Part 1: Bolts
1112	ISO metric hexagon nuts
1112.1	Part 1: ISO metric hexagon nuts – Style 1—Product grades A and B
1112.2	Part 2: ISO metric hexagon nuts – Style 2—Product grades A and B
1112.3	Part 3: ISO metric hexagon nuts—Product grade C
1237	Plain washers for metric bolts, screws and nuts for general purposes
1237.1	Part 1: General plan
1237.2	Part 2: Washers for bolts, screws and nuts—Product grades A, C and F

AS	
1604	Specification for preservative treatment
1604.1	Part 1: Sawn and round timber
2082	Timber—Hardwood—Visually stress-graded for structural purposes
2858	Timber—Softwood—Visually stress-graded for structural purposes
3519	Timber—Machine proof grading
5100	Bridge design
5100.1	Part 1: Scope and general principles
5100.2	Part 2: Design loads
5100.5	Part 5: Concrete
5604	Timber—Natural durability ratings
AS/NZS	
1328	Glued laminated structural timber
1328.1	Part 1: Performance requirements and minimum production requirements
1393	Coach screws—Metric series with ISO hexagon heads
1748	Timber—Solid—Stress-graded for structural purposes
1748.1	Part 1: General requirements
3679	Structural steel
3679.1	Part 1: Hot-rolled bars and sections
4063	Characterization of structural timber
4063.1	Part 1: Test methods
4063.2	Part 2: Determination of characteristic values
4357	Structural laminated veneer lumber
4357.0	Part 0: Specifications
4672	Steel prestressing materials
4672.1	Part 1: General requirements
4672.2	Part 2: Testing requirements
5100	Bridge design
5100.6	Part 6: Steel and composite construction
ISO	
7040	Prevailing torque type hexagon nuts (with non-metallic insert)—Property classes 5, 8 and 10
7041	Prevailing torque type hexagon nuts (with non-metallic insert), style 2—Property classes 9 and 12
10511	Prevailing torque type hexagon thin nuts (with non-metallic insert)

1.4 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

1.4.1 A17-grade timber

A stress grade of timber for which the specific suite of characteristic values, given in Appendix A, are applicable.

NOTE: A17-grades are assigned to seasoned hardwood timber in accordance with the grading Standard AS 2082.

1.4.2 Distribution width

The effective width of an SLT deck carrying the load from half of the axle loads of the design vehicle (one line of wheels along the length of the vehicle).

1.4.3 F-grade timber

A stress grade of timber for which the specific suite of characteristic values given in Appendix A are applicable.

NOTE: F-grades are assigned to timber in accordance with the appropriate grading Standard, i.e. AS 2082, AS 2858, AS/NZS 1748.1 or AS 3519.

1.4.4 Hardwood

Wood from trees classified botanically as *Angiosperms*.

NOTES:

- 1 Although the term 'hardwood' is popularly interpreted to indicate the relative hardness of the wood, this interpretation is misleading as the wood of many hardwoods is relatively soft.
- 2 The structural difference between hardwoods and softwoods is that hardwoods have vessels or pores and softwoods do not, that is, the wood of softwoods is non-pored.
- 3 For a depiction of the cell structure of hardwood, see Figure 1.4.4.

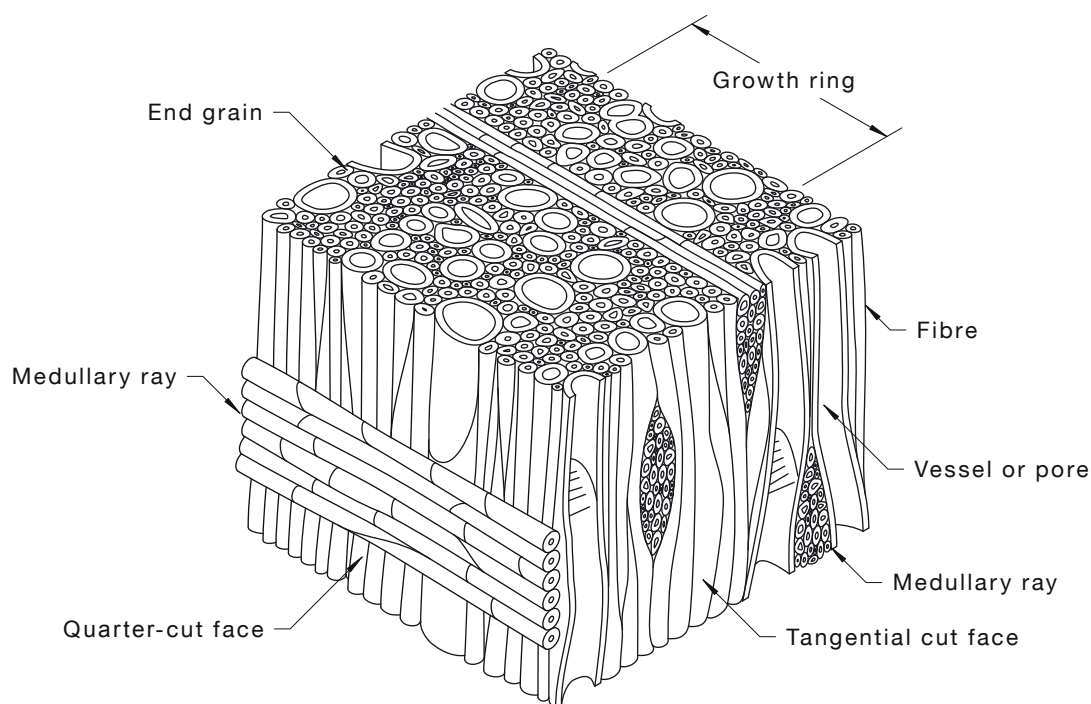


FIGURE 1.4.4 CELL STRUCTURE OF HARDWOOD

1.4.5 Hazard class

A number prefixed with the letter 'H', identifying the degree of hazard, as prescribed in AS 1604.1, for which the timber has been treated, e.g. 'H3'.

1.4.6 Joint group

The classification assigned to a timber species or species group for the purpose of calculating joint capacity.

NOTES:

- 1 Seasoned timber species or species groups are classified into six joint groups (JD1 to JD6).
- 2 The joint group classifications for a range of timber species or species groups are given in Appendix A for hardwoods and softwoods.

1.4.7 MGP grade timber

Machine graded pine graded in accordance with AS/NZS 1748.1 for which the specific suite of characteristic values given in Appendix A are applicable.

1.4.8 Natural durability

The inherent resistance of the outer heartwood of a timber species to decay and insect attack.

1.4.9 Preservative

A chemical or a mixture of chemicals in a form suitable for application to timber in order to preserve it from attack by timber-destroying agents.

1.4.10 Primary structural elements

Members and connections whose failure may result in collapse of a significant portion of a structure.

NOTE: An example is web members in a stress-laminated timber (SLT) deck or timber elements of a truss.

1.4.11 Seasoned timber

Kiln-dried timber in which the average moisture content is nominally between 10% and 15%.

1.4.12 Secondary structural elements

Members and connections whose failure could result in localized collapse.

NOTE: An example is laminate in a stress-laminated timber (SLT) deck.

1.4.13 Softwood

Wood from trees classified botanically as *Gymnospermae*.

NOTES:

- 1 Although the term 'softwood' is popularly interpreted to indicate the relative softness of the wood, this interpretation is misleading as the wood of many softwoods can be relatively hard.
- 2 Commercial timbers of this group are nearly all conifers.
- 3 For a depiction of the cell structure of softwood, see Figure 1.4.13.

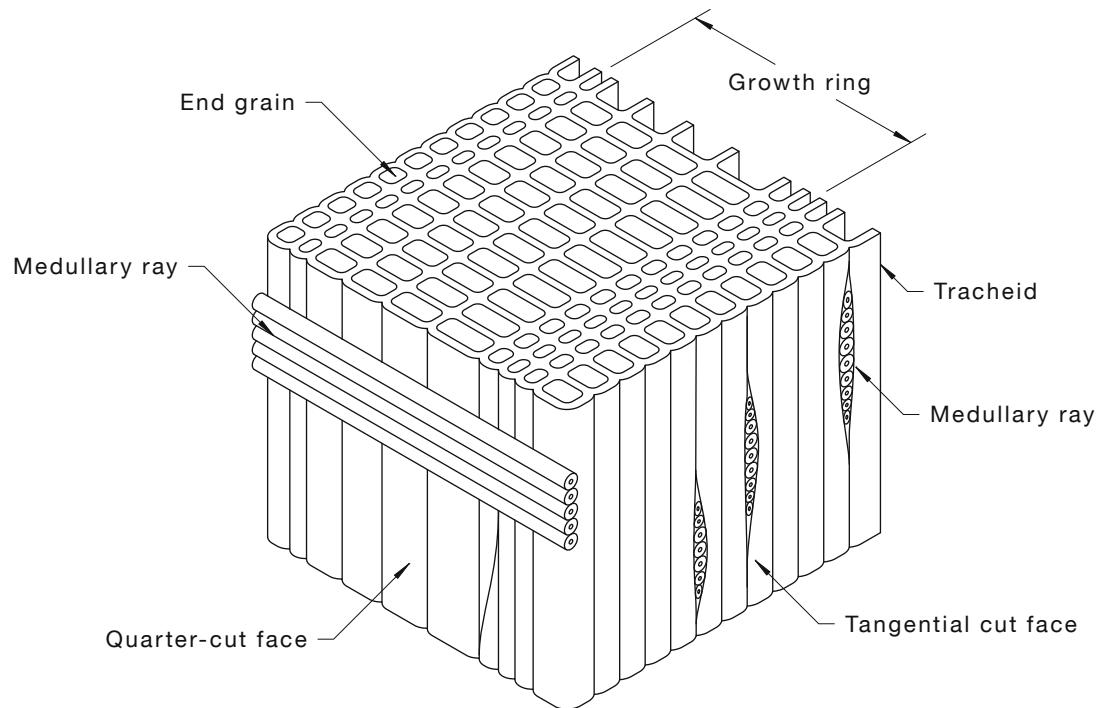


FIGURE 1.4.13 CELL STRUCTURE OF SOFTWOOD

1.4.14 Strength group

The classification assigned to a timber species or species group for the purposes of determining characteristic values for bearing, shear at joint details and tension perpendicular to grain.

NOTES:

- 1 Seasoned timber species or species groups are classified into eight strength groups (SD1 to SD8).
- 2 The strength group classifications for a range of timber species or species groups are given in Appendix A for hardwoods and softwoods.
- 3 Procedures for assigning species to strength group classifications are given in AS 2878.

1.4.15 Stress grade

A classification assigned to structural timber or wood products that indicates a suite of characteristic values of strength and stiffness properties suitable for structural design.

NOTE: Typical examples of stress grades are—

- (a) F-grades for sawn timber;
- (b) MGP grades for sawn timber;
- (c) A17 grades for sawn timber;
- (d) GL grades for glued laminated timber; and
- (e) proprietary stress grades detailed in a manufacturer's product specification.

1.4.16 Stress laminated timber (SLT) deck

A timber deck where dimensioned pieces of timber are placed side by side and held together by pressure applied using steel bars or strands.

1.4.17 Structural laminated veneer lumber (LVL)

An assembly of veneers laminated with adhesive, in which the grain direction of the outer veneers, and most of the other veneers, is in the longitudinal direction, manufactured in conformance with the requirements of AS/NZS 4357.0, and intended for structural application.

1.4.18 Tendon

Wire, strand or bar (or any discrete group of such wires, strands or bars) that is intended to be pretensioned or post-tensioned.

1.5 NOTATION

Symbols used in this Standard are listed below.

Unless contrary intention appears, the following applies:

- The symbols used in this Standard shall have the meanings ascribed to them below, with respect to the structure, or member, or condition to which a clause is applied.
- Where non-dimensional ratios are involved, both the numerator and denominator are expressed in identical units.
- The dimensional units for length, force and stress in all expressions or equations shall be taken as millimetres (mm), newtons (N) and megapascals (MPa) respectively.
- An asterisk (*) placed after a symbol as a superscript (e.g. M^*) denotes a design action effect due to the design load.

Symbol	Definition
A	cross-sectional area
A_c	cross-sectional area of compression member
A_l	bearing area for loading parallel to grain
A_p	cross-sectional area of the prestressing element; <i>or</i>
	bearing area for loading perpendicular to the grain; <i>or</i>
	bearing area behind bearing plate
A_s	shear plane area
A_{sj}	transverse shear plane area at joint section
A_t	net cross-sectional area of tension member
A_w	effective area of a washer for bearing
b	breadth of member; <i>or</i>
	overall width of the deck
b_{eff}	effective timber thickness
C_{bj}	butt joint modification factor
$C_{bj(min)}$	minimum butt joint modification factor
D	diameter of fastener
D_w	distribution width
d	depth of member; <i>or</i>
	depth of SLT deck
d_{ch}	depth of steel channel (PFC)
d_{ch-c}	clear depth of steel channel (PFC) between fillet radii
d_h	diameter of the hole to accommodate the prestressing element
d_p	depth of SLT plate deck, or flange thickness of T-beam or cellular deck

d_s	distance measured perpendicular to grain from the centreline of the loaded connector to the side edge of the timber, towards which the load is being applied
d_t	largest dimension of the cross-section for a tension member
E	modulus of elasticity
E_{flange}	modulus of elasticity of flange material
E_p	modulus of elasticity of tendons
E_{web}	modulus of elasticity of web material
EMC	equilibrium moisture content
f_{pb}	characteristic minimum breaking strength of prestressing element
f_{py}	yield strength of tendons
f_y	yield strength of the steel bearing plate
f'_b	characteristic value in bending for the material
f'_{b-fl}	characteristic value in bending for the flange material
f'_{b-w}	characteristic value in bending for the web material
f'_c	characteristic value in compression parallel to grain
f'_{cj}	characteristic value for bolts in bearing parallel to the grain
f'_l	characteristic value for bearing parallel to grain
f'_p	characteristic value for bearing perpendicular to grain
f'_{pj}	characteristic bearing capacity for timber in joints
f'_s	characteristic value in shear
f'_{sj}	characteristic value in shear for timber in joints
f'_t	characteristic value in tension parallel to grain
f'_{tp}	characteristic value in tension perpendicular to the grain
I	second moment of area about the relevant axis
I_x	second moment of area
j_2	modification factor for creep
k	geometric plate bearing factor
k_e	effective length factor
k_1	duration of load modification factor
k_4	moisture condition modification factor
k_6	temperature effects modification factor
k_9	strength sharing modification factor
k_{10}	column stability factor
k_{11}	size modification factor
k_{11-fl}	size modification factor for flange material

k_{11-w}	size modification factor for web material
k_{12}	beam stability factor
k_{13}	end grain modification factor
L	effective design span
L_a	length of anchorage plate
L_{ay}	distance between lateral restraints
L_{az}	distance between torsional restraints along a beam
L_c	length from centre-to-centre of intersection with supporting members
L_p	length of bearing plate
l_p	depth of penetration of the threaded portion of the coach screw into the innermost member
l_{par}	required end distance for a member in tension and compression
M^*	design action effect in bending about the appropriate axis
M_x^*	design action effect in bending about the major principal x-axis
M_y^*	design action effect in bending about the minor principal y-axis
N^*	design action effect in compression
N_j^*	design action effect in direct tension on the joint
N_1^*	design bearing force parallel to the grain
N_p^*	design bearing force perpendicular to the grain
N_t^*	design action effect in tension
N_θ^*	design bearing force at an angle θ to the grain
$N_{d,tb}$	design capacity of bolt in tension
$N_{d,tc}$	tensile capacity of a single coach screw
n	frequency of butt joints (number of laminates between butt joints plus 1); <i>or</i> number of bolts, coach screws or dowels in a connection
P	force applied to prestressing element during stressing operation
$P_{(max)}$	maximum jacking force
$P_{(min)}$	minimum allowable force in prestressing element during service life
Q_k	characteristic capacity for an axially loaded coach screw
Q_{kl}	characteristic capacity for a laterally loaded single bolt or dowel bearing parallel to the grain and acting in single shear
Q_{kp}	characteristic capacity for a laterally loaded single bolt or dowel bearing perpendicular to the grain and acting in single shear
Q_{sk}	characteristic capacity for a laterally loaded single bolt, dowel or coach screw in a joint system; <i>or</i> characteristic capacity for a laterally loaded single bolt in a bolted joint system

Q_{skl}	system capacity for a laterally loaded bolted or dowelled connection loaded parallel to the grain
Q_{skp}	system capacity for a laterally loaded bolted or dowelled connection loaded perpendicular to the grain
R_u	nominal capacity
r	ratio relevant to load combination under consideration
S^*	design action effects
S_b	beam stability coefficient
S_c	column stability coefficient
S_p	centre to centre spacing of prestressing elements
S_{pb}	distance along the length of an SLT deck between butt joints in a group of four adjacent laminates (see Figure 5.4.3)
t_p^*	combined thickness of bearing plate and PFC web
t_p	thickness of bearing plate; <i>or</i>
	depth of penetration of the coach screw
t_w	thickness of web for T-beam SLT decks and cellular SLT decks; <i>or</i>
	thickness of web of steel channel (PFC)
t_{wE}	effective width of web using transformed section
V^*	design shear force
V_j^*	design action effect in shear on the joint
W_a	height of anchorage plate
W_p	height of bearing plate
w_f	width of flange for T-beam SLT decks and cellular SLT decks
y	distance from top face of deck to centroid of deck for T-beam SLT deck
Z	section modulus
Z_{bottom}	section modulus of the bottom of the T-beam for a single cell
Z_{top}	section modulus of the top of the T-beam for a single cell
θ	angle between direction of grain and direction of bearing force applied
ρ_b	beam material constant
ρ_c	column material constant
ρ_h	density of hardwood timber
ρ_s	density of softwood timber
$\sigma_{(min)}$	minimum uniform pressure in service
$\sigma_{d(max)}$	maximum uniform pressure at construction
$\sigma_{d(min)}$	minimum uniform pressure at construction
ϕ	capacity reduction factor
ϕ_{fl}	capacity reduction factor for flange material
ϕ_w	capacity reduction factor for web material

ϕM	design bending capacity
ϕM_x	design bending capacity about the major principal x-axis
ϕM_y	design bending capacity about the minor principal y-axis
ϕN	design axial capacity
$\phi N_{d,j}$	design capacity for a Type 2 joint (see Clause 7.4.3.3)
ϕN_l	design capacity for bearing parallel to the grain
ϕN_p	design capacity for bearing perpendicular to the grain
ϕN_t	design capacity of member in tension
ϕN_x	design capacity in compression for buckling about the x-axis
ϕN_y	design capacity in compression for buckling about the y-axis
ϕN_θ	design capacity for bearing at an angle θ to the grain
ϕR_u	design capacity
ϕV	design shear capacity
$\phi V_{d,j}$	design capacity for a Type 1 joint (see Clause 7.4.3.2)

SECTION 2 MATERIALS

2.1 TIMBER

2.1.1 General

All timber used in accordance with this Standard shall be heart-free and shall comply with the requirements of the appropriate Standards, as follows:

- (a) *Visually graded sawn timber* AS 2082 or AS 2858.
- (b) *Mechanically graded timber* AS/NZS 1748.1.
- (c) *Proof-graded timber* AS 3519.
- (d) *Structural laminated veneer lumber* AS/NZS 4357.0.
- (e) *Glued laminated timber* AS/NZS 1328.1.
- (f) *Other timber products or grades* Timber products or grades not listed in this Standard may have properties established by testing and evaluation methods consistent with those described in the AS/NZS 4063 series. In addition, for other timber-based products, modification factors for duration of load effect for strength and stiffness shall be determined based on authoritative research. Consideration shall also be given to the determination of the structural durability of adhesives used for manufacture.

Timber, treated by impregnation with waterborne chemicals such as preservatives, is classified as unseasoned timber unless seasoning is specified. Such timber shall be dried after treatment, and shall be re-graded upon completion of seasoning.

2.1.2 Engineered wood products

2.1.2.1 Glued-laminated timber

Glued-laminated timber shall be bonded with Type 1 adhesive specified in accordance with AS/NZS 1328.1.

2.1.2.2 Laminated veneer lumber (LVL)

Structural LVL is usually manufactured with the grain of all veneers orientated in the longitudinal direction; however, in some instances, special constructions may incorporate cross-band veneers. For LVL not containing cross-band veneers, section properties shall be calculated using the actual cross-section dimensions.

For LVL containing cross-band veneers, the thickness of an individual ply shall be assumed to be in proportion to its nominal thickness, as the finished minimum LVL thickness is to the total of the nominal veneer thicknesses. Section properties for cross-banded LVL shall be determined as follows.

Any veneers with nominal grain direction at right angles to the direction of stress shall be ignored for the calculation of area, first moment of area and second moment of area when assessing the bending, tension and compressive capacity and flexural rigidity.

NOTE: It is appropriate to assume the full sectional area is effective in resisting in-plane shear.

2.1.3 Density

2.1.3.1 Hardwood

The density of hardwood timber (ρ_h) shall be taken either—

- (a) as not less than 1100kg/m³; or
- (b) from Table A6, Appendix A, for the relevant species.

2.1.3.2 Softwood

The density of softwood timber (ρ_s) shall be taken either—

- (a) as not less than 700kg/m³; or
- (b) from Table A7, Appendix A, for the relevant species.

2.2 CONNECTORS

Steel bolts, nuts, washers, coach screws and dowels shall comply with AS 1110.1, AS 1111.1, AS 1112.1, AS 1112.2, AS 1112.3, AS 1237.1, AS 1237.2, AS/NZS 1393, AS/NZS 3679.1, ISO 7040, ISO 7041 and ISO 10511, as applicable.

2.3 PRESTRESSING TENDONS

2.3.1 Properties of tendons

2.3.1.1 Strength

The characteristic minimum breaking strength (f_{pb}) for commonly used tendons shall be as specified in Table 2.3.1.1.

NOTE: For tendons of dimensions not covered in Clause 2.3.1, refer to AS/NZS 4672.1.

The yield strength of tendons (f_{py}) shall be taken either as the 0.1% proof stress as specified in AS/NZS 4672.1, or determined by test data. In the absence of test data it shall be taken as follows:

- (a) For all grades of strand 0.82 f_{pb} .
- (b) For hot-rolled bars (super grade)..... 0.81 f_{pb} .

TABLE 2.3.1.1
TENSILE STRENGTH OF COMMONLY USED STRAND AND BAR

Material type and Standard	Nominal diameter mm	Area mm ²	Characteristic minimum breaking load kN	Characteristic minimum breaking strength (f_{pb}) MPa
7 wire ordinary strand, AS/NZS 4672.1	9.5	55.0	102	1850
	12.7	98.6	184	1870
	15.2	140	250	1790
	15.2	143	261	1830
7 wire compacted strand, AS/NZS 4672.1	15.2	165	300	1820
	18.0	223	380	1700
Hot-rolled bars, AS/NZS 4672.1 (super grade only)	26	562	579	1030
	29	693	714	1030
	32	840	865	1030
	36	995	1025	1030
	40	1232	1269	1030

2.3.1.2 Modulus of elasticity

The modulus of elasticity of commonly used tendons (E_p) shall be—

- (a) taken as equal to—
 - (i) for stress-relieved steel strand to AS/NZS 4672.1 200 ±5 GPa; or
 - (ii) for hot-rolled high tensile alloy steel bars to AS/NZS 4672.1.... 205 ±10 GPa; or
- (b) determined by test.

2.3.2 Materials for ducts, anchorages and tendons**2.3.2.1 Ducts**

Sheaths and removable formers used to form ducts shall be capable of maintaining their required cross-section and profile during construction.

2.3.2.2 Anchorages

The quality and properties of anchorages shall be established by testing and shall be certified where required by the authority. A test report or test certificate shall include results in relation to the following:

- (a) Tests performed to verify the design properties of materials by a laboratory accredited by signatories to the International Laboratory Accreditation Corporation (ILAC) through their Mutual Recognition Agreement (MRA), in the field and class of testing, on behalf of the manufacturer for the purpose of establishing compliance with this Standard. The test report or test certificate shall include the appropriate logo or further details of the ILAC (MRA) signatory.

NOTE: In Australia, an ILAC (MRA) accredited body is the National Association of Testing Authorities (NATA) and in New Zealand is the International Accreditation New Zealand (IANZ).

- (b) Additional tests on materials not considered in this Standard but as agreed between the purchaser and manufacturer.
- (c) Tests and/or certificates on the design properties of materials issued and/or verified by a third party certification body.

2.3.2.3 Tendons

Prestressing tendons shall comply with AS/NZS 4672.1 and AS/NZS 4672.2.

Tendons shall not be galvanized.

2.3.3 Construction requirements for tendons**2.3.3.1 Fabrication**

The fabrication of tendons shall comply with the following:

- (a) Cutting of tendons shall be carried out so damage to tendons, ducts and anchorages is avoided.
- (b) Tendons shall not be welded.
- (c) Prestressing bars shall be within manufacturing tolerances and not bent in the threaded portion.

Small adjustments on site shall be carried out cold. If the bar temperature is lower than 10°C, the bar temperature shall be raised above this value by means of steam or hot water.

2.3.3.2 Protection

Before stressing, tendons shall be protected from stray current arcing and splashes from the cutting operation of an oxy-acetylene torch or an arc-welding process.

The threaded ends of prestressing bars shall be provided with suitable protection, at all times.

If tendons are to have a coating or wrapping, such coating or wrapping shall be inert with respect to both the steel and the timber.

After stressing and anchoring, all tendons and anchorages shall be protected from physical damage and corrosion.

2.3.3.3 Tensioning

Tensioning of tendons shall be carried out in a safe manner and in accordance with the following:

- (a) The stressing procedure shall ensure the force in a tendon increases at a uniform time rate and that the force is transferred gradually to the timber.
- (b) The prestressing force applied to the tendon shall be measured at the jack by measuring the jack pressure. The prestressing force shall be measured to an accuracy of $\pm 3\%$.
- (c) The tendon extension shall be measured.
- (d) A check shall be made for each tendon, on the correlation between the measured extension and the calculated extension derived from the prestressing force, using the load-elongation curves for the tendons and assumed friction values for the cable. Any disparity between the two figures greater than 10% of the calculated extension shall be investigated.
- (e) No stressing shall be carried out when the air temperature is lower than 0°C .

2.3.3.4 Maximum jacking forces

The maximum jacking force $[P_{(\text{max})}]$ applied to a tendon during the stressing operation shall not exceed—

- (a) for pretensioned tendons $0.80f_{pb}A_p$;
- (b) for stress-relieved post-tensioned tendons $0.85f_{pb}A_p$; or
- (c) for post-tensioned tendons and bars not stress-relieved $0.75f_{pb}A_p$.

SECTION 3 DESIGN FOR STRENGTH AND STABILITY

3.1 DESIGN REQUIREMENTS

3.1.1 Aim

The aim of structural design shall be to provide a structure that does not reach any of the limit states defined in AS 5100.1, which requires that the structure be durable, serviceable and adequately strong while serving its intended function. The structure shall also satisfy other relevant requirements such as robustness, ease of construction and economy.

3.1.2 Design for ultimate limit states (ULSs)

The structure, as a whole, and its components shall be designed for the requirements of all the ULSs specified in AS 5100.1.

3.1.3 Design for serviceability limit states (SLSs)

The structure and its components shall be designed for serviceability by controlling deflection and vibration in accordance with the requirements of Clauses 3.5 and 3.6.

3.2 STRENGTH

The structure and its components shall be designed for strength as follows:

- (a) The most adverse design loads shall be determined in accordance with AS 5100.2.
- (b) The design action effects (S^*) resulting from the design loads at the ULS shall be determined by an analysis in accordance with Sections 5 to 7, as appropriate.
- (c) The design capacity (ϕR_u) shall be determined from the nominal capacity (R_u) determined from Sections 5 to 7, as appropriate, where the capacity reduction factor (ϕ) shall not exceed the appropriate value given in Table 3.2.
- (d) All members and connections shall be proportioned so that the design capacity (ϕR_u) is not less than the design action effects (S^*), i.e. $S^* \leq \phi R_u$.

TABLE 3.2
CAPACITY REDUCTION FACTORS

Type of material or fastener		Application of structural member	
		Category 1	Category 2
		Secondary structural elements	Primary structural elements
		Capacity reduction factor (ϕ)	
1 Structural timber material and applicable standard			
(a)	Sawn timber including MGP15, A17, and F-grades F17 and higher	0.85	0.75
(b)	Sawn timber including F-grades lower than F17 and MGP10 and MGP12	0.70	0.60
(c)	Glue-laminated timber to AS/NZS 1328.1	0.85	0.75
(d)	Structural laminated veneer lumber to AS/NZS 4357.0	0.90	0.80
2 Type of fastener and applicable standard			
(a)	Bolts conforming to AS 1110.1 or AS 1111.1		
	- M16 and smaller	0.80	0.75
	- larger than M16	0.65	0.60
(b)	Coach screws conforming to AS/NZS 1393		
	- M16 and smaller	0.80	0.75
	- larger than M16	0.65	0.60
(c)	Dowels conforming to AS/NZS 3679.1 for rounds		
	- ϕ 12 and smaller	0.80	0.75

NOTE: For definitions of primary and secondary structural elements, see Clause 1.4.10 and Clause 1.4.12 respectively.

3.3 STABILITY

The structure as a whole and its parts shall be designed to maintain stability against sliding, overturning and uplift, as specified in AS 5100.1.

3.4 DURABILITY

The structure and its components shall be designed for durability in accordance with Section 4.

3.5 DEFLECTION

3.5.1 General

The deflections of timber bridges under service conditions shall comply with the deflection limits specified in AS 5100.2. Deflections shall be calculated by an elastic analysis in accordance with Clause 6.2.2 and modified in accordance with Clause 3.5.2 as appropriate.

3.5.2 Modification factor for creep

The calculated elastic deflection due to bending or compression shall be multiplied by the modification factor for creep (j_2) given in Figure 3.5.2, up to a maximum value of 2.0.

Where there is a recovery period of more than 10 times the period of the applied action between applications, the creep component of deformation for that action type shall be assumed to be totally covered.

NOTE: The duration of actions specified for calculation of design capacity are not intended for estimation of deformation.

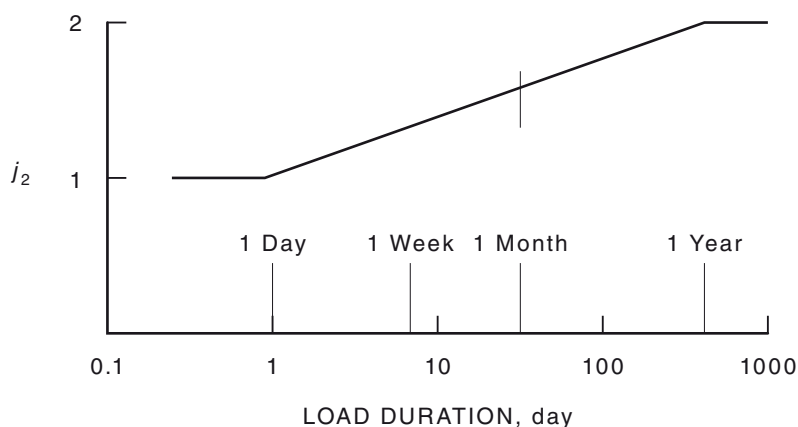


FIGURE 3.5.2 MODIFICATION FACTOR FOR CREEP (j_2)

3.6 VIBRATION

The design of timber bridges for vibration under service conditions shall comply with the vibration requirements specified in AS 5100.2.

3.7 MODIFICATION FACTORS

3.7.1 Duration of load

The effect of duration of load on strength shall be as given by the modification factor k_1 in Table 3.7.1. In checking the design capacity, design combinations shall be considered.

For any given combination of loads of differing duration, the factor k_1 to be used shall be as appropriate to the action that is of the shortest duration.

For the purposes of interpretation in the selection of load-duration factors for calculation of design capacity, the following shall apply:

- Permanent actions including dead loads and superimposed loads, as well as prestress in stress-laminated timber (SLT) decks, shall be considered to be of 'permanent duration'.
- Serviceability vehicle or pedestrian loads that are applied at frequent but irregular intervals, such that the structure is loaded well below the nominal imposed action for most of each day, shall be considered to be of 'five months duration'.
- Imposed actions, such as those arising during construction, and imposed actions that are infrequent (e.g. ultimate pedestrian loads) and applied for periods of a few days and at infrequent intervals, shall be considered to be of 'five days duration'.
- Ultimate actions from road traffic, rail traffic, collision loads, earthquakes, floods or wind shall be considered to be of 'five minutes duration'.

TABLE 3.7.1
DURATION OF LOAD MODIFICATION FACTOR

Effective duration of peak action	k_1	
	For the strength of timber	For the strength of connections using laterally loaded fasteners
5 minutes	1.00	1.00
5 hours	0.97	0.86
5 days	0.94	0.77
5 months	0.80	0.69
Permanent	0.57	0.57

NOTE: The effective duration of a peak action refers to the cumulative duration for which the peak action occurs.

3.7.2 Moisture condition

The value of k_4 shall be 1.0, except where seasoned timber is subjected to conditions in which its average moisture content for a 12 month period is expected to exceed 15%.

In such circumstances (excluding LVL), the value of k_4 shall be determined as follows:

$$k_4 = 1 - 0.3 \left(\frac{EMC - 15}{10} \right) \geq 0.7 \quad \dots 3.7.2$$

where

k_4 = moisture condition modification factor

EMC = equilibrium moisture content, which is the highest annual average moisture content that the timber will attain in service, which is up to 25% for locations within 100km of the coast with high humidity and poor ventilation, or 18% for well-ventilated locations

Where LVL will be subjected to an average moisture content exceeding 15% for a 12 month period, the modification factors for strength (k_4) given in Table 3.7.2 shall be used.

TABLE 3.7.2
MOISTURE CONTENT FACTORS FOR LVL

Property	Equilibrium moisture content (EMC)		
	$\leq 15\%$	15% to 25%	$\geq 25\%$
Bending and compression	$k_4 = 1.0$	$k_4 = 1.45 - 0.03EMC$	$k_4 = 0.7$
Tension and shear	$k_4 = 1.0$	$k_4 = 1.30 - 0.02EMC$	$k_4 = 0.8$

3.7.3 Temperature effects

Where seasoned timber is used in structures erected in coastal regions of Queensland north of latitude 25°S, and all other regions of Australia north of latitude 16°S, the strength shall be modified by a factor k_6 equal to 0.9. Otherwise, k_6 shall be equal to 1.0.

3.7.4 Strength sharing effects for SLT decks

The strength sharing modification factor (k_9) for SLT decks, excluding web elements, shall be obtained from Table 3.7.4.

TABLE 3.7.4
MODIFICATION FACTOR STRENGTH SHARING

Material	k_9
Sawn timber including F-grades, MGP and A17	1.5
LVL and glulam	1.0

3.7.5 Size effects

Except where in-grade testing demonstrates a different effect of size, the capacity in bending and tension for solid timber shall be modified by the size modification factor k_{11} as follows:

- For bending, k_{11} shall be the lesser of $(300/d)^{0.167}$ or 1.0 (where d is the depth), except for glulam where k_{11} shall be 1.0.
- For tension parallel to grain, k_{11} shall be the lesser of $(150/d_t)^{0.167}$ or 1.0 (where d_t is the largest dimension of the cross-section).

3.7.6 Beam stability factor

In the design of slender bending members, a factor k_{12} shall be used to allow for the effects of slenderness on strength. The beam stability factor (k_{12}) shall be determined as follows:

- For $S_b \leq 10$

$$k_{12} = 1.0 \quad \dots 3.7.6(1)$$
- For $10 \leq S_b \leq 20$

$$k_{12} = 1.5 - 0.05S_b \quad \dots 3.7.6(2)$$
- For $S_b \geq 20$

$$k_{12} = \frac{200}{S_b^2} \quad \dots 3.7.6(3)$$

where

$$S_b = \text{beam stability coefficient determined in accordance with Clause 3.7.7}$$

3.7.7 Beam stability coefficient (S_b)

The beam stability coefficient (S_b) for sections bending about their minor axis shall be 0.

The beam stability coefficient (S_b) for a rectangular section bending about its major principal x-axis shall be calculated in accordance with relevant equations from Table 3.7.7.

Values for the beam material constant (ρ_b) shall be calculated in accordance with Paragraph A3, Appendix A.

TABLE 3.7.7
BEAM STABILITY COEFFICIENTS FOR RECTANGULAR SECTIONS

Description	Diagram	S_b
Beams that bend about their major axis, being loaded along their compression edge, and having discrete lateral restraints along the compression edge at distances L_{ay} apart.		$1.25\rho_b \frac{d}{b} \sqrt{\frac{L_{ay}}{d}}$
Beams that bend about their major axis, being loaded along their tension edge, and having discrete lateral restraints along the tension edge at distances L_{ay} apart.		$\rho_b \left(\frac{d}{b}\right)^{1.35} \left(\frac{L_{ay}}{d}\right)^{0.25}$
Beams that bend about their major axis having a continuous lateral restraint system along the compression edge at distances L_{ay} apart.		$S_b = 0$ if $\frac{L_{ay}}{d} \leq 64 \left(\frac{b}{\rho_b d}\right)^2$
Beams that bend about their major axis having a continuous lateral restraint system along the tension edge at distances L_{ay} apart.		$S_b = 2.25\rho_b \frac{d}{b}$ if $\frac{L_{ay}}{d} \leq 64 \left(\frac{b}{\rho_b d}\right)^2$
Beams that bend about their major axis having a continuous lateral restraint system along the tension edge and equally spaced torsional restraints at distances L_{az} apart.		$S_b = \frac{\rho_b 1.5 d/b}{\sqrt{\left(\frac{\pi d}{L_{az}}\right)^2 + 0.4}}$ if $\frac{L_{ay}}{d} \leq 64 \left(\frac{b}{\rho_b d}\right)^2$

LEGEND:

- b = breadth of member
 d = depth of member
 L_{ay} = distance between lateral restraints
 L_{az} = distance between torsional restraints along a beam
 S_b = beam stability coefficient
 ρ_b = beam material constant