

Australian/New Zealand Standard™

**Composite structures—Composite
steel-concrete construction in buildings**



AS/NZS 2327:2017

This Joint Australian/New Zealand Standard was prepared by Joint Technical Committee BD-032, Composite Construction. It was approved on behalf of the Council of Standards Australia on 25 October 2017 and by the New Zealand Standards Approval Board on 6 November 2017.
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Consult Australia
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This Standard was issued in draft form for comment as DR AS/NZS 2327:2016.

Australian/New Zealand Standard™

Composite structures—Composite steel-concrete construction in buildings

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Technical Committee BD-032, Composite Construction, to supersede AS 2327.1—2003 *Composite structures, Part 1—Simply supported beams*.

This Standard incorporates Amendment No. 1 (June 2020). The changes required by the Amendment are indicated in the text by a marginal bar and amendment number against the clause, note, table, figure or part thereof affected.

The objective of this Standard is to set out minimum requirements for the design, detailing and construction of composite steel-concrete members (beams, columns, slabs, joints) in buildings. The Standard is to be used by structural engineers when designing steel framed building structures.

This revision incorporates a number of technical and editorial changes, as follows:

- (a) Changes to the strength of concrete, raising the maximum compressive cylinder strength to 100 MPa.
- (b) Changes to the yield strength of steel, raising the maximum tensile yield strength to 690 MPa.
- (c) Provisions for the design of composite slabs using profiled steel sheeting.
- (d) Provisions for the design of composite beams.
- (e) Provisions for the design of composite columns.
- (f) Provisions for the design of composite joints.
- (g) Provisions for system behaviour floor design.
- (h) Provisions for fire design.
- (i) Provisions for earthquake design.

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

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the appendices to which they apply. A ‘normative’ appendix is an integral part of a Standard, whereas an ‘informative’ appendix is only for information and guidance.

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Australian/New Zealand Standard**Composite structures—Composite steel-concrete construction in buildings**

A1 | SECTION 1 GENERAL REQUIREMENTS

1.1 APPLICATIONA1 | **1.1.1 Scope and general**

This Standard sets out minimum requirements for the design, detailing and construction of composite steel-concrete members (beams, columns, slabs, joints) in buildings.

This Standard does not cover the design of composite beams and columns—

- (a) where the elements of the steel section are less than 3 mm thick or the value of the yield stress (f_y) assumed in design exceeds 690 MPa;
- A1 | (b) where the concrete characteristic compressive strength at 28 days is outside the range of 20 MPa to 120 MPa; or
- (c) for road or railway bridges (see NOTE).

A1 | NOTE: For the design of composite bridge beams, reference should be made to AS/NZS 5100.6.

1.1.2 Normative references

The following normative documents are referred to in this Standard:

AS

- 1012 Methods of testing concrete
- 1012.12.1 Determination of mass per unit volume of hardened concrete—Rapid measuring method
- 1012.12.2 Determination of mass per unit volume of hardened concrete—Water displacement method
- 1110 ISO metric hexagon bolts and screws—Product grades A and B (series)
- 1111 ISO metric hexagon bolts and screws—Product grade C (series)
- 1112 ISO metric hexagon nuts (series)
- 1163 Cold-formed structural steel hollow sections
- 1170 Structural design actions
- 1170.4 Part 4: Earthquake actions in Australia

A1 | **[Deleted]**

- 1379 Specification and supply of concrete
- 1397 Continuous hot-dip metallic coated steel sheet and strip—Coatings of zinc and zinc alloyed with aluminium and magnesium
- 1530 Methods for fire tests on building materials, components and structures
- 1530.4 Part 4: Fire-resistance tests for elements of construction
- 1554 Structural steel welding
- 1554.2 Part 2: Stud welding (steel studs to steel)
- 1579 Arc-welded steel pipes and fittings for water and waste-water

	3597	Structural and pressure vessel steel—Quenched and tempered plate
	3600	Concrete structures
	3610	Formwork for concrete
A1	[Deleted]	
	4100	Steel structures
	AS/NZS	
	1163	Cold-formed structural steel hollow sections
	1170	Structural design actions
	1170.0	Part 0: General principles
	1170.1	Part 1: Permanent, imposed and other actions
	1170.2	Part 2: Wind actions
	1170.3	Part 3: Snow and ice actions
	1252	High-strength steel fastener assemblies for structural engineering—Bolts, nuts and washers
	1252.1	Part 1: Technical requirements
A1	[Deleted]	
	[Deleted]	
	1554	Structural steel welding
	1554.1	Part 1: Welding of steel structures
	1554.4	Part 4: Welding of high-strength quenched and tempered steels
	1594	Hot-rolled steel flat products
A1	[Deleted]	
	2425	Bar chairs in reinforced concrete—Product requirements and test methods
	3678	Structural steel—Hot-rolled plates, floorplates and slabs
	3679	Structural steel
	3679.1	Part 1: Hot-rolled bars and sections
	3679.2	Part 2: Welded I-sections
	4600	Cold-formed steel structures
	4671	Steel reinforcing materials
	5100	Bridge design
	5100.6	Part 6: Steel and composite construction
	ISO	
	3183	Petroleum and natural gas industries—Steel pipe for pipeline transportation systems
	13918	Welding—Studs and ceramic ferrules for arc stud welding
	NZS	
	1170	Structural design actions
	1170.5	Part 5: Earthquake actions—New Zealand
	3101	Concrete structure Standard—The design of concrete structures
	3104	Specification for concrete production
A1	3404	Steel structures Standard
	EN	
A1	[Deleted]	

A1	1992	Design of concrete structures
	1992-1-2	Part 1-2 General rules—Structural fire design
	13381	Test methods for determining the contribution to the fire resistance of structural members (series)

Where a normative reference is made with an option of an Australian or a New Zealand Standard, the Standard that shall apply is the same as the jurisdiction where the construction occurs.

Documents that are referenced for informative purposes are listed in the Bibliography.

1.1.3 Definitions

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

NOTE: Definitions applying only to a particular clause or section are given in that clause or section and referred in this Clause (1.1.3).

1.1.3.1 *Administrative definitions*

1.1.3.1.1 *Authority*

A body having regulatory powers, in the area in which the structure is to be erected, to control the design and erection of the structure.

1.1.3.1.2 *Boundary element*

Portion along wall or diaphragm edge strengthened with structural steel sections and/or longitudinal steel reinforcement and transverse reinforcement.

1.1.3.1.3 *Collector element*

Also known as a drag strut, this is a member that serves to transfer loads between floor diaphragms and the members of the seismic force resisting system.

1.1.3.1.4 *Drawings*

The drawings forming part of the project documents setting out the work to be executed.

1.1.3.1.5 *May*

Indicates the existence of an option.

1.1.3.1.6 *Shall*

Indicates that a statement is mandatory.

1.1.3.1.7 *Should*

Indicates a recommendation.

1.1.3.1.8 *Specification*

The requirements in the project document, describing the design, materials and procedure of the work to be executed.

1.1.3.2 *Technical definitions*

1.1.3.2.1 *Action*

The cause of stress, deformation or displacement in a structure, or in a component member of the structure.

1.1.3.2.2 *Action effect*

The force, moment, deformation, or like effect, produced in the members of a structure (or its foundations) by an action or combination of actions.

1.1.3.2.3 *Active link*

The short section of beam in an eccentrically braced frame (EBF) designed and detailed to undergo stable shear and/or flexural inelastic deformation.

1.1.3.2.4 *Capacity factor*

A factor by which the nominal capacity or strength is multiplied to obtain the design capacity or strength.

1.1.3.2.5 *Characteristic strength*

The value of a material strength, as assessed by a standard test, which has a 95% probability of being exceeded in all such tests on the same material.

1.1.3.2.6 *Collector beam*

The beam outside the active link region in an eccentrically braced frame (EBF).

1.1.3.2.7 *Complete shear connection of the composite beam ($\beta = 1$)*

The condition where the moment capacity of the cross-section of the composite beam is not governed by the strength of the shear connection.

1.1.3.2.8 *Composite beam*

A steel beam and a solid or composite slab, interconnected by shear connection to act together to resist action effects as a single structural member.

1.1.3.2.9 *Composite column*

A column comprised of a structural steel section or tubular member which also comprises reinforced concrete. The capacity of this column is considered greater than the sum of the constituent structural steel and reinforced concrete parts.

1.1.3.2.10 *Composite joint*

Consists of a steel connection acting in combination with a reinforced concrete or composite slab.

1.1.3.2.11 *Composite slab*

A cast in situ concrete slab that incorporates profiled steel sheeting as permanent soffit formwork.

1.1.3.2.12 *Concentrically braced frame (CBF) system*

A braced frame in which the members are subject primarily to axial forces.

1.1.3.2.13 *Concrete*

A mixture of cement, aggregates and water, with or without the addition of chemical admixtures, which conforms to AS 3600 or NZS 3101.

1.1.3.2.14 *Concrete slab*

A slab cast monolithically with in situ concrete and reinforcement, with or without profiled steel sheeting.

1.1.3.2.15 *Connector group*

The shear connectors grouped at a transverse cross-section of a beam.

1.1.3.2.16 *Connector set*

The shear connectors between a transverse cross-section and an end of a beam.

1.1.3.2.17 *Construction stage*

One of the periods defined in Appendix A.

1.1.3.2.18 Cover

The least distance between the surface of reinforcement or shear connectors and the nearest permanent surface of the concrete, excluding any applied surface finish.

1.1.3.2.19 Cover slab

Concrete above the steel ribs in a composite slab.

1.1.3.2.20 Critical cross-section

A transverse cross-section at which the ratio of either the design bending moment (M^*) to the design moment capacity (ϕM_{bv}), or the design vertical shear force (V^*) to the design vertical shear capacity (ϕV_u) is a maximum.

1.1.3.2.21 Degree of shear connection (β)

The value obtained when the compressive force in the concrete at the strength limit state is divided by the compressive force in the concrete corresponding to complete shear connection of composite beams in the absence of vertical shear force.

1.1.3.2.22 Design action effect

The action effect computed from the design action (load).

1.1.3.2.23 Design capacity

The product of the nominal capacity and the capacity factor.

1.1.3.2.24 Design life

The period over which a structure or structural element performs its intended function without undue maintenance.

1.1.3.2.25 Design load

The combination of loads and load factors as specified in AS/NZS 1170.0.

1.1.3.2.26 Eccentrically braced frame (EBF)

A braced frame in which at least one end of each brace frames only into a beam in such a way that at least one stable, deformable link beam is formed in each beam if the elastic limit of the frame is exceeded. In this event, energy is dissipated through shear and/or flexural yielding in the link beams (termed the active link regions) whereas the bracing members and columns remain essentially elastic.

1.1.3.2.27 Effective section

The portion of a composite beam cross-section considered effective in resisting action effects in bending.

1.1.3.2.28 Effective span

The span used in the calculation of design action effects allowing for different end support conditions of the composite beam.

1.1.3.2.29 Effective width of concrete flange

The overall width of the portion of a concrete slab, at a composite beam cross-section, considered effective in resisting compression after allowing for shear lag.

1.1.3.2.30 Effective width of steel flange

The overall width of the portion of a flange of a steel beam, at a composite beam cross-section, considered effective in resisting compression after allowing for flange buckling.

1.1.3.2.31 *Exposed surface area to mass ratio*

The ratio of the surface area exposed to the fire of the mass of steel, noting that in the case of members with fire protection material applied, the exposed surface area is to be taken as the internal surface area of the fire protection material.

1.1.3.2.32 *Fitment*

Unit of reinforcement commonly used to restrain from buckling the longitudinal reinforcing bars in beams, columns and piles; carry shear, torsion and diagonal tension; act as hangers for longitudinal reinforcement; or provide confinement to the core concrete.

NOTE: Also referred to commonly as a stirrup, ligature or helical reinforcement.

1.1.3.2.33 *Full interaction*

The condition of a composite beam assuming no slip occurs along the length of the beam at the concrete/steel interface.

1.1.3.2.34 *Geometrical slenderness ratio*

The geometrical slenderness ratio, (L_e/r) for a composite compression member taken as the effective length (L_e), divided by the radius of gyration (r) computed for the gross section about the affected axis.

1.1.3.2.35 *Helical reinforcement*

Unit of reinforcement that is wound in a helical fashion around the main longitudinal reinforcing bars in a column or pile restraining them from buckling and to carry shear, torsion and diagonal tension; or, unit of reinforcement around tendons at an anchorage to resist bursting action effects.

1.1.3.2.36 *In-service condition*

Period after completion of construction when the structure is serving its intended function.

1.1.3.2.37 *Lightweight concrete*

Concrete, as previously defined, having a saturated surface-dry density in the range 1800 kg/m³ to 2100 kg/m³.

1.1.3.2.38 *Limit state*

Any limiting condition or criterion beyond which a structure, or a member, fails to fulfil its intended function.

1.1.3.2.39 *Nominal capacity*

The capacity of a member or component calculated, without the capacity factor, in accordance with this Standard.

1.1.3.2.40 *Normal-weight concrete*

Concrete, as previously defined, having a saturated surface-dry density greater than 2100 kg/m³ and less than or equal to 2800 kg/m³.

1.1.3.2.41 *One-way action*

Flexural action assumed to occur in one direction only.

1.1.3.2.42 *One-way slab*

A solid or composite slab characterized by one-way action.

1.1.3.2.43 *Ponding*

Appreciably non-uniform depth of slab as a result of the steel beam or formwork deflecting under the weight of the plastic concrete and slab reinforcement.

1.1.3.2.44 *Precast slab*

Slab incorporating precast concrete units with or without cast in situ concrete.

1.1.3.2.45 *Prestressed slab*

Slab incorporating prestressed tendons.

1.1.3.2.46 *Profiled steel sheeting*

Steel sheeting cold-formed into a profile used as permanent formwork for the soffit of composite slabs.

1.1.3.2.47 *Proof testing*

The application of specified test loads to a member or assemblage of members, to demonstrate the structural performance of only that member or assemblage.

1.1.3.2.48 *Prop*

A temporary support fitted beneath a steel beam or formwork to support loads during construction.

1.1.3.2.49 *Reinforcement, reinforcing steel*

Steel bar or mesh in accordance with AS/NZS 4671 placed in a concrete slab.

1.1.3.2.50 *Serviceability limit state*

The loss of fitness for intended use under specified in-service conditions.

1.1.3.2.51 *Shear connection*

The interconnection between the steel member and concrete of a composite member, which enables the two components to act together as a single structural member, comprising the shear connectors, slab concrete and reinforcement.

1.1.3.2.52 *Shear connector*

A mechanical device attached to a steel member which forms part of the shear connection.

1.1.3.2.53 *Shear ratio (γ)*

The ratio at a cross-section of the design vertical shear force (V^*) to the design vertical shear capacity (ϕV_u).

1.1.3.2.54 *Solid slab*

A concrete slab with a flat soffit and without a haunch, cast in situ on removable formwork and reinforced in accordance with AS 3600 or NZS 3101.

1.1.3.2.55 *Ultimate limit state*

Collapse, or loss of structural integrity, under specified extreme-load conditions.

1.1.3.2.56 *Tensile strength*

The maximum strength in tension specified for a grade and type of steel.

1.1.3.2.57 *Tributary area*

The plan area from which dead and live loads acting on the slab are assumed to be received by a supporting composite beam.

1.1.3.2.58 *Two-way action*

Flexural action in two directions, usually at right angles to one another.

1.1.3.2.59 *Two-way slab*

A solid slab characterized by two-way action.

1.1.3.2.60 Yield strength (or stress)

The minimum yield stress in tension specified for a grade and type of steel.

1.1.4 Existing structures

When the strength or serviceability of an existing structure is to be evaluated, the general principles of this Standard (AS/NZS 2327) shall be applied using the actual properties of the materials in the structure. If proof testing of members is used it shall be in accordance with the load testing provisions of this Standard (AS/NZS 2327).

1.1.5 Design information**1.1.5.1 Design data**

The following design details shall be shown on the drawings:

- (a) The reference number and date of issue of current design Standards and any amendments to them.
- (b) The nominal design live loads during construction and in-service.
- (c) The durability exposure classification for the concrete and the corrosion protection for the exposed steelwork and profiled steel sheeting.
- (d) The determined fire-resistance level.
- (e) The grades and types of reinforcement.
- (f) The grades of steel in the steel sections.
- (g) The types and grades of shear connectors and their method of attachment.
- (h) The type, class and strength designation of the concrete.
- (i) Any seismic frames and seismic member categories.

1.1.5.2 Design details

The project drawings and the specification shall include the following design details:

- (a) The dimensions and camber and designation of each steel member.
- (b) The support or joint details for the steel beams including location, size, grade and category of bolts or welds.
- (c) Details of the type, size, location and spacing of shear connectors, particularly in relation to the position of profiled steel sheeting ribs.
- (d) The overall thickness of the slab inclusive of profiled steel sheeting and the size and location of any openings, rebates, major voids or conduits in the slab.
- (e) The grade, size, quantity and location of all reinforcement, and other structural embedments.
- (f) The finish and method of control for unformed concrete surfaces.
- (g) In the case of solid slabs, the class of formwork for the surface finish specified in accordance with AS 3610.
- (h) In the case of composite slabs, the proprietary name, base metal thickness, coating class for the profiled steel sheeting.
- (i) The concrete curing procedure.
- (j) The location and details of any movement joints or planned construction joints in the concrete slabs.
- (k) The minimum period of time before stripping of forms or removal of props.

- (l) The values of the nominal live loads used in design.
- (m) The assumed construction sequence.
- (n) The climatic or other local conditions affecting the durability design of the structure.
- (o) The design life of the structure.
- (p) Any other constraint on construction assumed in the design.
- (q) Fire-resistance requirements and fire-protection details.
- (r) Any other requirements.

1.1.6 Construction

Composite members designed in accordance with this Standard (AS/NZS 2327) shall be constructed so that all the requirements of the design, as contained in the project drawings and specification, are satisfied.

1.1.7 Notation

The symbols used in this Standard (AS/NZS 2327) are listed in this Clause (1.1.7). Symbols that occur in more than one clause are defined below and used in the various clauses without further reference. Symbols which occur only in one clause are defined in that clause.

Unless otherwise specified, the following rules apply:

- (a) Where non-dimensional ratios are involved, both the numerator and denominator are expressed in identical units.
- (b) The dimensional units for length, force and stress in all expressions or equations are to be taken as millimetres (mm), newtons (N) and megapascals (MPa) respectively.
- (c) The units of fractional powers of stress (e.g. $\sqrt{f'_c}$) are to be taken as those for stress.
- (d) An asterisk superscript placed after a symbol (e.g. M^*) denotes a design action effect resulting from the design load for the ultimate limit state.

The symbols used are as follows:

A	=	cross-sectional area of the steel beam
A_w	=	cross-sectional area of the web(s) of the steel beam
b	=	clear width of plate element outstand
b_1, b_2	=	centre-to-centre spacing of adjacent beams or distance from centre of steel beam to edge of slab outstand
b_b	=	width of the base of the concrete rib within a composite slab
b_{eff}	=	effective width of the concrete slab compression flange
b_{e1}, b_{e2}	=	concrete slab effective width outstands on opposite sides of steel beam centre-line
b_f	=	width of a steel beam flange
b_s	=	support width
b_{sf1}	=	effective width of steel beam top flange
b_{sf2}	=	overall width of steel beam bottom flange
D_{comp}	=	overall composite beam depth
D_s	=	overall depth of a concrete slab including the thickness of any profiled steel sheeting if present

	d	= overall depth of a steel beam
	d_1	= clear depth between flanges of a steel beam ignoring fillets or welds
	d_b	= nominal diameter of a reinforcing bar
	d_{bs}	= nominal shank diameter of a headed-stud or a high-strength structural bolt shear connector
	E_c	= mean value of the modulus of elasticity of concrete at 28 days
	E_{cT}	= elastic modulus of the slab concrete at $T^\circ\text{C} > 20^\circ\text{C}$
	E_s	= elastic modulus of steel, 200×10^3 MPa
	E_{sT}	= elastic modulus of steel at $T^\circ\text{C} > 20^\circ\text{C}$
	F_c	= compressive force in the concrete flange at a cross-section at the ultimate limit state
	F_{cc}	= compressive force in concrete slab at a cross-section with complete shear connection
	f'_c	= characteristic compressive (cylinder) strength of concrete at 28 days
	f_{cd}	= design value of the cylinder compressive strength of concrete ($\phi_c f'_c$)
	f'_{cj}	= estimated characteristic compressive strength of concrete at j days but taken as not greater than f'_c or $f'_{cj} = 100$ MPa
	f_{cmi}	= mean value of the in situ compressive strength of the concrete at the age being considered
	f_{uc}	= characteristic tensile strength of the shear-connector material
	f_y	= yield strength of the structural steel
	f_{yd}	= design value of the yield strength of structural steel (ϕf_y)
	f_{yp}	= yield strength of the profiled steel sheeting
	$f_{yp,d}$	= design value of the yield strength of the profiled steel sheeting (ϕf_{yp})
	f_{sy}	= characteristic yield strength of the steel reinforcement
A1	G	= permanent action (dead load)
	h	= overall depth of a composite slab
	h_c	= thickness of the concrete flange; thickness of concrete above main flat surface at the top of the ribs to the steel sheeting
	h_e	= effective thickness of concrete slab
	h_p	= height of profiled steel sheeting excluding embossments
	h_{sc}	= overall height of a shear connector
	k	= elastic neutral axis parameter
	L_{ef}	= effective span
A1	M^*	= design bending moment at a cross section
	M_{Rd}	= design value of the moment resistance of the composite section
	[Deleted]	
	n	= total number of shear connectors provided between a cross section and an end of the composite beam

n'_i	=	number of shear connectors between an intermediate point and the point of zero moment
$n_{c,i}$	=	minimum number of shear connectors (with the same design shear capacity P_{Rd}) determined between a potentially critical cross section (i) and the ends of the beam to achieve complete shear connection
n_x	=	number of shear connectors in a group at a transverse cross section of a composite beam
n_0	=	modular ratio E_s/E_c
P_{Rd}	=	design shear capacity of a shear connector
P_{Rk}	=	nominal shear capacity of a shear connector
Q	=	imposed action (live load)
R_u	=	nominal capacity of a composite member
r_e	=	elastic neutral axis parameter measured from below the steel beam top flange
r_p	=	plastic neutral axis parameter
S^*	=	design action effects in general
T	=	steel temperature in degrees Celsius
T_l	=	limiting steel temperature in degrees Celsius
t_f	=	thickness of the flange of a steel beam
t_{f1}, t_{f2}	=	values of t_f corresponding to the top and bottom flanges, respectively
t_w	=	thickness of the web(s) of a steel beam
V^*	=	design vertical shear force acting at a composite beam cross section
V_u	=	nominal vertical shear capacity of a composite beam cross-section at the strength limit state
v_L^*	=	design longitudinal shear force to be resisted
v_{Lp}^*	=	design longitudinal shear force to be resisted along a shear plane
β	=	degree of shear connection at a cross-section of a composite beam
β_m	=	degree of shear connection at the maximum moment cross-section of a composite beam
Δ	=	maximum deflection of a composite beam under serviceability loads
δ	=	deflection of the composite member
δ_{inc}	=	incremental deflection
δ_{tot}	=	total deflection
ε	=	yield stress factor
γ	=	shear force ratio
λ_e	=	plate element slenderness
λ_{ep}	=	plate element plasticity slenderness limit
λ_{ey}	=	plate element yield slenderness limit

A1

- ρ_c = density of concrete
- ϕ = capacity factor impacting a limit state

1.2 MATERIALS

1.2.1 Steel

1.2.1.1 Structural steel

Structural steel shall conform, giving consideration to the application and scope of the Standard, with one of the following as appropriate:

AS/NZS 1163, AS/NZS 1594, AS/NZS 3678, AS/NZS 3679.1, AS/NZS 3679.2, AS 1579, AS 3597 or ISO 3183.

1.2.1.2 Bolts, nuts and washers

- A1 | Bolts, nuts and washers shall conform with AS 1110, AS 1111, AS 1112 or AS/NZS 1252.

1.2.1.3 Welds and welding

Welding consumables, deposited weld metal and welding used to fabricate the steel beam or attach channel shear connectors to the top flange shall conform with AS/NZS 1554.1, and welding of headed-stud shear connectors shall conform with AS/NZS 1554.2.

1.2.1.4 Shear connectors

Shear connectors shall conform with AS/NZS 1554.2, AS/NZS 1252 or ISO 13918.

Alternatively, shear connectors not conforming with the above may be used, provided that the weld collars conform with the requirements of ISO 13918 and they conform with the other requirements of this Standard.

For shear connectors other than bolts and headed studs conforming with the above, the shear capacity evaluated from the standard tests in Appendix G shall be provided.

1.2.1.5 Profiled steel sheeting

- A1 | The steel strip used to produce the profiled steel sheeting shall conform with AS 1397. The shear bond values evaluated from the standard tests in this document shall be provided.

NOTE: The amount of oil residue on the surface of profiled steel sheeting after manufacture should not exceed 200 mg/m².

1.2.2 Concrete and reinforcement

1.2.2.1 Concrete

The ingredients for, and the manufacture of, fresh (plastic) concrete, shall conform with AS 1379 or NZS 3104.

1.2.2.2 Reinforcement

Reinforcement used in a composite member shall conform with AS/NZS 4671.

1.2.2.3 Spacing of reinforcement and tendons

- A1 | **[Deleted]**

For the minimum distance between bars, ducts and tendons and placement of the concrete and its compaction, the clear spacing between bars (or bundled bars) shall be the greater of 1.5 times the size of the largest aggregate particle, 1.5 times the diameter of the vibrator and 30 mm.

The maximum spacing between bars shall be based on crack control provisions determined from AS 3600 or NZS 3101.

A1 | **1.2.2.4 Nominal size of concrete aggregate for composite slabs**

The nominal size of the aggregate (20 mm maximum) depends on the smallest dimension in the structural element within which concrete is placed, and shall not exceed the least of:

- (a) 0.8 times the nominated cover.
- (b) $b_0/3$, where b_0 is the mean width of the ribs (minimum width for re-entrant profiles).
- (c) 0.8 times the distance as measured between the outside of the reinforcing bar or duct and the profiled steel sheeting.
- (d) $0.4h_c$.

A1 | **1.2.2.5 Nominal size of concrete aggregate for composite columns and beams**

The nominal size of the aggregate (20 mm maximum) depends on the smallest dimension in the structural element within which concrete is placed, and shall not exceed 0.8 times the nominated cover.

1.2.3 Mechanical properties

The mechanical properties used for calculating the nominal (unfactored) strengths of the component parts of the composite member shall be determined in accordance with the following:

- (a) *Steel sections* AS 4100 or NZS 3404.
- (b) *Bolts and nuts* AS 1111, AS 1112 and AS/NZS 1252.
- (c) *Welds* AS/NZS 1554.1 and AS/NZS 1554.4.
- (d) *Shear connectors* of the following types:
 - (i) *Headed studs* AS 1554.2.
 - (ii) High-strength structural bolts (*Property Class 8.8*) AS/NZS 1252.
- (e) *Galvanized steel strip for profiled steel sheeting* AS 1397.
- (f) *Concrete* AS 3600 or NZS 3101.
- (g) *Reinforcement* AS/NZS 2425 and AS/NZS 4671.

1.3 CONSTRUCTION

1.3.1 General

The requirements of this section shall be satisfied for the construction stages defined in Appendix A. Due allowance shall be made for differential deflections between structural elements to avoid uncertain load distributions, possible damage, or undue distortion.

1.3.2 Construction sequence and loads

A1 | The construction sequence shall conform to that detailed on the drawings or in the project specification (see Clause 1.1.3.1.8). It shall be assured during all stages of construction that the live loads (including stacked materials) do not cause a more adverse effect on the structure than that assumed in design.

1.3.3 Structural steel

Fabrication and erection of steelwork shall be in accordance with AS 4100 for Australia or AS/NZS 5131 for New Zealand.

1.3.4 Concrete

1.3.4.1 *Manufacture and delivery*

Concrete manufacture and delivery shall be in accordance with AS 1379 or NZS 3109, including quality assessment for concrete as supplied.

1.3.4.2 *Concrete after delivery*

Handling, placing, compacting, curing and protection of plastic concrete after delivery shall be in accordance with AS 3600 or NZS 3101, including determination of in situ strength at various stages of construction.

Reinforcement shall be supplied in accordance with AS/NZS 4671 and fixed in accordance with AS 3600 or NZS 3109. Reinforcement bar chairs shall be in accordance with AS/NZS 2425.

1.3.5 Formwork and falsework

1.3.5.1 *General*

The arrangement of falsework shall take account of the deflections of the steel beams during concreting to prevent undue distortion of the slab soffit.

Removal of slab formwork/falsework and props to beams shall not commence until the concrete has attained a characteristic compressive strength f_{cj}' of 15 MPa, that is, end of Construction Stage 4. The minimum period of time before stripping forms or removing props shall be not less than that given in the project drawings or specification.

All dirt, excess water, ceramic ferrules and other deleterious matter accumulated during construction shall be removed from the top surface of the formwork prior to concrete placement. Oil shall not come into contact with the surface of profiled steel sheeting.

1.3.5.2 *Solid slabs*

Formwork and falsework for solid slabs shall conform with AS 3610.

1.3.5.3 *Composite slabs*

For the maximum deflection of the sheeting while it supports the plastic concrete, see Section 2.

1.3.5.4 *Composite columns*

Formwork and falsework shall conform with AS 3610.

1.4 GENERAL DESIGN REQUIREMENTS

1.4.1 General

The aim of structural design in accordance with this Standard is to provide composite members and structures that have the necessary strength, serviceability, stability, durability and fire-resistance and satisfy other objectives such as economy and ease of construction.

The design of a composite structure and its components shall take into account the limit states of stability, strength, serviceability, fire resistance and any other design criteria, in accordance with the procedures specified in this Standard.

1.4.2 Loads

The design of a composite member for strength, serviceability, stability and fire resistance shall take account of the action effects arising directly from the loads specified in Clause 1.5.

1.4.3 Ultimate limit state

Once composite action is fully developed the composite member shall be proportioned so that the ultimate limit state of strength is satisfied by ensuring that the design capacity (ϕR_u) is not less than the design action effect (S^*) for all critical cross-sections and regions, such that:

$$R_{Rd} = \sum \phi_i R_{u,i} \geq S^* \quad \dots 1.4.3$$

where

ϕ_i = capacity factor for material i, not greater than the value given in Table 1.4.3

$R_{u,i}$ = nominal capacity of material i

R_{Rd} = design resistance

S^* = corresponding design action effect

TABLE 1.4.3
CAPACITY FACTOR FOR THE ULTIMATE LIMIT STATE

Type of action effect	Capacity factor (ϕ)
Axial	
(a) Concrete in compression	0.65
(b) Steel in compression	0.90
(c) Concrete in tension	0.80
(d) Steel in tension	0.90
Bending of composite beams and composite slabs	
(a) Steel	0.90
(b) Concrete	0.80
Vertical shear	
(a) Steel	0.90
(b) Concrete	0.60
Longitudinal shear	
(a) Concrete slab	0.63
(b) Shear connectors	0.80

1.4.4 Serviceability limit states

The composite structure shall be designed so that, under the design actions for the serviceability limit state, its deflection and vibration, as well as cracking of the concrete floor system, shall be controlled in accordance with this Standard (AS/NZS 2327).

1.4.5 Durability

The durability requirements of concrete shall be in accordance with AS 3600 or NZS 3101.

These requirements apply to plain, reinforced and prestressed concrete structures and members with a design life of 50 years $\pm 20\%$.

NOTES:

- More stringent requirements should be considered for structures with a design life in excess of 50 years (e.g., monumental structures), while some relaxation of the requirements may be acceptable for structures with a design life of less than 50 years (e.g. temporary structures).
- Durability is a complex topic and conformance with these requirements may not be sufficient to ensure a durable structure.

The durability requirements of structural steel shall be in accordance with AS 4100 or NZS 3404.

The durability requirements of cold-formed steel shall be in accordance with AS/NZS 4600.

1.4.6 Fire resistance

The composite structure shall be designed and detailed in accordance with this document so that its fire-resistance period for structural adequacy is not less than the corresponding period specified for the determined fire-resistance level. The concrete slab component of the composite beam shall be designed and detailed in accordance with this document, so that its fire-resistance periods for structural adequacy, insulation and integrity are not less than the corresponding periods specified by the determined fire-resistance level.

1.4.7 Structural robustness

The composite structure shall be designed and detailed in accordance with the robustness provisions in AS/NZS 1170.0.

1.4.8 Design for earthquakes

The composite structure shall be designed and detailed in accordance with this document to meet the requirements of the earthquake loading provisions of AS 1170.4 or NZS 1170.5.

1.4.9 Proof testing

Proof testing shall be in accordance with AS/NZS 1170.0.

1.5 ACTIONS AND DESIGN SITUATIONS

1.5.1 General

1.5.1.1 Actions

The design of the member for the limit states specified in Clause 1.4 shall take account of the action effects directly arising from the following actions:

- (a) Permanent and imposed, wind, snow and earthquake loads determined in accordance with AS/NZS 1170.1, AS/NZS 1170.2, AS/NZS 1170.3, and AS 1170.4 or NZS 1170.5 respectively.
- (b) Construction loads, determined in accordance with this Standard (AS/NZS 2327).
- (c) Any other specific loads.

Uniformly distributed imposed loads for the in-service condition may be reduced in accordance with Clause 1.5.1.3.

1.5.1.2 Other actions

Any other action that affects the stability, strength, or serviceability of the member, including but not limited to the following, shall be taken into account:

- (a) Removal of construction props.
- (b) Foundation movement.
- (c) Temperature changes and gradients.
- (d) Transient dynamic actions.
- (e) Shrinkage or creep of concrete.

1.5.1.3 Reduction of uniformly distributed imposed loads

Uniformly distributed imposed loads acting on a composite beam or composite column during the in-service condition may be reduced in accordance with AS/NZS 1170.1, taking into account the magnitude of the tributary area.

1.5.1.4 Load combinations

1.5.1.4.1 General

Except as noted herein, the design loads for the limit state shall be determined from the combinations of actions specified in AS/NZS 1170 and shall include any other actions.

1.5.1.4.2 Pattern loading requirements for floor systems

When design checks are carried out for continuous beams and continuous floor systems, for two-dimensional framed structures and for three-dimensional framed structures and floor systems, alternative arrangements of the vertical loads shall be considered in order to determine the critical load combinations. Variations in the load intensity on individual spans shall be considered, including partial loading as specified in AS/NZS 1170.1, together with variations in the loading patterns, whereby some spans are loaded and others unloaded.

The loading arrangements to be considered shall include at least the following:

- (a) The factored permanent action (dead load), without variations in pattern.
- (b) For factored imposed action (live load), where the pattern of loaded and unloaded spans is fixed, the full factored imposed action (live load) applied in the specified pattern.
- (c) For imposed action (live load), where the pattern of loaded and unloaded spans is variable, as follows:
 - (i) For continuous beams and two-dimensional frames and floor systems, the factored imposed action (live load) on—
 - (A) on alternate spans;
 - (B) any two adjacent spans; and
 - (C) all spans.
 - (ii) For three-dimensional framed structures and floor systems, patterned variations of the factored imposed action (live load) shall be applied in chequerboard arrangements, including the principles of Items (A), (B) and (C) of Item (i) above, to determine the peak design action effects at each critical section.
 - (iii) Notwithstanding Items (i) and (ii), for beams and slabs at the strength limit state, for which the imposed action (live load) (Q) is less than three-quarters of the permanent action (dead load) (G), the factored imposed action (live load) on all spans.

NOTE: The load arrangements listed are the minimum to be considered for design. In particular, for deflection or vibration-sensitive structures and slender floor systems, additional load arrangements should be considered.

1.5.2 Construction stages

The construction stages used for the purposes of assessing construction loads and the initiation of composite action are defined in Appendix A.

1.6 METHODS OF STRUCTURAL ANALYSIS

1.6.1 General

The following methods of analysis may be used for strength, serviceability and robustness:

- (a) Linear elastic analysis with or without redistribution.
- (b) Rigid plastic global analysis, provided that it is shown that sections where plastic rotations are assumed, have sufficient rotation capacity.

- (c) Elastic-plastic analysis, taking into account the non-linear material properties.
- (d) Advanced analysis.

1.6.2 Effective width of concrete flanges in composite beams

Allowance shall be made in the analysis for the flexibility of concrete flanges affected by shear in their plane (shear lag) either by means of rigorous analysis, or by using an effective width of flange.

The effective width of concrete flanges to be used in the analysis shall be determined in accordance with the following provisions.

A1 | When elastic global analysis is used, a constant effective width shall be assumed over the whole of each span and this value is calculated as follows—

(a) the effective width at mid-span calculated for a span supported at both ends; and

A1 | (b) the effective width at the support for a cantilever segment.

A1 | **1.6.3 [Deleted]**

1.7 DESIGN ASSISTED BY TESTING

Where use is made of design assisted by testing, see Appendix I.

SECTION 2 DESIGN OF COMPOSITE SLABS

2.1 GENERAL

2.1.1 Scope

This section deals with composite floor slabs spanning only in the direction of the ribs, including cantilever slabs. It applies to designs for building structures where the imposed loads are predominantly static, including industrial buildings where floors may be subject to moving loads.

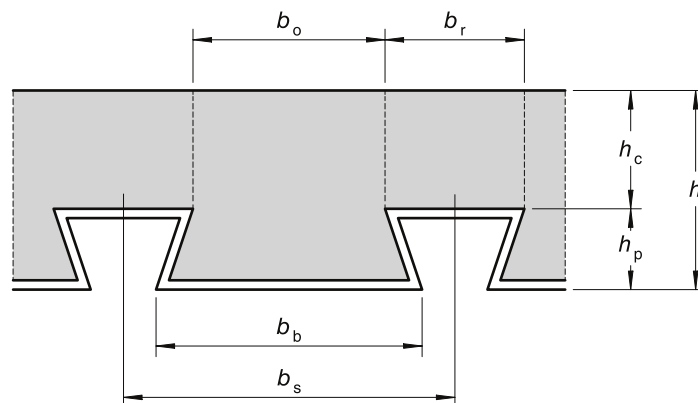
The scope is limited to sheets with narrowly spaced webs, where these are defined by an upper limit on the ratio b_T/b_s of 0.6, see Figure 2.1.1.

For structures where the imposed load is largely repetitive or applied abruptly, such as to produce dynamic effects, composite slabs may be used. When they are used special care shall be taken in the detailed design to ensure that the composite action does not deteriorate over time.

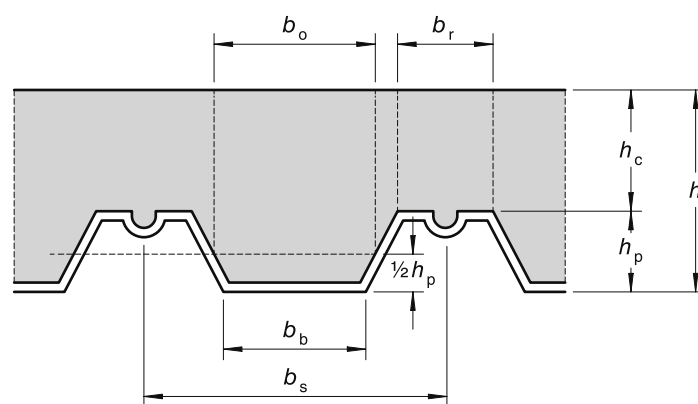
NOTE: Composite slabs may be considered to provide lateral restraint to the steel beams and to act as a diaphragm to resist horizontal actions. Specific rules for these cases are given in this Standard (AS/NZS 2327).

To use a steel beam economically, the top (compression) flange should be restrained laterally. The restraint provided by the sheeting to the beams depends on the sheeting orientation and the fixings. During construction, the restraints provided by sheeting spanning in a direction parallel to a beam are normally assumed to be negligible, but sheeting spanning perpendicularly to a beam can provide restraint provided the sheet fixings to the critical flange have been designed to carry a transverse force equal to 2.5% of the maximum force in the critical flange. Sharing of this force between fasteners is permitted according to AS 4100 or NZS 3404. It shall be ensured that the restraint assumed in design is provided by the fixing arrangement.

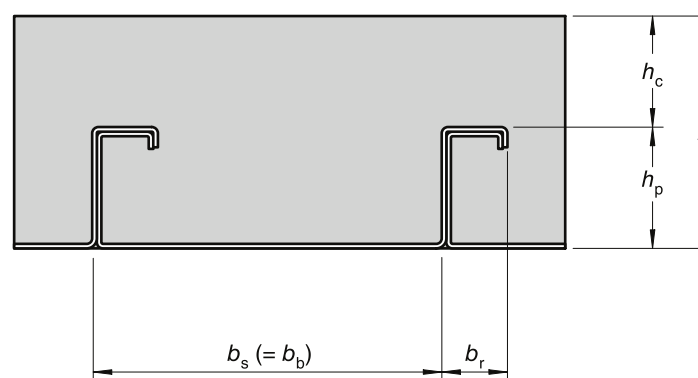
NOTE: Continuous lateral restraint occurs when through-deck welded shear connectors are provided (irrespective of other fixings), but when there are no shear connectors or shear connectors are welded through holes in the sheeting, restraint is limited by the resistance of the fixings. This depends not only on the shear resistance of an individual fixing, but also on their spacing along the beam. For further information refer to ECCS publication No. 88.



(a) Re-entrant trough profile



(b) Open trough profile



(c) Clipped-pan profile

FIGURE 2.1.1 SHEET AND SLAB DIMENSIONS

2.1.2 Types of shear connection

The profiled steel sheet shall be capable of transmitting horizontal shear at the interface between the sheet and the concrete; composite behaviour between steel sheeting and concrete that is lost after 5000 cycles of loading applied in standard tests according to Appendix H is not considered effective for composite action.

Composite behaviour between profiled sheeting and concrete shall be ensured by one or more of the following means (see Figure 2.1.2):

- (a) Mechanical interlock provided by deformations in the profile (indentations or embossments).
- (b) Frictional interlock for profiles shaped in a re-entrant form.
- (c) End anchorage provided by welded studs or another type of local connection between the concrete and the steel sheet, only in combination with (a) or (b).

Other means of achieving composite behaviour are not excluded, but are not within the scope of this Standard (AS/NZS 2327).

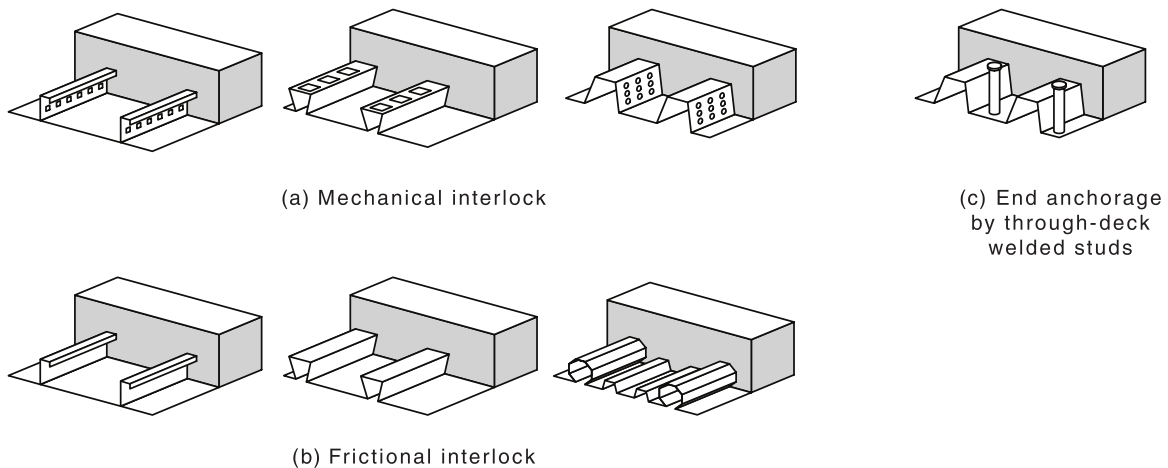


FIGURE 2.1.2 FORMS OF INTERLOCK IN COMPOSITE SLABS

2.1.3 Full shear connection and partial shear connection

A span of a slab has full shear connection when an increase in the resistance of the longitudinal shear connection would not increase the design-bending resistance of the member. Otherwise, the slab is deemed to have partial shear connection.

2.2 DETAILING PROVISIONS

2.2.1 Slab thickness and reinforcement

The overall depth of the composite slab h shall be not less than 90 mm, or the minimum depth determined for fire and serviceability considerations, see Sections 6 and 7. The thickness of the concrete h_c above the main flat surface of the top of the ribs of the sheeting shall be not less than 40 mm.

If the slab is acting compositely with the beam or is used as a diaphragm, the overall depth h shall not be less than 100 mm and h_c shall not be less than 50 mm.

Transverse reinforcement shall be provided within the depth h_c of the concrete. Longitudinal reinforcement shall be provided within the depth h of the composite slab.

For non-prestressed systems, the amount of top reinforcement in the primary span direction shall not be less than the top reinforcement area determined in the transverse direction. The amount of top reinforcement in the transverse direction shall be in accordance with Table 2.2.1. The spacing of the reinforcement bars shall not exceed $2h$ and 300 mm, whichever is the lesser.

TABLE 2.2.1
MINIMUM (SECONDARY) TRANSVERSE TOP REINFORCEMENT

Slab depth, h (mm)	Depth of concrete over profile rib, h_c (mm)	Reinforcement area, D500 MPa grade (mm ² /m)
≤ 125	$h_c \geq 40$	135
$125 < h \leq 150$	$h_c \geq 40$	175
$150 < h \leq 175$	$h_c \geq 40$	225
$175 < h \leq 225$	$h_c \geq 45$	290
$225 < h \leq 300$	$h_c \geq 55$	350

NOTES:

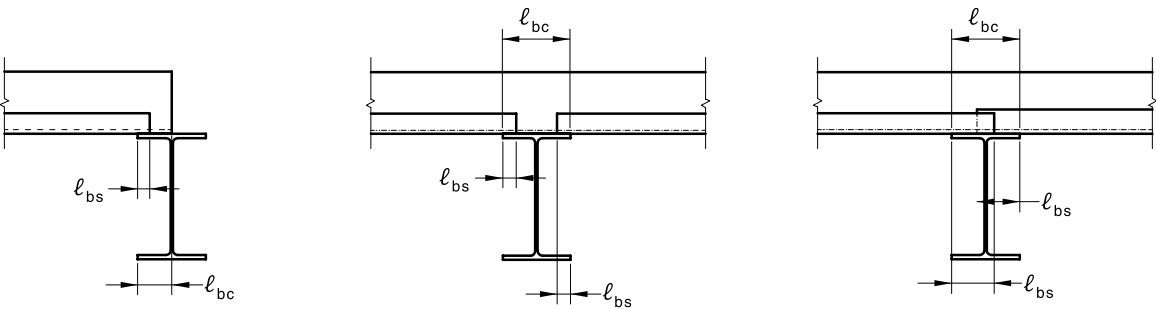
- 1 Overall slab depth (h) should not exceed $4 \times h_c$.
- 2 The above values are minimum reinforcement areas for a slab enclosed within a building.
- 3 See also Clause 2.8.4, Control of cracking of concrete.

2.2.2 Bearing requirements

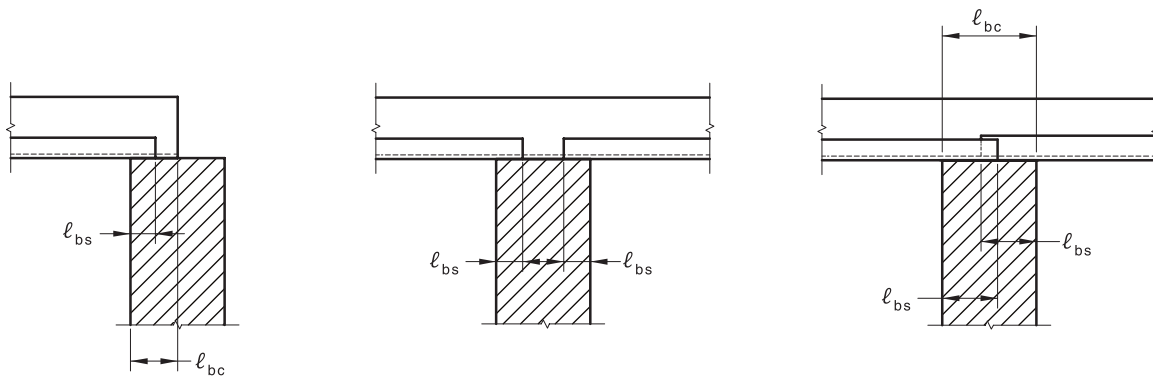
The bearing length shall be such that: damage to the slab and the bearing is avoided; fastening of the sheet to the bearing is achieved without damage to the bearing; and collapse cannot occur as a result of accidental displacement during erection.

The bearing lengths ℓ_{bc} and ℓ_{bs} , as indicated in Figure 2.2.2, shall not be less than the following limiting values:

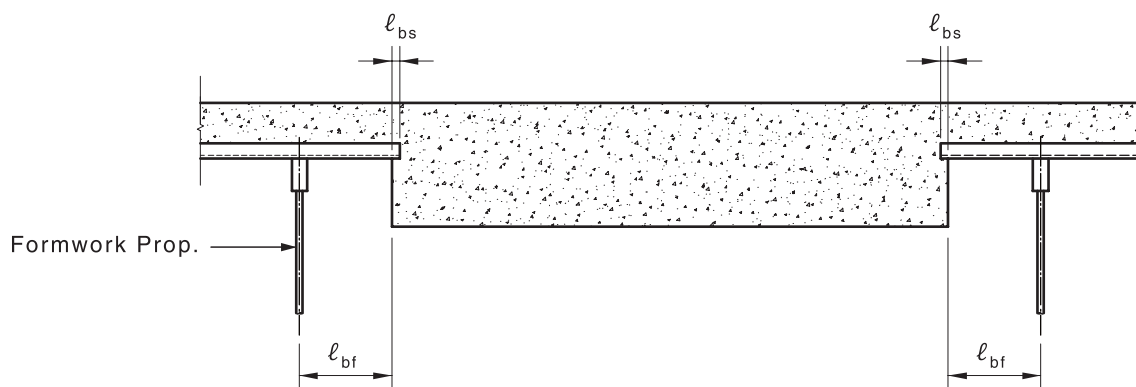
- (a) For composite slabs bearing on steel or concrete: $\ell_{bs} = 50$ mm and $\ell_{bc} = 75$ mm.
- (b) For composite slabs bearing on other materials: $\ell_{bs} = 70$ mm and $\ell_{bc} = 100$ mm.
- (c) For composite slabs cast on temporary forms or falsework, $\ell_{bs} = 25$ mm, together with $\ell_{bf} = 300$ mm maximum, see Figure 2.2.2(c).



(a) Composite slabs bearing on steel or concrete



(b) Composite slabs bearing on other materials



(c) Composite slabs cast on temporary forms or falsework

FIGURE 2.2.2 MINIMUM BEARING LENGTHS

2.3 ACTIONS AND ACTION EFFECTS

2.3.1 Design situations

Design situations and limit states shall be considered in design so as to ensure safety and serviceability.

The following situations shall be considered:

- Profiled steel sheeting as shuttering* Verification shall be undertaken for the behaviour of the profiled steel sheeting while it is acting as formwork for the wet concrete and construction loads. Account shall be taken of the effect of props, if any.
- Composite slab* Verification shall be undertaken for the floor slab after composite behaviour has commenced and any props have been removed.

2.3.2 Actions for profiled steel sheeting as shuttering

The following loads shall be taken into account in calculations for the steel deck as shuttering—

- weight of concrete and steel deck;
- construction loads including local heaping of concrete during construction, in accordance with Appendix A;
- storage load, if any; and
- ‘ponding’ effect (increased depth of concrete due to deflection of the sheeting)

2.3.3 Actions for composite slab

Loads and load arrangements shall be in accordance with AS/NZS 1170.1.

2.4 ANALYSIS FOR INTERNAL FORCES AND MOMENTS

2.4.1 Profiled steel sheeting as formwork

The design of the profiled steel sheeting as formwork shall be in accordance with Clauses 2.5 and 2.6.

Plastic redistribution of moments shall not be allowed for serviceability limit states when temporary supports are used.

2.4.2 Composite slab

The methods of structural analysis that shall be used are given in Clause 1.6.

If the effects of cracking of concrete are neglected in the analysis for ultimate limit states, the bending moments at internal supports may be reduced by up to 30%, and corresponding increases made to the sagging bending moments in the adjacent spans.

Plastic analysis without any direct check on rotation capacity may be used for the ultimate limit state if reinforcing steel of class N or E in accordance with AS 3600 or NZS 3101 is used and the span is not greater than 3.0 m.

A continuous slab may be designed as a series of simply supported spans. Nominal reinforcement in accordance with Clause 2.8.4 shall be provided over intermediate supports.

2.4.3 Effective width of composite slab for concentrated point and line loads

Where concentrated point or line loads are to be supported by the slab, they shall be considered to be distributed over an effective width, unless a more exact analysis is carried out.

Concentrated point or line loads parallel to the span of the slab shall be considered to be distributed over a width b_m , measured immediately above the ribs of the sheeting, see Figure 2.4.3(A), and given by:

$$b_m = b_p + 2(h_c + h_f) \quad \dots 2.4.3(1)$$

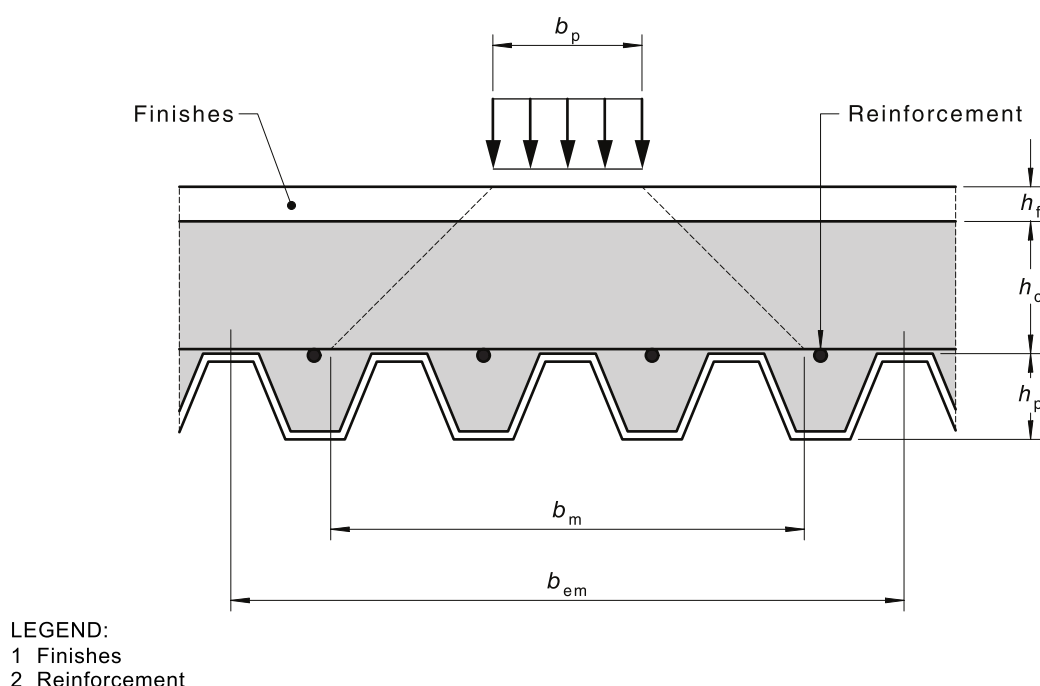


FIGURE 2.4.3(A) DISTRIBUTION OF CONCENTRATED LOAD

A1 | For concentrated line loads perpendicular to the span of the slab, Equation 2.4.3(1) shall be used for b_m , with b_p taken as the length of the concentrated line load.

If h_p/h does not exceed 0.6, in the absence of a more refined analysis, the width of the slab considered to be effective for global analysis and for resistance shall be determined from Equations 2.4.3(2) to 2.4.3(4):

(a) For bending and longitudinal shear—

(i) for simple spans and exterior spans of continuous slabs

$$b_{em} = b_m + 2 L_p \left(1 - \frac{L_p}{L} \right) \leq \text{slab width} \quad \dots 2.4.3(2)$$

(ii) for interior spans of continuous slabs

$$b_{em} = b_m + 1.33 L_p \left(1 - \frac{L_p}{L} \right) \leq \text{slab width} \quad \dots 2.4.3(3)$$

(b) For vertical shear—

$$b_{ev} = b_m + L_p \left(1 - \frac{L_p}{L} \right) \leq \text{slab width} \quad \dots 2.4.3(4)$$

where

L_p = the distance from the centre of the load to the nearest support

L = the span length

The variation of the composite slab effective width with span L (given in Equations 2.4.3(2) to 2.4.3(4)), is shown graphically in Figure 2.4.3(B).

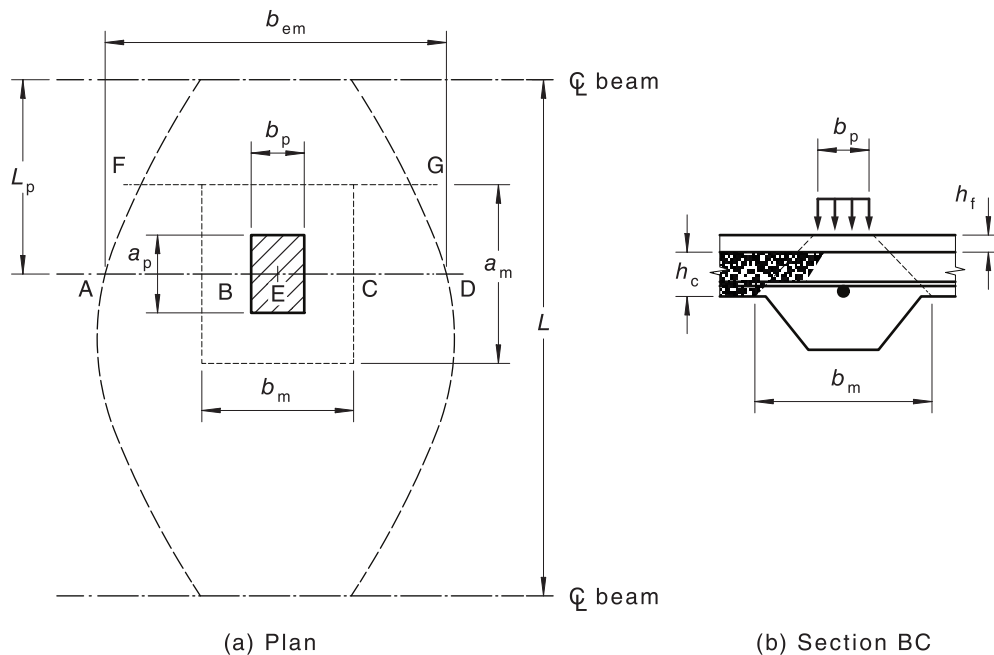


FIGURE 2.4.3(B) EFFECTIVE WIDTH OF COMPOSITE SLAB FOR CONCENTRATED LOAD

If the imposed actions do not exceed the following values, the greater thereof, a nominal transverse reinforcement, is permitted without calculation:

- (i) Concentrated load: 7.5 kN; or
- (ii) Distributed load: 5.0 kN/m².

This nominal transverse reinforcement shall have a cross-sectional area of not less than 0.2% of the area of structural concrete above the ribs, and shall extend over a width of not less than b_{em} as calculated in this Clause (2.4.3). Minimum anchorage lengths shall be provided beyond this width in accordance with AS 3600 or NZS 3101.

NOTE: Reinforcement provided for other purposes may fulfil all, or part, of this rule.

Where the above conditions are not satisfied, the distribution of bending moments caused by line or point loads shall be determined, and the transverse reinforcement determined using AS 3600 or NZS 3101.

2.5 VERIFICATION OF PROFILED STEEL SHEETING AS FORMWORK FOR ULTIMATE LIMIT STATES

Verification of the profiled steel sheeting for ultimate limit states shall be given in accordance with AS/NZS 4600 or Appendix F. Due consideration shall be given to the effect of embossments or indentations on the design resistances.

2.6 SERVICEABILITY LIMIT STATE REQUIREMENTS FOR PROFILED STEEL SHEETING USED AS FORMWORK

Section properties shall be determined in accordance with AS/NZS 4600 or Appendix F.

The deflection δ_s of the sheeting under its own weight plus the weight of wet concrete, excluding the construction load, shall not exceed $\delta_{s,max}$.

L_e is effective span of profiled sheeting used as formwork, which is the lesser of: the distance between centres of permanent or temporary supports; and the clear span between permanent or temporary supports plus the overall depth of the profiled sheets h_p .

Deflection of the profiled sheeting used as formwork shall be measured at the location of the ribs.

NOTE: In the case of stringent design requirements, pan deflection in the service design calculations should be included.

If the maximum deflection δ_s of the sheeting under its own weight plus that of the wet concrete and reinforcement, calculated for serviceability, is less than 1/10 of the slab depth, the ponding effect may be ignored in the design of the steel sheeting. If this limit is exceeded, this effect shall be allowed for. It may be assumed in design that the nominal thickness of the concrete is increased over the whole span by $0.7\delta_s$. If the beams supporting the sheeting also deflect appreciably, then the effect of this movement shall be included in the calculations.

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NOTE: The deflection should not exceed the values provided in Table B2.

2.7 ULTIMATE LIMIT STATE REQUIREMENTS FOR COMPOSITE SLABS

2.7.1 Design criterion

The design values of internal forces shall not exceed the design values of resistance for the ultimate limit states.

2.7.2 Flexure for composite slabs

The bending resistance M_{Rd} of any cross-section shall be determined by plastic theory based on full or partial shear connection. The partial connection method shall be used only for composite slabs with a ductile longitudinal shear behaviour, as defined in this Clause (2.7.2).

The longitudinal shear behaviour shall be considered as ductile if the failure load in the standard tests in Appendix H exceeds the load causing a recorded end slip of 0.1 mm by more than 10%. If the maximum load is reached at a midspan deflection exceeding $L/50$, the failure load shall be taken as the load at the midspan deflection of $L/50$.

NOTE: As an alternative to the partial connection method, or for composite slabs with brittle longitudinal shear behaviour, the m - k method given in Appendix H may be used.

In hogging bending regions, the contribution of the steel sheeting shall only be taken into account where the sheet is continuous and when, for the construction phase, redistribution of moments by plastification of cross-sections over supports has not been used.

For the effective area A_{pe} of the steel sheeting, the width of embossments and indentations in the sheet shall be neglected, unless it is shown by tests that a larger area is effective. The area A_{pe} shall be measured over the width b of the slab considered.

The effect of local buckling of compressed parts of the sheeting shall be taken into account by using the effective widths not exceeding twice the limiting values given in AS/NZS 4600.

NOTE: One should note that an increased local buckling coefficient is able to be included in the calculation of the effective width, whereby $k = 10.0$ should be used when the concrete is in its hardened state. A local buckling coefficient of 4.0 should still be used for plate elements in the wet concrete and construction stage.

At any cross-section, the design bending moment M shall not exceed the design resistance M_{Rd} .

The design resistance is:

$$M_{Rd} = N_{p,d}z + M_{pr,d} \quad \dots 2.7.2(1)$$

where

$N_{p,d}$ = design axial force resisted by the profiled sheeting, as given by Equation 2.7.2(3)

$M_{pr,d}$ = plastic resistance moment of the profiled steel sheeting reduced by the axial force $N_{p,d}$. For simplification, its value may be taken as equal to:

$$1.25M_{pa,d} \left(1 - \frac{N_{p,d}}{N_{yp,d}} \right) \leq M_{pa,d}$$

$M_{pa,d}$ = design plastic resistance in bending of the profiled sheeting
 $= \phi M_{pa}$

ϕ = capacity reduction factor (see Table 1.4.3)

M_{pa} = nominal plastic resistance in bending of the profiled sheeting

z = composite lever arm calculated with Equation 2.7.2(4)

The design axial force resisted by the profiled sheeting in full shear connection $N_{FSC,d}$ is:

$$N_{FSC,d} = \min(N_{yp,d}, N_{c,d}) \quad \dots 2.7.2(2)$$

where

$N_{yp,d}$ = design axial force resisted by the profiled sheeting at yield

$$\begin{aligned}
 &= f_{yp,d} A_{pe} \\
 f_{yp,d} &= \phi f_{yp} \\
 \phi &= \text{capacity reduction factor (see Table 1.4.3)} \\
 N_{c,d} &= 0.85 f_{cd} h_c b \\
 f_{cd} &= \phi_c f'_c \\
 \phi_c &= \text{capacity reduction factor (see Table 1.4.3)}
 \end{aligned}$$

The design axial force resisted by the profiled sheeting $N_{p,d}$ at a particular cross-section is:

$$N_{p,d} = \min(N_{\tau,d}, N_{FSC,d}) \quad \dots 2.7.2(3)$$

where

$$\begin{aligned}
 N_{\tau,d} &= \text{design axial force resisted by the shear connection between the profiled sheeting and the concrete slab relying on the mechanical or frictional interlock [Types (a) and (b) as defined in Clause 2.1.2]} \\
 &= \tau_{u,Rd} b L_x \\
 \tau_{u,Rd} &= \text{design shear strength } (\phi \tau_{u,Rk}) \text{ obtained from slab tests meeting the basic requirements of the partial connection method given in Appendix H} \\
 L_x &= \text{distance of the cross-section being considered to the nearest support for a simply-supported slab; for continuous spans where Figure 2.7.2(C) applies, distance of the cross-section being considered to the nearest support reduced by } 0.1L \text{ for any shear span that includes hogging bending where } L \text{ is the span being considered}
 \end{aligned}$$

At a particular cross-section, the design is classified as based on full or partial shear connection depending on the magnitude of the axial force resisted by the profiled sheeting:

- (a) Full shear connection if $N_{p,d} = N_{FSC,d}$.
- (b) Partial shear connection if $N_{p,d} < N_{FSC,d}$.

For simplification, the distance z shall be determined based on:

$$z = h - 0.5h_1 - e_p + (e_p - e) \frac{N_{p,d}}{N_{yp,d}} \quad \dots 2.7.2(4)$$

where

$$\begin{aligned}
 h_1 &= x_{pl} \text{ when the section is designed in partial shear connection or when the section is designed in full shear connection with } x_{pl} < h_c \text{ (i.e. if the neutral axis is above the steel sheeting as shown in Figure 2.7.2(A)); or} \\
 &= h_c \text{ when the section is designed in full shear connection and } x_{pl} \geq h_c \text{ (i.e. if the neutral axis is in the steel sheeting as shown in Figure 2.7.2(B)).} \\
 x_{pl} &= \text{location of the plastic neutral axis from the extreme compressive fibre of the composite slab} \\
 &= N_{p,d} / (0.85 f_{cd} b) \\
 e &= \text{distance from the centroidal axis of the profiled sheeting to the extreme fibre of the composite slab in tension} \\
 e_p &= \text{distance from the plastic neutral axis of the profiled sheeting to the extreme fibre of the composite slab in tension}
 \end{aligned}$$

If the contribution of the steel sheeting is neglected, the hogging bending resistance of a cross-section shall be calculated from the stress distribution in Figure 2.7.2(C).

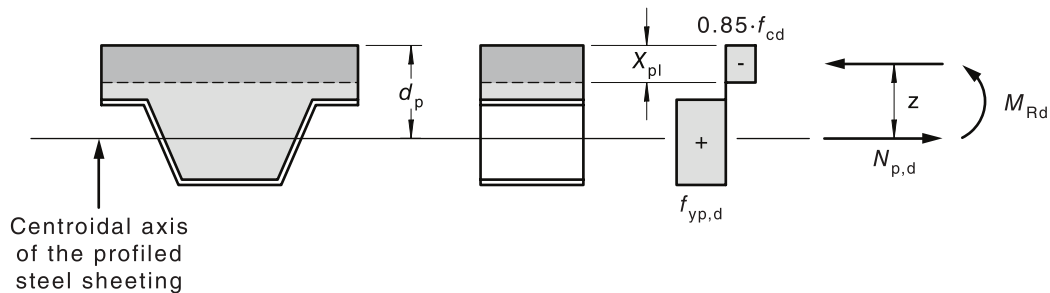


FIGURE 2.7.2(A) STRESS DISTRIBUTION FOR SAGGING BENDING IF THE NEUTRAL AXIS IS ABOVE THE STEEL SHEETING

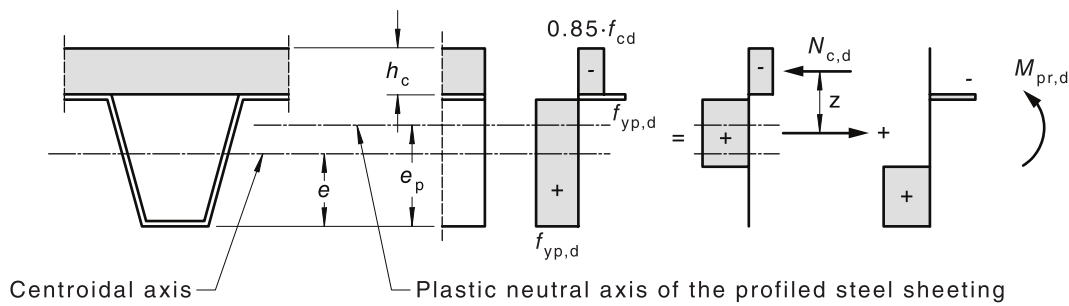


FIGURE 2.7.2(B) STRESS DISTRIBUTION FOR SAGGING BENDING IF THE NEUTRAL AXIS IS IN THE STEEL SHEETING

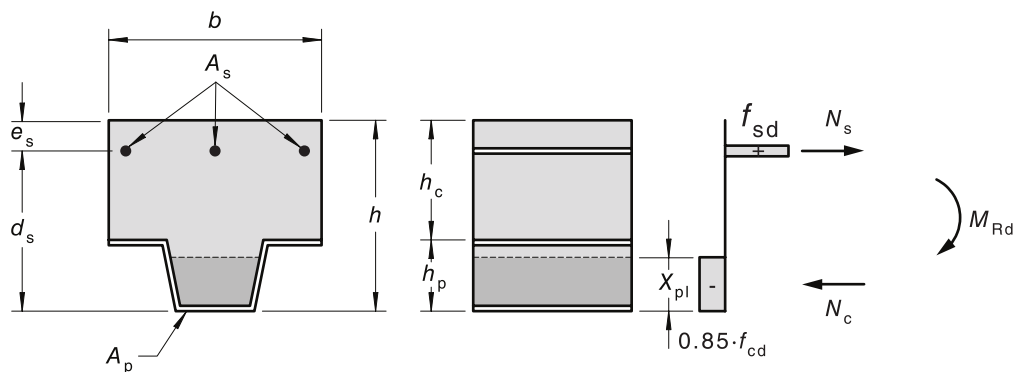


FIGURE 2.7.2(C) STRESS DISTRIBUTION FOR HOGGING BENDING

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In Equation 2.7.2(3), $N_{\tau,d}$ may be increased by μR^* provided that $\tau_{u,Rd}$ is determined without taking into account the additional longitudinal shear resistance caused by the support reaction, where:

R^* = support reaction

μ = nominal factor

NOTE: The recommended value for μ is 0.5.

In the partial connection method, additional bottom reinforcement may be taken into account.

NOTE: For the m - k method, if additional bottom reinforcement is included, this shall be incorporated into the tests defined in Appendices D and H.

In the presence of an end anchorage of Type (c), as defined in Clause 2.1.2, the value for $N_{\tau,d}$ in Equation 2.7.2(3) may be increased by the design resistance of the end anchorage. The design resistance $P_{pb,Rd}$ of a headed stud through-deck welded to the top flange of the supporting steel beam and used for end anchorage shall be taken as the smaller of the design shear resistance of the stud in accordance with Clause 3.6 or the bearing resistance of the sheet determined with the following Equation:

$$P_{pb,Rd} = k_{\varphi} d_{do} t f_{yp,d} \leq A_{pe,pb} f_{yp,d} \quad \dots 2.7.2(5)$$

with:

$$k_{\varphi} = 1 + a/d_{do} \leq 6.0 \quad \dots 2.7.2(6)$$

where

d_{do} = the diameter of the weld collar

a = the distance from the centre of the stud to the end of the sheeting, to be not less than $1.5d_{do}$

t = the thickness of the sheeting

$A_{pe,pb}$ = effective cross-sectional area of the profiled steel sheeting with width equal to the spacing between adjacent shear connectors along the length of the beam, with the width of embossments and indentations in the sheet neglected, unless it is shown by tests that a larger area is effective (for sheeting with holes, the net area shall be used)

NOTE: For weld collars conforming with the requirements of ISO 13918, the diameter of the weld collar d_{do} may be taken as 1.1 times the diameter of the shank of the stud d_{bs} .

2.7.3 Flexure and longitudinal shear for post-tensioned composite slabs

At any cross-section, the design bending moment M shall not exceed the design resistance M_{Rd} .

The bending resistance of a post-tensioned composite slab to be used in reinforced concrete or prestressed concrete structures shall be determined based on equilibrium and strain-compatibility considerations, and shall be consistent with the following assumptions:

- (a) Plane concrete sections normal to the axis remain plane after bending.
- (b) Concrete has no tensile strength.
- (c) The distribution of compressive stress in the concrete is determined from a stress-strain relationship for the concrete in accordance with AS 3600 or NZS 3101, and is modified to account for the capacity reduction factors as specified in Table 1.4.3.
- (d) The maximum compressive strain in the reinforcement does not exceed 0.003.

- (e) The contribution of the profiled steel sheeting shall be included only for ductile post-tensioned slabs and accounted for based on full and partial connection theory, with its material response described by an elastic-perfectly plastic model defined by the steel sheeting elastic modulus and design yield strength. The effect of local buckling of compressed parts of the sheeting shall be taken into account as specified in Clause 2.7.2. A post-tensioned slab is classified as ductile if the peak load is at least 1.1 times the load at which a slip of 0.5 mm is observed. Composite post-tensioned slabs which do not fall in this category shall be designed for strength ignoring the contribution of the profiled steel sheeting.
- (f) Material properties of steel reinforcement and prestressing strands are determined in accordance with AS 3600 or NZS 3101, and the capacity reduction factors shall be adopted as specified in Clause 1.3.3.
- (g) All components forming the cross-section possess sufficient ductility to reach the adopted stress levels. As a consequence of this latter assumption, the possible occurrence of brittle failures of one of the components forming the cross-section, for example, rupture of the steel sheet, shall be verified separately.

For simplification, the design resistance is determined as:

$$M_{Rd} = N_{c,d} z_c - N_{pre,d} z_{pre} + M_{pr,d} \quad \dots 2.7.3(1)$$

where

$N_{c,d}$ = design axial force resisted by the concrete assuming a rectangular stress block in which—

(i) the maximum strain in the extreme compression fibre is taken as 0.003; and

(ii) a uniform stress of $f_{cd} (= \phi_c \alpha_2 f'_c)$ acts on an area bounded by the edges of the cross-section and by a line parallel to the neutral axis under the loading concerned, located at a distance γx_{pl} from the extreme compressive fibre, where $\alpha_2 = 0.85 - 0.0015f'_c$ (with limits of $\alpha_2 \geq 0.67$) and $\gamma = 0.97 - 0.0025f'_c$ (with limits of $\gamma \geq 0.67$). For any section where the width reduces from the neutral axis towards the compression face, α_2 shall be reduced by 10%

z_c = level arm for $N_{c,d}$ measured from the line of action of $N_{p,d}$ as given by Equation 2.7.2(4)

$N_{pre,d}$ = design axial force resisted by the prestressing strands. In the absence of a more accurate calculation and, provided the minimum effective stress in the strands is not less than $0.5f_{pb}$, the maximum stress that would be reached in bonded strands at ultimate strength σ_{pu} shall be taken as given by Equation 2.7.3(2)

$$= \phi \sigma_{pu} A_{pre}$$

A_{pre} = area of prestressing strands located at d_{pre} (where d_{pre} is defined as the distance from the extreme compressive fibre of the concrete to the centroid of prestressing strands)

z_{pre} = level arm for $N_{pre,d}$ measured from the line of action of $N_{p,d}$

$$= h - d_{pre} - e_p + (e_p - e) N_{p,d} / N_{yp,d}$$

$M_{pr,d}$ = plastic resistance moment of the profiled steel sheeting reduced by the axial force $N_{p,d}$ (as defined in Clause 2.7.2)

$N_{p,d}$ = design axial force resisted by the profiled sheeting calculated with Equation 2.7.2(3) replacing $N_{FSC,d}$ with $N_{FSC,d} = \min(N_{yp,d}, N_{c,d} - N_{pre,d})$

In the presence of non-prestressed reinforcement, its contribution to the design moment resistance of Equation 2.7.3(1) shall be included assuming an elastic-perfectly plastic model defined by the reinforcement elastic modulus and design yield strength. The actual stress resisted by the reinforcement shall be determined based on the calculated strains. Its design resistance shall be determined with the capacity reduction factor specified in Table 1.4.3 for the steel material.

The ultimate strength σ_{pu} for the bonded strands to be used in the calculation of $N_{pre,d}$ in Equation 2.7.3(1) is:

$$\sigma_{pu} = f_{pb} \left(1 - \frac{k_1 k_2}{\gamma} \right) \quad \dots 2.7.3(2)$$

where

- f_{pb} = characteristic minimum breaking strength of the prestressing strand
- f_{ypre} = yield strength of the prestressing strand
- k_1 = 0.28 if $f_{ypre}/f_{pb} \geq 0.9$; or
= 0.4 otherwise
- k_2 = $\frac{1}{bd_{pre}f'_c} [A_{pre}f_{pb} + A_{pc}f_{yp} + (A_{st} - A_{sc})f_{ys}]$
- A_{st}, A_{sc} = cross-sectional areas of the tensile and compressive non-prestressed steel reinforcement
- f_{ys} = yield strength of the non-prestressed steel reinforcement

In the calculation of k_2 to be used in Equation 2.7.3(2), compressive reinforcement shall be taken into account only if d_{sc} (the distance from the extreme compressive fibre of the concrete to the centroid of compressive reinforcement) is not greater than $0.15d_{pre}$, in which case k_2 shall be taken as not less than 0.17.

Strength requirements shall be deemed satisfied if the post-tensioned slab is designed in accordance with AS 3600 or NZS 3101 ignoring the presence of the profiled steel sheeting and accounting for the concrete slab, steel reinforcement and prestressing strands.

NOTE: The possibility of ignoring the presence of the profiled steel sheeting is permitted only when verifying the ultimate limit state. When verifying the serviceability limit state, the presence of the sheeting determines the shrinkage distribution to be used in the design even if the sheeting is not considered in determining the flexural strength and stiffness when the concrete is hardened.

For a ductile post-tensioned composite slab connecting to a band beam, the longitudinal shear resistance shall be calculated in accordance with Clause 2.7.2 considering the contribution of mechanical and frictional interlock [Types (a) and (b) as defined in Clause 2.1.2] and shall not include the additional longitudinal shear resistance provided by the support reaction.

2.7.4 Vertical shear

The vertical shear resistance $V_{v,Rd}$ of a composite slab over a width equal to the distance between centres of ribs, shall be determined in accordance with AS 3600 or NZS 3101. The cross-sectional area of the profiled steel sheeting in the tensile zone may be considered in the calculation of the vertical shear resistance, provided that it is fully anchored at the cross-section under consideration.

NOTES:

- 1 If the sheeting is not fully anchored, its contribution may be determined from Clause 2.7.2.
- 2 In calculating the vertical shear resistance of a composite slab close to a support, anchorage to the sheeting may be provided by a headed stud through-deck welded to the top flange of the supporting steel beam (see Clause 2.7.2).

The vertical shear resistance of a post-tensioned composite slab at the face of a band beam shall be determined in accordance with AS 3600 or NZS 3101 ignoring the contribution of the steel sheeting.

2.7.5 Punching shear

The punching shear resistance $V_{v,Rd}$ of a composite slab at a concentrated load shall be determined in accordance with AS 3600 or NZS 3101. The critical perimeter shall be determined as shown in Figure 2.7.5 and, for a loaded area $a_p \times b_p$, which is applied to a screed with a thickness h_f , shall be taken to be:

$$c_p = 2\pi h_c + 2(b_p + 2h_f) + 2(a_p + 2h_f + 2d_p - 2h_c) \quad \dots 2.7.5$$

where

d_p = The distance from the centroidal axis of the profiled steel sheeting and the extreme fibre of the composite slab in compression

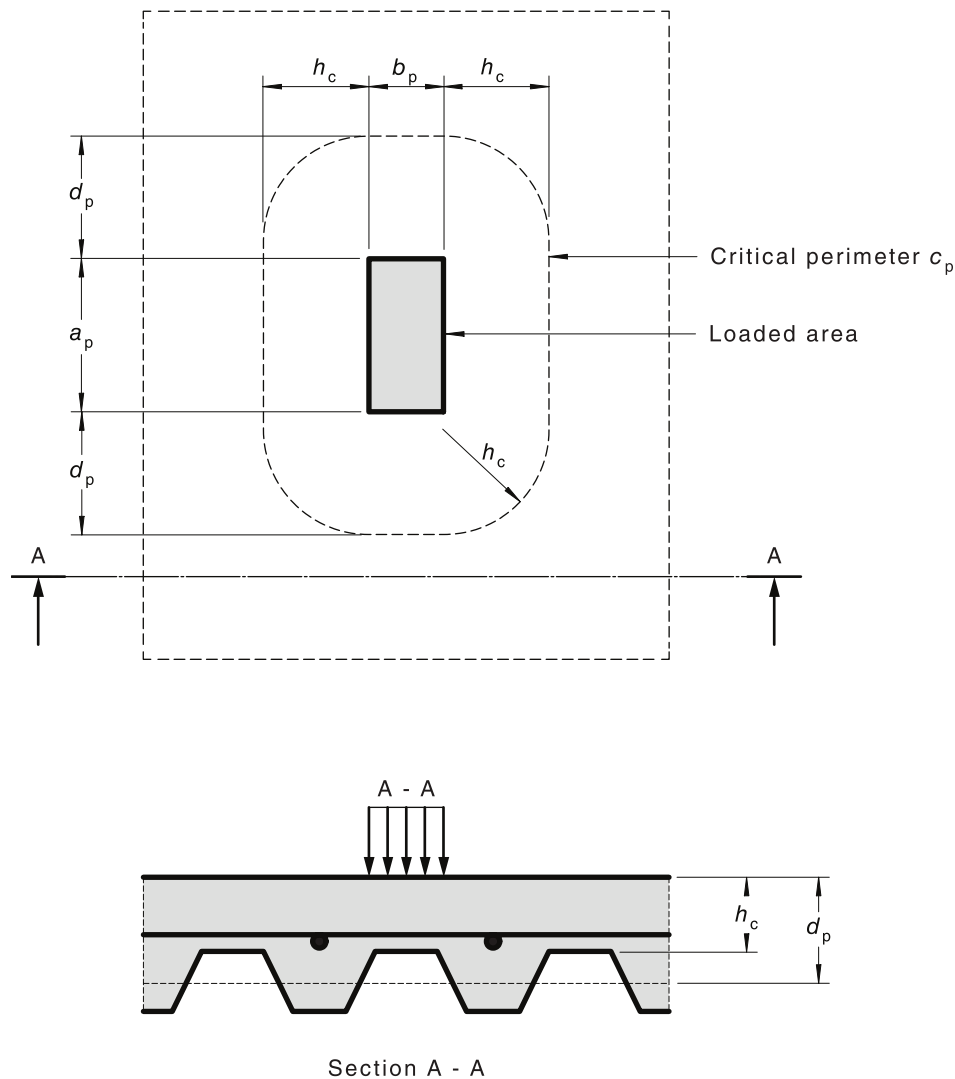


FIGURE 2.7.5 CRITICAL PERIMETER FOR PUNCHING SHEAR

2.8 VERIFICATION OF COMPOSITE SLABS FOR SERVICEABILITY LIMIT STATES

2.8.1 General

The deflection of a composite slab shall be determined in accordance with Clause 2.8.2 or Clause 2.8.3, and shall be controlled in accordance with Clause 6.2.

The requirements for crack control shall be in accordance with Clause 2.8.4.

2.8.2 Slab deflection by refined calculation

The calculation of the deflection of a slab by refined calculation shall make allowance for the following:

- Cracking and tension-stiffening of the concrete.
- Shrinkage and creep properties of the concrete accounting for the presence of the steel sheeting.
- Expected load history.
- Expected construction procedure.

- (e) Deflection of formwork or settlement of props during construction (particularly when the slab formwork is supported on suspended floors or beams below).
- (f) Relaxation of prestressing strands in post-tensioning composite slabs.
- (g) For slabs with steel sheeting profiles that exhibit slip at service conditions, account shall be taken for the partial interaction behaviour between the steel sheeting and the concrete slab in the refined calculation.

2.8.3 Slab deflection by simplified calculation

2.8.3.1 General

This clause applies to the design of composite slabs when the effects of end slip are deemed to be insignificant. For external spans, the effects of end slip shall be neglected if the initial slip load in the standard tests according to Appendix H (defined as the load causing an end slip of 0.5 mm) exceeds 1.2 times the design service load. Where the initial slip load occurs at a load below 1.2 times the design service load, end anchors should be provided. Alternatively, deflections should be calculated including the effect of end slip.

Deflections due to loading applied to the steel sheeting alone shall be calculated in accordance with Clause 2.6. The short-term deflection and the time-dependent deflections due to creep and shrinkage shall be calculated in accordance with Clauses 2.8.3.2, 2.8.3.3 and 2.8.3.4, respectively.

2.8.3.2 Short-term deflection

The short-term deflections δ_0 that occur immediately on the application of the external loads and prestressing shall be calculated using the value of E_{cj} (where E_{cj} is the mean value of the modulus of elasticity of the concrete determined at the time under consideration) determined in accordance with AS 3600 or NZS 3101 and the value of the effective second moment of area of the member (I_{ef}).

The material properties for the concrete and losses of prestress in the strands shall be those corresponding to the age of the slab when the external loads and the prestressing are first applied (i.e. the age when δ_0 is to be determined). The value of I_{ef} shall be determined from the values of I_{ef} at nominated cross-sections as follows:

- (a) For a simply supported span, the value at midspan.
- (b) In a continuous slab—
 - (i) for an interior span, half the midspan value plus one quarter of each support value; or
 - (ii) for an end span, half the midspan value plus half the value at the continuous support.
- (c) For a cantilever, the value at the support.

For the purpose of the above determinations, the value of I_{ef} at each of the cross-sections nominated in Items (a) to (c) above is given by:

When $M_s^* \leq M_{cr}$

$$I_{ef} = I_{ef,max} \quad \dots 2.8.3.2(1)$$

Otherwise

$$I_{ef} = \frac{I_{cr}}{1 - \left(1 - \frac{I_{cr}}{I_{uncl}}\right) \left(\frac{M_{cr}}{M_s^*}\right)^2} \leq I_{ef,max} \quad \dots 2.8.3.2(2)$$

where

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- $I_{ef,max}$ = maximum effective second moment of area and equal to I_{uncr}
 I_{cr} = second moment of area of the cracked slab section (i.e. ignoring the contribution of the concrete in tension) with the steel reinforcement and steel sheeting transformed to an equivalent area of concrete
 I_{uncr} = second moment of area of the uncracked slab section with the steel reinforcement and steel sheeting transformed to an equivalent area of concrete
 M_s^* = maximum in-service moment resisted by the cross-section
 $M_{cr} = Z(f'_{ct,f} - \sigma_{cs} + \sigma_{cpre}) \geq 0$. . . 2.8.3.2(2)
 where
 Z = section modulus of the uncracked section, referred to the extreme fibre at which cracking occurs
 $f'_{ct,f}$ = characteristic flexural tensile strength of concrete in accordance with AS 3600 or NZS 3101
 σ_{cs} = maximum shrinkage-induced tensile stress on the uncracked section at the extreme fibre at which cracking occurs (see Clause 2.8.3.4). The design shrinkage strain of concrete to be used in this calculation should be the one related to the time when deflection is to be calculated
 σ_{cpre} = compressive stress induced by the post-tensioning, accounting for all prestressing losses, at the time when deflection is to be calculated, at the extreme fibre at which cracking occurs

2.8.3.3 Creep deflection

The deflection component due to creep δ_{cc} shall be determined by multiplying the short-term deflection produced by the sustained load by the following creep multiplier:

$$\alpha_{cc} = \frac{E_c I_{ef}}{E_{ef,cc} I_{ef,cc}} - 1 \quad \dots 2.8.3.3$$

where

- E_c = mean value of the elastic modulus at the time of first loading (or calculated at 28 days if time of first loading is not known and is expected to be greater than 28 days)
 $E_{ef,cc} = \frac{E_c}{1 + \phi_{cc}}$
 ϕ_{cc} = creep coefficient calculated for concrete at the time of interest t for a load first applied at t_0 , in accordance with AS 3600 or NZS 3101 considering the following conditions in the calculation of the hypothetical thickness $t_h (= 2A_g/u_e)$:
 (a) A_g equals the gross-sectional area of the composite slab (therefore using the actual composite slab thickness in the calculation of A_g); and
 (b) u_e is taken equal to the slab width (therefore assuming that drying occurs only from the exposed surface of the slab only)
 I_{ef} = effective second moment of area calculated with Equation 2.8.3.2(1) using E_c for the concrete modulus
 $I_{ef,cc}$ = effective second moment of area calculated with Equation 2.8.3.2(1) using

$E_{\text{ef.cc}}$ for the concrete modulus

NOTE: When evaluating $I_{\text{ef.cc}}$, the second moment of area associated with the cracked cross-section may be determined based on the cracked geometry identified for the short-term deflection calculations.

2.8.3.4 Shrinkage deflection

The deflection component due to shrinkage δ_{cs} shall be determined from a long-term analysis considering only shrinkage effects expressed by the following shrinkage-induced curvature:

$$\kappa_{\text{cs}} = (1 - \gamma_{\text{cs}}) \kappa_{\text{cs,cr}} + \gamma_{\text{cs}} \kappa_{\text{cs,uncr}} \quad \dots 2.8.3.4$$

and

$$\gamma_{\text{cs}} = \left(\frac{M_{\text{cr}}}{M_s^*} \right)^2 \leq 1$$

where

$\kappa_{\text{cs,uncr}}$ = curvature produced by shrinkage over an uncracked section based on a long-term analysis and considering the effective modulus of elasticity $E_{\text{ef.cs}}$ for the concrete component

$\kappa_{\text{cs,cr}}$ = curvature produced by shrinkage over a cracked section based on a long-term analysis and considering the effective modulus of elasticity $E_{\text{ef.cs}}$ for the concrete component

$$E_{\text{ef.cs}} = \frac{E_c}{1 + 0.55\phi_{\text{cc}}}$$

The shrinkage profile to be used in the calculation of the shrinkage deflection and of the cracking moment shall be based on a linearly varying shrinkage distribution with $0.2\varepsilon_{\text{cs}}$ shrinkage strain at the slab soffit and $1.2\varepsilon_{\text{cs}}$ at the exposed surface of the slab, where ε_{cs} is the concrete shrinkage strain. The reference shrinkage value of ε_{cs} is calculated in accordance with AS 3600 or NZS 3101 adopting a hypothetical thickness t_h equal to the slab thickness h .

NOTES:

- 1 The non-uniform shrinkage profile develops due to the impermeable steel sheeting at the slab soffit. The non-uniform linear profile is an approximation of the real shrinkage gradient introduced to simplify the design calculations. The conditions specified for the hypothetical thickness t_h are based on the fact that the non-uniform shrinkage gradient has been calibrated against shrinkage profiles exhibited by concrete slabs exposed on both sides with same thickness as the composite slabs.
- 2 The application of surface treatments or installation floor coverings can influence and reduce the ability of the concrete to dry from its upper face. In these cases, it is possible to reduce the drying shrinkage component used in the deflection calculations to reflect the reduction in drying taking place from the slab upper surface, as long as the adopted solution becomes part of the structural design specifications. It is important to account for this effect only for the duration of time over which the surface treatments or coverings are expected to be reducing the drying of the upper slab surface.

2.8.4 Control of cracking of concrete

Cracking requirements for slabs are specified in Clause 6.3.

SECTION 3 DESIGN OF COMPOSITE BEAMS

3.1 GENERAL

This section outlines the ultimate and serviceability limit state design of composite beams. The effective section of a composite beam shall be determined in accordance with Clause 3.4 and used for strength and deflection design in accordance with Clauses 3.5 and 3.10. The effective section shall be determined for each potentially critical cross-section defined in Clause 3.5.3, except at the ends of the beam where the steel beam alone shall be assumed to act.

The design action effects arising from the design loads specified in Clause 1.4 for the ultimate limit state (strength) after the development of composite action, (that is, Construction Stages 5 and 6 as defined in Appendix A and for the in-service condition) shall be determined in accordance with the procedure given in Clause 3.3.

NOTE: Prior to the development of composite action, the steel beam shall be designed in accordance with AS 4100 or NZS 3404 for the loads and other actions during construction.

3.2 STEEL BEAM REQUIREMENTS

The steel beam shall be entirely below, but in contact with, the soffit of the concrete slab, and shall be of structural steel, symmetrical about its vertical axis (that is, doubly symmetric or monosymmetric), suitably proportioned and have one of the following forms (see Figure 3.2)—

- (a) a hot-rolled I-section, or channel section;
- (b) a welded I-section;
- (c) a rectangular cold-formed hollow section;
- (d) a fabricated I-section, Tee section, channel section or rectangular hollow section; or
- (e) any of the above sections where an additional plate is welded to the bottom flange.

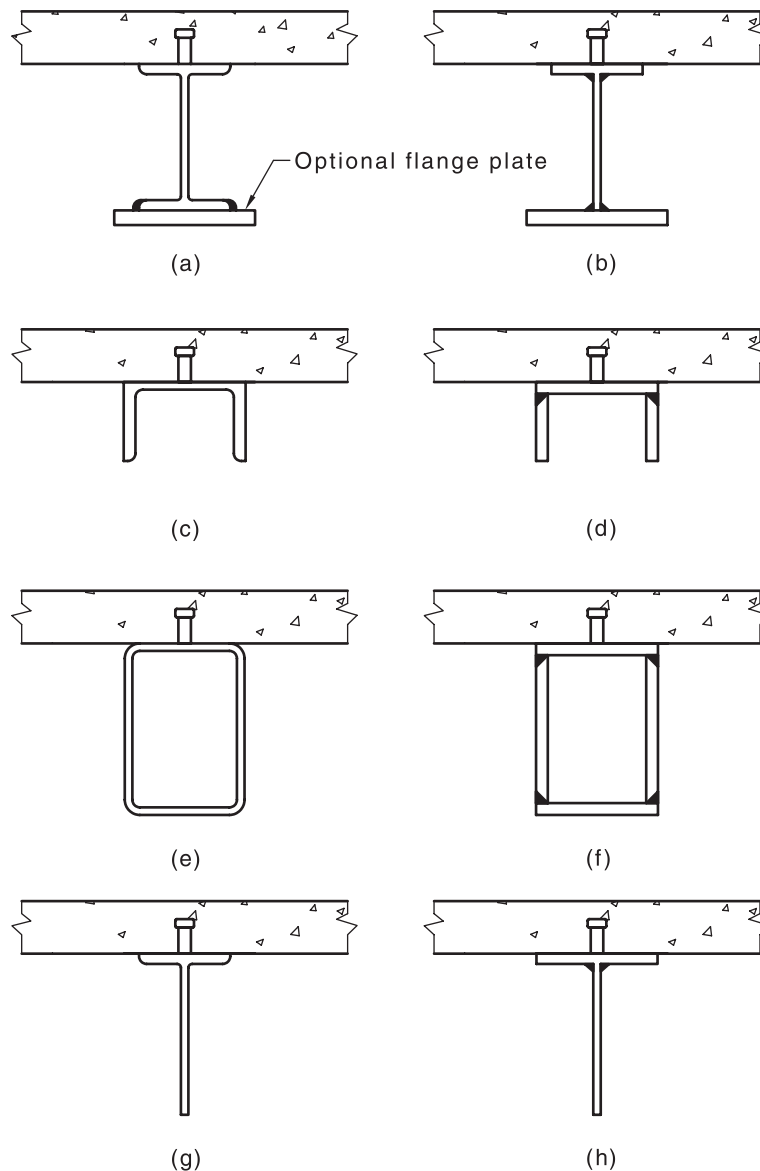


FIGURE 3.2 ALTERNATIVE STEEL BEAM TYPES

3.3 CALCULATION OF DESIGN ACTION EFFECTS DUE TO DESIGN LOADS

3.3.1 General

For the purpose of conforming with the requirements for the strength limit state, the design action effects in a composite beam and its joints shall be determined using the calculation procedure in Clause 3.3.2.

3.3.2 Calculation procedure

The composite beam shall be considered to have an effective span L_{ef} . The design loads calculated in accordance with Section 1.4 shall be assumed to act over the tributary area, taking into account the effect of any propping to the slab. Except for the case of non-linear resistance to bending (as defined in Clause 3.5.4.5), when calculating the design action effects for the composite beam, the effects of the construction sequence shall be ignored, whereby it shall be assumed that the design loads are entirely resisted by the action of the composite beam.

NOTES:

- 1 It is assumed that at the ultimate limit state, the stresses in the composite beam section being checked for strength are not affected by the sequence of construction or loading, and that they may be calculated using rectangular stress block theory in accordance with Section 6.
- 2 If the capacity of a composite beam is being checked for Construction Stages 5 and 6, slab propping can affect the tributary area determination; however, the design action effects M^* and V^* are calculated without regard for the sequence of construction or loading.
- 3 If the capacity of a composite beam is being checked for the in-service condition, any previous slab propping neither affects the tributary area determination nor the calculation of M^* and V^* .

3.3.3 Effective span

The effective span of a composite beam (L_{ef}) shall be taken as the approximate distance between points of zero bending moment. For typical continuous composite beams, where a moment envelope from various load arrangements governs the design, and for cantilevers, L_{ef} is taken as shown in Figure 3.4.2.1.

3.4 EFFECTIVE SECTION OF A COMPOSITE BEAM**3.4.1 General**

The effective width of the concrete compression flange shall be determined in accordance with Clause 3.4.2.

The region of the concrete slab within the effective width shall be designed for longitudinal shear in accordance with Section 3.8.

The portion of the steel beam considered to form part of the effective section of the composite beam cross-section shall be determined in accordance with Clause 3.4.3.

Any vertical construction joint that falls within the effective width shall be designed in accordance with Section 3.8, taking into account the surface condition of the original concrete face. Any concrete that falls above a horizontal construction joint (for example, when a screed is poured on top of an existing slab) shall be ignored when calculating the effective section, unless the joint is designed for longitudinal shear and the specified compressive strength f'_c of the concrete is at least as great as that assumed in design for the remainder of the slab.

3.4.2 Effective width of concrete compression flange**3.4.2.1 Solid slab**

Where the concrete flange is a solid slab the effective width shall be calculated in accordance with the following provisions.

At mid-span or an internal support, the total effective width b_{eff} , see Figure 3.4.2.1, may be determined as:

$$b_{eff} = b_0 + \sum b_{ei} \quad \dots 3.4.2.1(1)$$

where

b_0 = distance between the centres of the outstand shear connectors

b_{ei} = value of the effective width of the concrete flange on each side of the web and taken as $L_{ef}/8$ (but not greater than the geometric width b_i) The value b_i defines the distance from the outstand shear connector to a point mid-way between adjacent webs, measured at mid-depth of the concrete flange, except that at a free edge b_i is the distance to the free edge

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The effective width b_{eff} at an end support is determined as:

$$b_{\text{eff}} = b_0 + \sum \beta_i b_{\text{ei}} \quad \dots 3.4.2.1(2)$$

with

$$\beta_i = (0.55 + 0.025 L_{\text{ef}} / b_{\text{ei}}) \quad \dots 3.4.2.1(3)$$

where

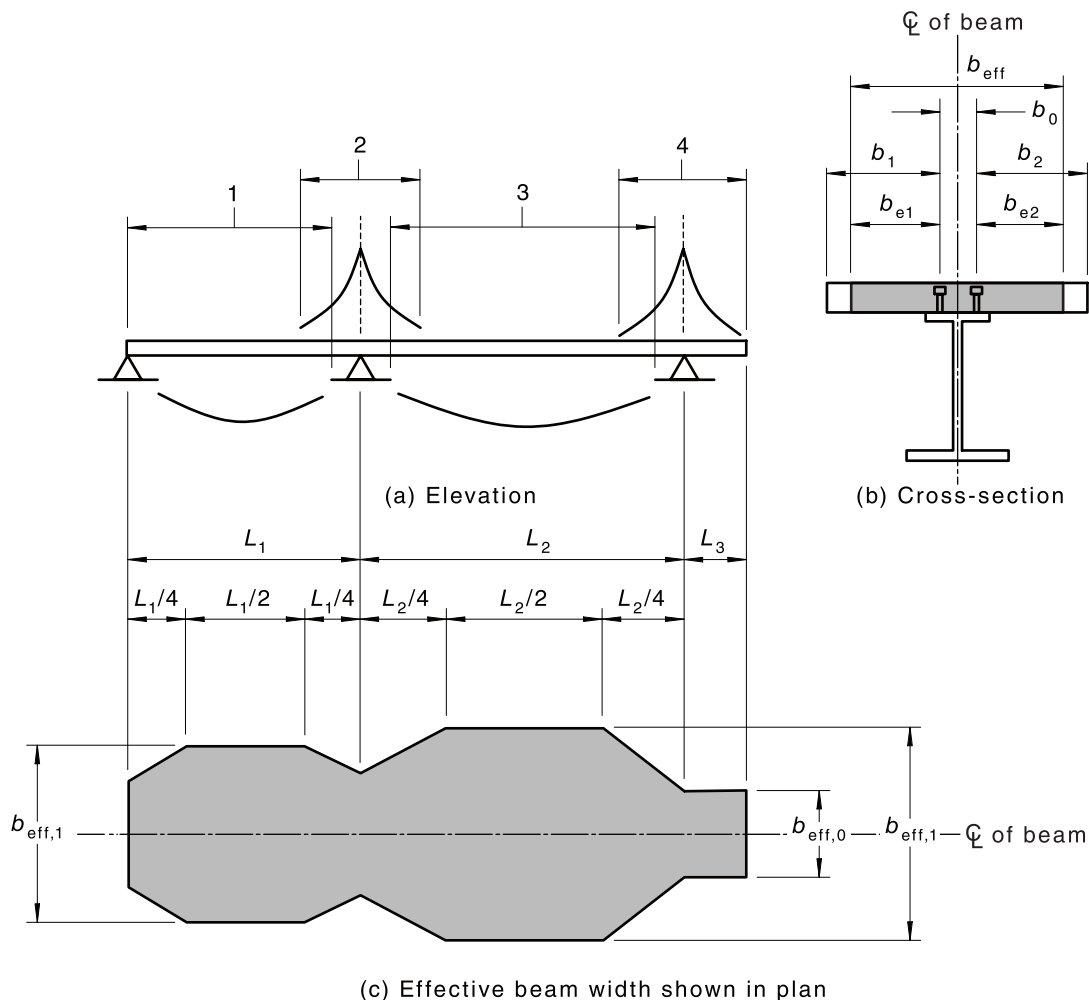
b_{ei} = effective width, see Equation 3.4.2.1(1), of the end span at mid-span and L_{ef} is the equivalent span of the end span according to Figure 3.4.2.1

The distribution of the effective width between supports and midspan regions shall be assumed to be as shown in Figure 3.4.2.1 or calculated by more refined analysis.

NOTE: Where the bending moment distribution is influenced by the resistance or the rotational stiffness of a joint, this should be considered in the determination of the length L_{ef} .

For analysis, b_0 may be taken as zero and b_i measured from the centre of the web.

When a slab has pockets or cut-outs within its effective width then, at the cross-sections of concern, b_{eff} shall be reduced by the width they encroach into this region.



LEGEND:

- $L_{ef} = 0.85 L_1$ for b_{eff} in Segment 1
- $L_{ef} = 0.25 (L_1 + L_2)$ for b_{eff} in Segment 2
- $L_{ef} = 0.70 L_2$ for b_{eff} in Segment 3
- $L_{ef} = 2 L_3$ for b_{eff} in Segment 4

FIGURE 3.4.2.1 EFFECTIVE SPANS FOR EFFECTIVE WIDTH OF CONCRETE FLANGE

3.4.2.2 Composite slab

For composite slabs in which the ribs are parallel to or within 15° of the steel beam axis, the effective width of the concrete flange shall be calculated in accordance with Clause 3.4.2.

For composite slabs in which the ribs form an angle greater than 15° from the axis of the steel beam, only the contribution of the concrete above the ribs shall be considered based on the effective width calculated in accordance with Clause 3.4.2.1.

3.4.2.3 Voided slab

Where the concrete flange consists of a voided slab the effective width is reduced to account for the loss in compression transfer which occurs as a consequence of the voided slab units. The effective width shall be:

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$$b_{\text{eff}} = \left(\frac{\sqrt{1.2 f'_c}}{40} \frac{32 d_b}{500} \frac{f_{sy}}{460} 1000 \right) + 2.5g \quad \dots 3.4.2.3$$

where

d_b = diameter of the transverse reinforcement

f_{sy} = characteristic strength of the reinforcement

g = gap between the ends of the precast units

The effective width determined from Equation 3.4.2.3 however cannot exceed that determined from Clause 3.4.2.1.

Voided slab depths shall not exceed 260 mm and the plastic neutral axis of the composite section shall lie in the steel beam.

3.4.3 Effective portion of steel beam

3.4.3.1 General

The effective portion of the steel beam cross-section at the ultimate limit state shall be determined in accordance with—

- (a) Clause 3.4.3.2 if the entire depth of the steel beam is in tension; or
- (b) Clause 3.4.3.3 if there is compression in any part of the beam.

For fabricated steel beams, or steel beams with an additional plate welded to the bottom flange, the welds connecting the plate elements of the beam together shall be designed to transmit the shear forces that develop on account of the axial tensile forces assumed to be carried by these elements.

The effect of holing of the steel beam shall be ignored in the following cases:

- (i) Where holes are drilled in the top flange to accommodate high-strength structural bolts used as shear connectors in accordance with Clause 3.6.2.1.
- (ii) Where holes are drilled or cut in the web so that their greatest internal dimension L_w satisfies—

$$L_w/d_1 \leq 0.10 \quad \dots 3.4.3.1$$

3.4.3.2 Tension in whole of steel beam ($\beta = 1$)

The whole of the steel beam section at a cross-section of a composite beam shall be assumed to be effective.

3.4.3.3 Compression in part of steel beam ($\beta \leq 1$)

When part of the compression flange, or the compression flange and part or all of the web of the steel beam is in compression, account shall be taken of the slenderness (λ_e) of each of these plate elements either partially or fully in compression, in order to determine the effective portion of the steel beam (see Note 1). The plate element slenderness (λ_e) is given by—

$$\lambda_e = \left(\frac{b}{t} \right) \sqrt{\frac{f_y}{250}} \quad \dots 3.4.3.3$$

where

b = clear width of the element outstand from the face of the supporting plate element or the clear width of the element between faces of supporting plate elements

t = element thickness

f_y = yield stress of plate element used in design

A1 | Steel beams with slender plate elements shall not be used (see Note 2). The effective portion of a steel beam with either compact (see Note 3) or non-compact (see Note 4) plate elements shall be calculated according to the following:

- (a) If the compression flange and web are compact, the entire steel section shall be assumed to be effective.
- (b) If the outstand of the compression flange is non-compact, the effective flange width shall be the maximum width for which the flange is compact.
- (c) If the web is non-compact, the effective portion of the web shall be determined in accordance with Figure 3.4.3.3(A) or 3.4.3.3(B) in which the length 'x' is ineffective. Cold-formed, rectangular hollow steel sections, manufactured in accordance with AS/NZS 1163, shall have a compact compression flange, calculated in accordance with Table 3.4.3.3 and assuming a uniform compressive stress distribution across the width of the compression flange.

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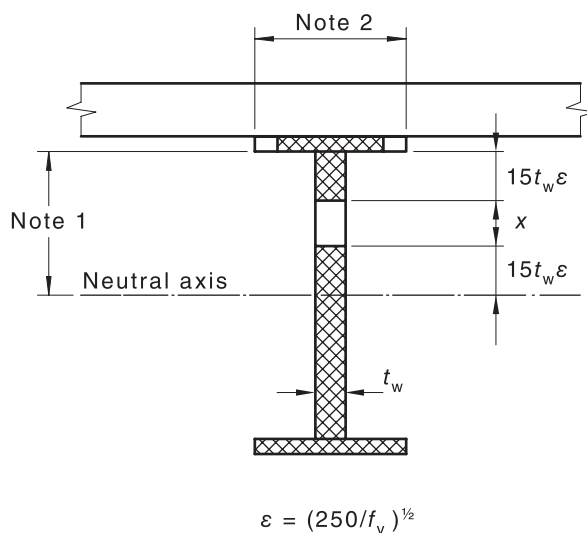
NOTES:

1 It is assumed that the entire width of the tension flange is effective.

A1 | 2 Slender plate elements are such that $\lambda_e > \lambda_{ey}$, where values of the yield slenderness limit λ_{ey} are given in Table 3.4.3.3(A) or Table 3.4.3.3(B).

A1 | 3 Compact plate elements are such that $\lambda_{ep} \geq \lambda_e$, where values of the plasticity slenderness limit λ_{ep} are given in Table 3.4.3.3(A).

4 Non-compact plate elements are such that $\lambda_{ey} \geq \lambda_e > \lambda_{ep}$.



Effective steel section

NOTES:

1 Determined in accordance with AS 4100 or NZS 3404.

2 Determined in accordance with Table 3.4.3.5, AS 4100 or NZS 3404.

FIGURE 3.4.3.3(A) EFFECTIVE PORTION OF STEEL BEAM WITH NON-COMPACT COMPRESSION FLANGE OR WEB IN SAGGING BENDING