SECTION 9 CONNECTIONS

9.1 GENERAL

9.1.1 Requirements for connections Connection elements consist of connection components (cleats, gusset plates, brackets, connecting plates) and connectors (bolts, pins and welds). The connections in a structure shall be proportioned so as to be consistent with the assumptions made in the analysis of the structure and to comply with this Section. Connections shall be capable of transmitting the calculated design action effects.

9.1.2 Classification of connections

9.1.2.1 *Connections in rigid construction* The connections shall comply with Clause 4.2.2. The joint deformations shall be such that they have no significant influence on the distribution of action effects nor on the overall deformation of the frame.

9.1.2.2 *Connections in semi-rigid construction* The connections shall comply with Clause 4.2.3. Connections between members in semi-rigid construction shall provide a predictable degree of interaction between members, based on the actual action-deformation characteristics of the connection as determined experimentally.

9.1.2.3 *Connections in simple construction* The connections shall comply with Clause 4.2.4. Connections between members in simple construction shall be capable of deforming to provide the required rotation at the connection. The connections shall not develop a level of restraining bending moment which adversely affects any part of the structure. The rotation capacity of the connection shall be provided by the detailing of the connection and shall have been demonstrated experimentally. The connection shall be considered as subject to reaction shear forces acting at an eccentricity appropriate to the connection detailing.

9.1.2.4 *Connections in structures analyzed by the plastic method* Connections in structures analyzed by the plastic method shall comply with Clause 4.5.3, in addition to the requirements of this Section.

9.1.3 Design of connections Each element in a connection shall be designed so that the structure is capable of resisting all design actions. The design capacities of each element shall be not less than the calculated design action effects. For earthquake load combinations, the connection shall be designed for the calculated design action effects, exhibit the required ductility and shall comply with Section 13.

Connections and the adjacent areas of members shall be designed by distributing the design action effects so that they comply with the following requirements:

(a) The distributed design action effects are in equilibrium with the design action effects acting on the connection.

(b) The deformations in the connection are within the deformation capacities of the connection elements.

(c) All of the connection elements and the adjacent areas of members are capable of resisting the design action effects acting on them.

(d) The connection elements shall remain stable under the design action effects and deformations.

Design shall be on the basis of a recognized method supported by experimental evidence.

Residual actions due to the installation of bolts need not be considered.

9.1.4 Minimum design actions on connections Connections carrying design action effects, except for lacing connections and connections to sag rods, purlins and girts, shall be designed to transmit the greater of—

(a) the design action in the member; and

(b) the minimum design action effects expressed either as the value or the factor times the member design capacity for the minimum size of member required by the strength limit state, specified as follows:

   (i) Connections in rigid construction—a bending moment of 0.5 times the member design moment capacity.

   (ii) Connections to beam in simple construction—a shear force of 0.15 times the member design shear capacity or 40 kN, whichever is the lesser.

   (iii) Connections at the ends of tensile or compression members—a force of 0.3 times the member design capacity, except that for threaded rod acting as a bracing member with turnbuckles, the minimum tensile force shall be equal to the member design capacity.

   (iv) Splices in members subject to axial tension—a force of 0.3 times the member design capacity in tension.

   (v) Splices in members subject to axial compression—for ends prepared for full contact in accordance with Clause 14.4.4.2, it shall be permissible to carry compressive actions by bearing on contact surfaces. When members are prepared for full contact to bear at splices, there shall be sufficient fasteners to hold all parts securely in place. The fasteners shall be sufficient to transmit a force of 0.15 times the member design capacity in axial compression.

   In addition, splices located between points of effective lateral support shall be designed for the design axial force (N^*) plus a design bending moment not less than the design bending moment (M^*)

   where

$$M^* = \frac{\delta N^* l_s}{1000}$$

   δ = appropriate amplification factor δ_b or δ_s determined in accordance with Clause 4.4

   l_s = distance between points of effective lateral support.

   When members are not prepared for full contact, the splice material and its fasteners shall be arranged to hold all parts in line and shall be designed to transmit a force of 0.3 times the member design capacity in axial compression.

   (vi) Splices in flexural members—a bending moment of 0.3 times the member design capacity in bending. This provision shall not apply to splices designed to transmit shear force only.

   A splice subjected to a shear force only shall be designed to transmit the design shear force together with any bending moment resulting from the eccentricity of the force with respect to the centroid of the connector group.

   (vii) Splices in members subject to combined actions—a splice in a member subject to a combination of design axial tension or design axial compression and design bending moment shall satisfy (iv), (v) and (vi) simultaneously.

For earthquake load combinations, the design action effects specified in this Clause may need to be increased to meet the required behaviour of the steel frame and shall comply with Section 13.

9.1.5 Intersections Members or components meeting at a joint shall be arranged to transfer the design actions between the parts and wherever practicable, with their centroidal axes meeting at a point. Where there is eccentricity at joints, the members and components shall be designed for the design bending moments which result.

The disposition of fillet welds to balance the design actions about the centroidal axis or axes for end connections of single angle, double angle and similar type members is not required for statically loaded members but is required for members and connection components subject to fatigue loading.

Eccentricity between the centroidal axes of angle members and the gauge lines for their bolted end connections may be neglected in statically loaded members, but shall be considered in members and connection components subject to fatigue loading.

9.1.6 Choice of fasteners Where slip in the serviceability limit state shall be avoided in a connection, high-strength bolts in a friction-type joint (bolting category 8.8/TF), fitted bolts or welds shall be used.

Where a joint is subject to impact or vibration, high-strength bolts in a friction-type joint (bolting category 8.8/TF), locking devices or welds shall be used.

9.1.7 Combined connections When non-slip fasteners (such as high-strength bolts in a friction-type connection or welds) are used in a connection in conjunction with slip-type fasteners (such as snug-tight bolts, or tensioned high-strength bolts in bearing-type connections), all of the design actions shall be assumed to be carried by the non-slip fasteners.

Where a mixture of non-slip fasteners is used, sharing of the design actions may be assumed. However, when welding is used in a connection in conjunction with other non-slip fasteners—

(a) any design actions initially applied directly to the welds shall not be assumed to be distributed to fasteners added after the application of the design actions; and

(b) any design actions applied after welding shall be assumed to be carried by the welds.

9.1.8 Prying forces Where bolts are required to carry a design tensile force, the bolts shall be proportioned to resist any additional tensile force due to prying action.

9.1.9 Connection components Connection components (cleats, gusset plates, brackets and the like) other than connectors shall have their capacities assessed using the provisions of Sections 5, 6, 7 and 8 as applicable.

9.1.10 Deductions for fastener holes

9.1.10.1 *Hole area* In calculating the deductions to be made for holes for fasteners (including countersunk holes), the gross areas of the holes in the plane of their axes shall be used.

9.1.10.2 *Holes not staggered* For holes that are not staggered, the area to be deducted shall be the maximum sum of the areas of the holes in any cross-sections at right angles to the direction of the design action in the member.

9.1.10.3 *Staggered holes* When holes are staggered, the area to be deducted shall be the greater of—

(a) the deduction for non-staggered holes; or

(b) the sum of the areas of all holes in any zig-zag line extending progressively across the member or part of the member, less $(s_p^2 t / 4 s_g)$ for each gauge space in the chain of holes

where

s_p = staggered pitch, the distance measured parallel to the direction of the design action in the member, centre-to-centre of holes in consecutive lines, (see Figure 9.1.10.3(1))

t = thickness of the holed material

s_g = gauge, the distance, measured at right angles to the direction of the design action in the member, centre-to-centre of holes in consecutive lines, (see Figure 9.1.10.3(1)). For sections such as angles with holes in both legs, the gauge shall be taken as the sum of the back marks to each hole, less the leg thickness (see Figure 9.1.10.3(2)).

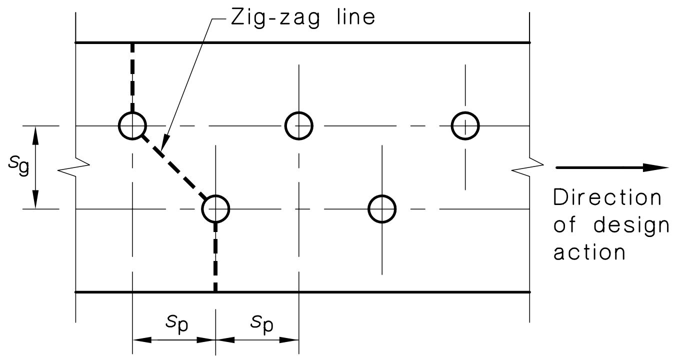

FIGURE 9.1.10.3.(1) STAGGERED HOLES

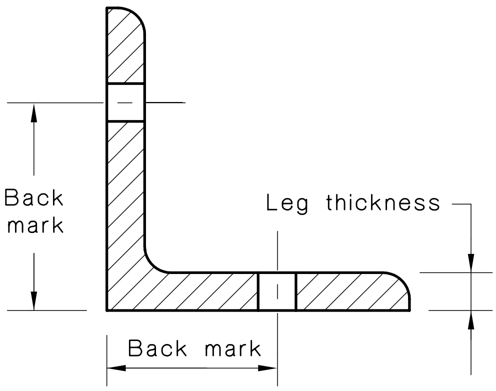

FIGURE 9.1.10.3(2) ANGLES WITH HOLES IN BOTH LEGS

9.1.11 Hollow section connections When design actions from one member are applied to a hollow section at a connection, consideration shall be given to the local effects on the hollow section.

9.2 DEFINITIONS For the purpose of this Section, the definitions below apply.

Bearing-type connection—connection effected using either snug-tight bolts, or high-strength bolts tightened to induce a specified minimum bolt tension, in which the design action is transferred by shear in the bolts and bearing on the connected parts at the strength limit state.

Friction-type connection—connection effected using high-strength bolts tightened to induce a specified minimum bolt tension so that the resultant clamping action transfers the design shear forces at the serviceability limit state acting in the plane of the common contact surfaces by the friction developed between the contact surfaces.

Full tensioning—a method of installing and tensioning a bolt in accordance with Clauses 15.2.4 and 15.2.5.

In-plane loading—loading for which the design forces and bending moments are in the plane of the connection, such that the design action effects induced in the connection components are shear forces only.

Non-slip fasteners—fasteners which do not allow slip to occur between connected plates or members at the serviceability limit state so that the original alignment and relative positions are maintained.

Out-of-plane loading—loading for which the design forces or bending moments result in design action effects normal to the plane of the connection.

Pin—an unthreaded fastener manufactured out of round bar.

Prying force—additional tensile force developed as a result of the flexing of a connection component in a connection subjected to tensile force. External tensile force reduces the contact pressure between the component and the base, and bending in part of the component develops a prying force near the edge of the connection component.

Snug tight—the tightness of a bolt achieved by a few impacts of an impact wrench or by the full effort of a person using a standard podger spanner.

9.3 DESIGN OF BOLTS

9.3.1 Bolts and bolting category The bolts and bolting categories listed in Table 9.3.1 shall be designed in accordance with this Clause and Clause 9.4.

Other property classes of bolts conforming to AS/NZS 1110, AS/NZS 1111 and AS/NZS 1559 may be designed in accordance with the provisions of this Clause and Clause 9.4.

TABLE 9.3.1

BOLTS AND BOLTNG CATEGORY

Bolting category	Bolt standard	Bolt grade	Method of tensioning	Minimum tensile strength (f_{uf}) (see Note 2) MPa
4.6/S	AS/NZS 1111	4.6	Snug tight	400
8.8/S	AS/NZS 1252	8.8	Snug tight	830
8.8/TB	AS/NZS 1252	8.8	Full tensioning	830
8.8/TF (See Note 1)	AS/NZS 1252	8.8	Full tensioning	830

NOTES:

1 Special category used in connections where slip in the serviceability limit state is to be restricted (see Clauses 3.5.5 and 9.1.6).

2 f_{uf} is the minimum tensile strength of the bolt as specified in the relevant Standard.

9.3.2 Bolt strength limit states

9.3.2.1 *Bolt in shear* A bolt subject to a design shear force (V_f^*) shall satisfy—

$$V_f^* \leq \phi V_f$$

where

ϕ = capacity factor (see Table 3.4)

V_f = nominal shear capacity of a bolt.

The nominal shear capacity of a bolt (V_f) shall be calculated as follows:

$$V_f = 0.62 f_{uf} k_r (n_n A_c + n_x A_o)$$

where

f_{uf} = minimum tensile strength of the bolt as specified in the relevant Standard (see Table 9.3.1)

k_r = reduction factor given in Table 9.3.2.1 to account for the length of a bolted lap connection (l_j). For all other connections, k_r equals 1.0

n_n = number of shear planes with threads intercepting the shear plane

A_c = minor diameter area of the bolt as defined in AS 1275

n_x = number of shear planes without threads intercepting the shear plane

A_o = nominal plain shank area of the bolt.

TABLE 9.3.2.1

REDUCTION FACTOR FOR A BOLTED LAP CONNECTION (k_r)

Length mm	$l_j < 300$	$300 \leq l_j \leq 1300$	$l_j > 1300$
k_r	1.0	$1.075 - (l_j/4000)$	0.75

9.3.2.2 *Bolt in tension* A bolt subject to a design tension force (N^*_{tf}) shall satisfy—

$$N^*_{tf} \leq \phi N_{tf}$$

where

ϕ = capacity factor (see Table 3.4)

N_{tf} = nominal tensile capacity of a bolt.

The nominal tension capacity of a bolt (N_{tf}) shall be calculated as follows:

$$N_{tf} = A_s f_{uf}$$

where A_s is the tensile stress area of a bolt as specified in AS 1275.

9.3.2.3 *Bolt subject to combined shear and tension* A bolt required to resist both design shear (V^*_f) and design tensile forces (N^*_{tf}) at the same time shall satisfy—

$$\left(\frac{V^*_f}{\phi V_f}\right)^2 + \left(\frac{N^*_{tf}}{\phi N_{tf}}\right)^2 \leq 1.0$$

where

ϕ = capacity factor (see Table 3.4)

V_f = nominal shear capacity calculated in accordance with Clause 9.3.2.1

N_{tf} = nominal tensile capacity calculated in accordance with Clause 9.3.2.2.

9.3.2.4 *Ply in bearing* A ply subject to a design bearing force (V^*_b) due to a bolt in shear shall satisfy—

$$V^*_b \leq \phi V_b$$

where

ϕ = capacity factor (see Table 3.4)

V_b = nominal bearing capacity of a ply.

The nominal bearing capacity of a ply (V_b) shall be calculated as follows:

$$V_b = 3.2 d_f t_p f_{up} \quad \ldots 9.3.2.4(1)$$

provided that, for a ply subject to a component of force acting towards an edge, the nominal bearing capacity of a ply (V_b) shall be the lesser of that given by Equation 9.3.2.4(1) and that given by Equation 9.3.2.4(2)—

$$V_b = a_e t_p f_{up} \quad \ldots 9.3.2.4(2)$$

where

d_f = diameter of the bolt

t_p = thickness of the ply

f_{up} = tensile strength of the ply

a_e = minimum distance from the edge of a hole to the edge of a ply, measured in the direction of the component of a force, plus half the bolt diameter. The edge of a ply shall be deemed to include the edge of an adjacent bolt hole.

9.3.2.5 *Filler plates* For connections in which filler plates exceed 6 mm in thickness but are less than 20 mm in thickness, the nominal shear capacity of a bolt (V_f) specified in Clause 9.3.2.1 shall be reduced by 15%. For multi-shear plane connections with more than one filler plate through which a bolt passes, the reduction shall be determined using the maximum thickness of filler plate on any shear plane through which the bolt passes.

9.3.3 Bolt serviceability limit state

9.3.3.1 *Design* For friction-type connections (bolting category 8.8/TF) in which slip in the serviceability limit state is required to be limited, a bolt subjected only to a design shear force (V^*_{sf}) in the plane of the interfaces shall satisfy—

$$V^*_{sf} \leq \phi V_{sf}$$

where

ϕ = capacity factor (see Clause 3.5.5)

V_{sf} = nominal shear capacity of a bolt, for a friction-type connection.

The nominal shear capacity of a bolt (V_{sf}) shall be calculated as follows:

$$V_{sf} = \mu n_{ei} N_{ti} k_h \qquad \ldots 9.3.3.1$$

where

μ = slip factor as specified in Clause 9.3.3.2

n_{ei} = number of effective interfaces

N_{ti} = minimum bolt tension at installation as specified in Clause 15.2.5.1.

k_h = factor for different hole types, as specified in Clause 14.3.5.2.

= 1.0 for standard holes

= 0.85 for short slotted and oversize holes

= 0.70 for long slotted holes.

The strength limit state shall be separately assessed in accordance with Clause 9.3.2.

9.3.3.2 *Contact surfaces* Where the surfaces in contact are clean 'as-rolled' surfaces, the slip factor (λ) shall be taken as 0.35. If any applied finish, or other surface condition including a machined surface, is used, the slip factor shall be based upon test evidence. Tests performed in accordance with the procedure specified in Appendix J shall be deemed to provide satisfactory test evidence.

A connection involving 8.8/TF bolting category shall be identified as such, and the drawings shall clearly indicate the surface treatment required at such a connection and whether masking of the connection surfaces is required during painting operations (see Clause 14.3.6.3).

9.3.3.3 *Combined shear and tension* Bolts in a connection for which slip in the serviceability limit state shall be limited, which are subject to a design tension force (N^*_{tf}), shall satisfy—

$$\left(\frac{V^*_{sf}}{\phi V_{sf}}\right) + \left(\frac{N^*_{tf}}{\phi N_{tf}}\right) \leq 1.0$$

where

V^*_{sf} = design shear force on the bolt in the plane of the interfaces

N^*_{tf} = design tensile force on the bolt

ϕ = capacity factor (see Clause 3.5.5)

V_{sf} = nominal shear capacity of the bolt as specified in Clause 9.3.3.1

N_{tf} = nominal tensile capacity of the bolt.

The nominal tensile capacity of the bolt (N_{tf}) shall be taken as—

$$N_{tf} = N_{ti}$$

where N_{ti} is the minimum bolt tension at installation as specified in Clause 15.2.5.1.

The strength limit state shall also be separately assessed in accordance with Clause 9.3.2.3.

9.4 ASSESSMENT OF THE STRENGTH OF A BOLT GROUP

9.4.1 Bolt group subject to in-plane loading The design actions in a bolt group shall be determined by an analysis based on the following assumptions:

(a) The connection plates shall be considered to be rigid and to rotate relative to each other about a point known as the instantaneous centre of the bolt group.

(b) In the case of a bolt group subject to a pure couple only, the instantaneous centre of rotation coincides with the bolt group centroid.

In the case of a bolt group subject to an in-plane shear force applied at the group centroid, the instantaneous centre of rotation is at infinity and the design shear force is uniformly distributed throughout the group.

In all other cases, either the results of independent analyses for a pure couple alone and for an in-plane shear force applied at the bolt group centroid shall be superposed, or a recognized method of analysis shall be used.

(c) The design shear force in each bolt shall be assumed to act at right angles to the radius from the bolt to the instantaneous centre, and shall be taken as proportional to that radius.

Each bolt shall satisfy the requirements of Clause 9.3.2.1 using the capacity factor (ϕ) for a bolt group (see Table 3.4) and the ply in bearing shall satisfy Clause 9.3.2.4.

9.4.2 Bolt group subject to out-of-plane loading The design actions in any bolt in a bolt group subject to out-of-plane loading shall be determined in accordance with Clause 9.1.3.

Each bolt shall comply with Clauses 9.3.2.1, 9.3.2.2 and 9.3.2.3 using the capacity factor (ϕ) for a bolt group (see Table 3.4), and the ply in bearing shall comply with Clause 9.3.2.4.

9.4.3 Bolt group subject to combinations of in-plane and out-of-plane loadings The design actions in any bolt in a bolt group shall be determined in accordance with Clauses 9.4.1 and 9.4.2.

Each bolt shall comply with Clauses 9.3.2.1, 9.3.2.2 and 9.3.2.3 using the capacity factor (ϕ) for a bolt group (see Table 3.4), and the ply in bearing shall comply with Clause 9.3.2.4.

9.5 DESIGN OF A PIN CONNECTION

9.5.1 Pin in shear A pin subject to a design shear force (V_f^*) shall satisfy—

$$V_f^* \leq \phi V_f$$

where

ϕ = capacity factor (see Table 3.4)

V_f = nominal shear capacity of the pin.

The nominal shear capacity of a pin (V_f) shall be calculated as follows:

$$V_f = 0.62 f_{yp} n_s A_p$$

where

f_{yp} = yield stress of the pin

n_s = number of shear planes

A_p = cross-sectional area of the pin

9.5.2 Pin in bearing A pin subject to a design bearing force (V_b^*) shall satisfy—

$$V_b^* \leq \phi V_b$$

where

ϕ = capacity factor (see Table 3.4)

V_b = nominal bearing capacity of the pin.

The nominal bearing capacity of a pin (V_b) shall be calculated as follows:

$$V_b = 1.4 f_{yp} d_f t_p k_p$$

where

f_{yp} = yield stress of the pin

d_f = pin diameter

t_p = connecting plate thickness(es)

k_p = 1.0 for pins without rotation, or

= 0.5 for pins with rotation.

9.5.3 Pin in bending A pin subject to a design bending moment (M^*) shall satisfy—

$$M^* \leq \phi M_p$$

where

ϕ = capacity factor (see Table 3.4)

M_p = nominal moment capacity of the pin.

The nominal moment capacity of a pin (M_p) shall be calculated as follows:

$$M_p = f_{yp} S$$

where

f_{yp} = yield stress of the pin

S = plastic section modulus of the pin.

9.5.4 Ply in bearing A ply subject to a design bearing force (V_b^*) due to a pin in shear shall satisfy Clause 9.3.2.4.

9.6 DESIGN DETAILS FOR BOLTS AND PINS

9.6.1 Minimum pitch The distance between centres of fastener holes shall be not less than 2.5 times the nominal diameter of the fastener (d_f).

NOTE: The minimum pitch may also be affected by Clause 9.3.2.4.

9.6.2 Minimum edge distance The minimum edge distance shall be as follows:

(a) *Standard holes* The minimum edge distance for a standard size bolt hole (see Clause 14.3.5.2) shall be as given in Table 9.6.2, where the edge distance is measured from the centre of a hole to the edge of a plate or rolled section.

(b) *Non-standard holes* The minimum edge distance for a non-standard size bolt hole shall be as given in Table 9.6.2, where the edge distance is measured from the nearer edge of a hole to the physical edge of a plate or rolled section, plus half the fastener diameter (d_f).

TABLE 9.6.2

MINIMUM EDGE DISTANCE

Sheared or hand flame cut edge	Rolled plate, flat bar or section: machine flame cut, sawn or planed edge	Rolled edge of a rolled flat bar or section
$1.75d_f$	$1.50d_f$	$1.25d_f$

NOTE: The edge distance may also be affected by Clause 9.3.2.4.

9.6.3 Maximum pitch The maximum distance between centres of fasteners shall be the lesser of $15t_p$ (where t_p = thickness of thinner ply connected) or 200 mm. However, in the following cases, the maximum distances shall be as follows:

(a) For fasteners which are not required to carry design actions in regions not liable to corrosion—the lesser of $32t_p$ or 300 mm.

(b) For an outside line of fasteners in the direction of the design action—the lesser of ($4t_p$ + 100) mm, or 200 mm.

9.6.4 Maximum edge distance The maximum distance from the centre of any fastener to the nearest edge of parts in contact with one another shall be 12 times the thickness of the thinnest outer connected ply under consideration, but shall not exceed 150 mm.

9.6.5 Holes Holes for bolts shall comply with Clause 14.3.5 and holes for pins shall comply with Clause 14.3.7.

9.7 DESIGN OF WELDS

9.7.1 Scope

9.7.1.1 *General* Welding shall comply with AS/NZS 1554.1, AS 1554.2 or AS/NZS 1554.5, as appropriate.

9.7.1.2 *Weld types* For the purpose of this Standard, welds shall be butt, fillet, slot or plug welds, or compound welds.

9.7.1.3 *Weld quality* Weld quality shall be either SP or GP as specified in AS/NZS 1554.1, except that where a higher quality weld is required by Clause 11.1.5, weld quality conforming with AS/NZS 1554.5 shall be used. Weld quality shall be specified on the design drawings.

9.7.2 Complete and incomplete penetration butt welds

9.7.2.1 *Definitions* For the purpose of this Clause, the definitions below apply.

Complete penetration butt weld—a butt weld in which fusion exists between the weld and parent metal throughout the complete depth of the joint.

Incomplete penetration butt weld—a butt weld in which fusion exists over less than the complete depth of the joint.

Prequalified weld preparation—a joint preparation prequalified in terms of AS/NZS 1554.1.

9.7.2.2 *Size of weld* The size of a complete penetration butt weld, other than a complete penetration butt weld in a T-joint or a corner joint, and the size of an incomplete penetration butt weld shall be the minimum depth to which the weld extends from its face into a joint, exclusive of reinforcement.

The size of a complete penetration butt weld for a T-joint or a corner joint shall be the thickness of the part whose end or edge butts against the face of the other part.

9.7.2.3 *Design throat thickness* Design throat thickness shall be as follows:

(a) *Complete penetration butt weld* The design throat thickness for a complete penetration butt weld shall be the size of the weld.

(b) *Incomplete penetration butt weld* The design throat thickness for an incomplete penetration butt weld shall be as follows:

  (i) Prequalified preparation for incomplete penetration butt weld except as otherwise provided in (iii), as specified in AS/NZS 1554.1.