



CIVL3206 Steel Structures 1

Laboratory Class: Connections in TensionGeneral Information

Aim - To examine the behaviour and failure of black bolted, high strength friction grip bolted, and welded connections in tension.

Other References - These notes should be read in conjunction with Chapters 3 & 10 of the Steel Structures 1 lecture notes, and Sections 7 & 9 of AS 4100.

Requirements - Students will be required to examine the specimens, measure the relevant dimensions, perform preliminary calculations, observe the tests, and write a report.

Initial Calculations to be Performed in Class

The class should divide into 4 groups – each will consider a different connection. There are 4 connections to consider:

- Bolted lap joint with 4.6 Grade bolts
- Bolted lap joint with 8.8 Grade bolts
- Single lap welded joint
- Single lap welded joint

Before the experiment, students are to examine the connections and measure all appropriate dimensions.

Consider all possible failure modes appropriate for each connection, and calculate the nominal capacity and design capacity for that failure mode using AS 4100. The modes of failure to be considered are:

- section tension yield (Clause 7.2)
- section tension fracture considering all possible fracture patterns (Clause 7.2 and 9.1.10)
- bolt shear (Clause 9.3.2.1)
- bolt serviceability (9.3.3.1)
- ply in bearing (Clause 9.3.2.4)
- weld shear (Clause 9.7.3.10) (based on both the nominal dimensions and the measured dimensions).

Take special care with the appropriate use of the capacity factor (ϕ) for each connection (Table 3.4 and Clause 3.5.5). Reference can be made to Tables 2.1, 9.3.1 and 9.7.3.10(1) to obtain the material properties of the plate, bolts and welds.

Check to see whether the joint meets the requirements of the code concerning clearances between one hole and another, and between each hole and the plate edges (Section 9.6).

Experiment

The bolts high strength bolted connection must be tensioned to 50 kN. A calibration curve has been obtained for the high strength friction grip bolts with their nuts and washers. This calibration indicates that a torque of approximately 10 lb.ft induces a force of 4.34 kN in the M12 bolt (Clause 15.2.4 and 15.2.5). *Calculate the torque required to tighten the bolts to the minimum bolt tension.*

The demonstrator will perform all the tests. Pay attention during each test to any events that might occur - your demonstrator will be explaining what is happening during testing. Each specimen will be tested to destruction. An autographic plot of each test will be recorded, together with the maximum load. For the welded connections, sketch the joint after failure, paying attention to any defects may have affected the results. In particular, examine the failure surfaces to assess whether full penetration of the weld was obtained. Compare the failure surfaces in the two joints to see whether any differences are detectable. Note any unusual features. Remove the autographic plot, and obtain photocopies of it for inclusion in the report.

Report

A report is required to be submitted. There is no need to replicate the information given in these notes. Please give *brief* answers to the following questions. While working together is encouraged, students are expected to make *individual* submissions.

Students should read the accompanying information on the requirements of a written report.

Introduction: Include a brief introduction, outlining the aim of the experiment.

Method: Very briefly summarise the test procedure and any observations made during each test. A brief sketch of the testing machine and the deformed shapes of the specimen would be useful.

Results: Tabulate the results (4 experiments – 4 tables). Each table should show all relevant dimensions, all calculated capacities applicable to that particular specimen, the actual capacity, the predicted and actual failure mode, and the ratio of the actual to the predicted capacity. Units should be included. Include any other data considered important. Include a photocopy of the autographic plot for each test, clearly labeling each curve, and the maximum load obtained in each test.

Discussion: Include a brief discussion of the following points, and other points considered important. A discussion of approximately 500 - 1000 words (1 - 2 pages in total – not for each question) would be suitable.

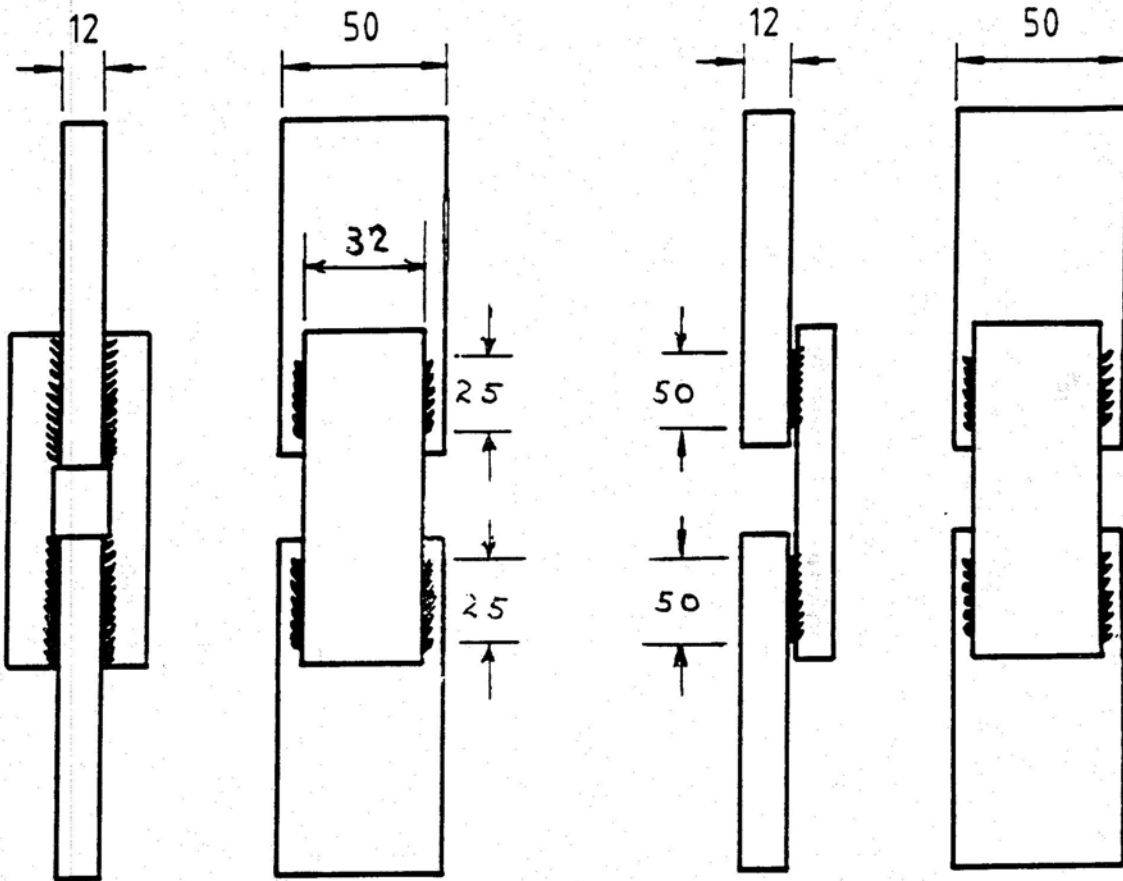
- For each connection, compare the predicted failure mode/load with the actual failure mode/load. Discuss any reasons why the predictions are the same as/different to/less than/greater than the observed results.
- Is the tightening of bolts important in using high-strength bolts? What difference does the tightening of the bolts in the friction grip joint make to (a) the load at first slip and (b) the failure load? In the light of your answers, why is the correct tightening of friction grip bolts important?
- Describe the mechanism of failure in each welded joint, and discuss the relative merits of using single and double lap joints. Do you think the code should make distinction between symmetric and asymmetric welded joints.
- Is there a difference between the nominal and measured dimensions/properties? How might this affect the calculations of an engineer in a design office using the data available? How is this considered in design? Pay particular attention to the nominal and measured dimensions of the welds. How important is it that welds be inspected to ensure that their dimensions are the same as those used in design? Suggest how this may be achieved.
- Are the resistance factors (ϕ) in AS 4100 are satisfactory for each type of joint? Reference should be made to the ratio of the actual failure load to the predicted failure load. Are these assertions true based on the results of a single test?
- Briefly discuss the relative merits of black bolted high strength friction grip bolted and welded joints in steel structures.
- In the design of steel structures, should AS 4100 use lower resistance factors on joints than on members, or should they be equal and why?

Appendix: Any calculations can be included in an appendix.

Workload: It is anticipated that the preparation of the report should take approximately 3 hours.

Tom Wilkinson

Senior Lecturer in Civil Engineering

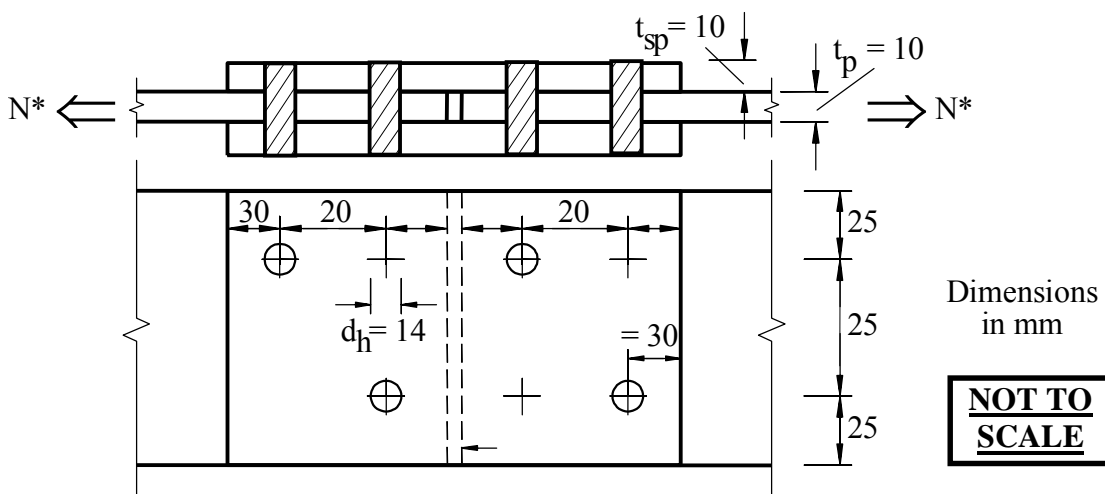


Double Lap

Single Lap

Each run of fillet weld to be 6mm nominal size

Connection Details for the Welded Lap Joints



Dimensions in mm

NOT TO SCALE

These are nominal dimensions only. Students must remeasure the dimensions to obtain the correct values/

SECTION 7 MEMBERS SUBJECT TO AXIAL TENSION

7.1 DESIGN FOR AXIAL TENSION A member subject to a design axial tension force (N^*) shall satisfy—

$$N^* / \phi N_t$$

where

ϕ = the capacity factor, see Table 3.4

N_t = the nominal section capacity in tension determined in accordance with Clause 7.2.

7.2 NOMINAL SECTION CAPACITY The nominal section capacity of a tension member shall be taken as the lesser of—

$$N_t = A_g f_y; \text{ and}$$

$$N_t = 0.85 k_t A_n f_u$$

where

A_g = the gross area of the cross-section

f_y = the yield stress used in design

k_t = the correction factor for distribution of forces determined in accordance with Clause 7.3

A_n = the net area of the cross-section, obtained by deducting from the gross area the sectional area of all penetrations and holes, including fastener holes. The deduction for all fastener holes shall be made in accordance with Clause 9.1.10. For threaded rods, the net area shall be taken as the tensile stress area of the threaded portion, as defined in AS 1275.

f_u = the tensile strength used in design.

7.3 DISTRIBUTION OF FORCES

7.3.1 End connections providing uniform force distribution Where for design purposes it is assumed that the tensile force is distributed uniformly to a tension member, the end connections shall satisfy both the following:

- (a) The connections shall be made to each part of the member and shall be symmetrically placed about the centroidal axis of the member.
- (b) Each part of the connection shall be proportioned to transmit at least the maximum design force carried by the connected part of the member.

For connections satisfying these requirements, the value of k_t shall be taken as 1.0.

7.3.2 End connections providing non-uniform force distribution If the end connections of a tension member do not satisfy the requirements of Clause 7.3.1, then the member shall be designed to comply with Section 8 using k_t equals 1.0, except that Clause 7.2 may be used for the following members:

- (a) *Eccentrically-connected angles, channels and tees* Eccentrically-connected angles, channels and tees may be designed in accordance with Clause 7.2, using the appropriate value of k_t given in Table 7.3.2.
- (b) *I-sections or channels connected by both flanges only* A symmetrical rolled or built-up member of solid I-section or channel section connected by both flanges only may be designed in accordance with Clause 7.2 using a value of k_t equal to 0.85, provided that—
 - (i) the length between the first and last rows of fasteners in the connection or, when the member is welded, the length of longitudinal weld provided to each side of the connected flanges shall be not less than the depth of the member; and
 - (ii) each flange connection shall be proportioned to transmit at least half of the maximum design force carried by the connected member.

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 ($s_p^2 / 4s_g$) 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)).

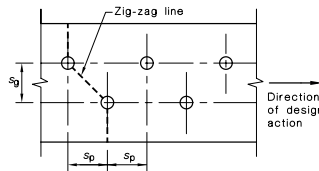


FIGURE 9.1.10.3(1) STAGGERED HOLES

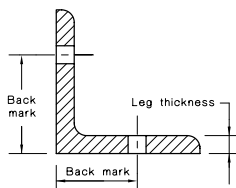


FIGURE 9.1.10.3(2) ANGLES WITH HOLES IN BOTH LEGS

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 BOLTING CATEGORY

Bolting category	Bolt standard	Bolt grade	Method of tensioning	Minimum tensile strength (f_{ut}) (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_{ut} 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—

$$V_f \leq \phi V_t$$

where

ϕ = capacity factor (see Table 3.4)

V_t = nominal shear capacity of a bolt.

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

$$V_t = 0.62 f_{ut} k_t (n_n A_c + n_x A_o)$$

where

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

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

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

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

n_x = number of shear planes without threads intersecting 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_{dt}^*) shall satisfy—

$$N_{dt}^* \leq \phi N_{tf}$$

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:

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

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 force (N_{dt}^*) at the same time shall satisfy—

$$\left(\frac{V_f^*}{\phi V_f}\right)^2 + \left(\frac{N_{dt}^*}{\phi N_{tf}}\right)^2 \leq 1.0$$

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:

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

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)—

$$V_b = a_c f_{up} \quad \dots 9.3.2.4(2)$$

where

- d_f = diameter of the bolt
- t_p = thickness of the ply
- f_{up} = tensile strength of the ply
- a_c = 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_{df}) in the plane of the interfaces shall satisfy—

$$V_{df} \leq \phi V_{sf}$$

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:

$$V_{sf} = \mu n_{ei} N_{ti} k_h \quad \dots 9.3.3.1$$

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 (μ) 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_{dt}^*), shall satisfy—

$$\left(\frac{V_{df}^*}{\phi V_{sf}}\right) + \left(\frac{N_{dt}^*}{\phi N_{tf}}\right) \leq 1.0$$

where

- V_{df}^* = design shear force on the bolt in the plane of the interfaces
- N_{dt}^* = 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.

9.6.3 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:

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

- Complete penetration butt weld** The design throat thickness for a complete penetration butt weld shall be the size of the weld.
- Incomplete penetration butt weld** The design throat thickness for an incomplete penetration butt weld shall be as follows:
 - Prequalified preparation for incomplete penetration butt weld except as otherwise provided in (iii), as specified in AS/NZS 1554.1.

- At the cap plate or baseplate of a compression member, welds shall have a length along each joint line of at least the maximum width of the member at the contact face.
- Where a beam is connected to the face of a compression member, the welds connecting the compression member components shall extend between the levels of the top and bottom of the beam and in addition—
 - for an unrestrained connection, a distance (d) below the lower face of the beam; and
 - for a restrained connection, a distance (d) above and below the upper and lower faces of the beam,
 where d is the maximum cross-sectional dimension of the compression member.

9.7.3.10 Strength limit state for fillet weld A fillet weld subject to a design force per unit length of weld (v_w^*) shall satisfy—

$$v_w^* \leq \phi v_w$$

where

- ϕ = capacity factor (see Table 3.4)
- v_w = nominal capacity of a fillet weld per unit length.

The design force per unit length (v_w^*) shall be the vectorial sum of the design forces per unit length on the effective area of the weld.

The nominal capacity of a fillet weld per unit length (v_w) shall be calculated as follows:

$$v_w = 0.6f_{uw}t_k$$

where

- f_{uw} = nominal tensile strength of weld metal (see Table 9.7.3.10(1))
- t_k = design throat thickness
- k_r = reduction factor given in Table 9.7.3.10(2) to account for the length of a welded lap connection (l_w). For all other connection types, k_r equals 1.0.

TABLE 9.7.3.10(1)
NOMINAL TENSILE STRENGTH OF WELD METAL (f_{uw})

Manual metal arc electrode (AS/NZS 1553.1)	Submerged arc (AS 1858.1) Flux cored arc (AS 2203) Gas metal arc (AS/NZS 2717.1)	Nominal tensile strength of weld metal, f_{uw} MPa
E41XX	W40X (see Note)	410
E48XX	W50X	480

NOTE: Not included in AS/NZS 2717.1.

TABLE 9.7.3.10(2)
REDUCTION FACTOR FOR A WELDED LAP CONNECTION (k_r)

Length of weld, l_w m	$l_w \leq 1.7$	$1.7 < l_w \leq 8.0$	$l_w > 8.0$
k_r	1.00	$1.10 - 0.06l_w$	0.62