C9.6.1 Minimum pitch

The minimum pitch of 2.5 bolt diameters relates primarily to the tools required to install a bolt. Most practical pitches are larger than this (Ref. 2 uses 3.5 bolt diameters for M20 bolts). The reference to Clause 9.3.2.4 relates to the possibility of plate tearout between the bolt holes.

C9.6.2 Minimum edge distance

Slightly different definitions of edge distance are used for standard and non-standard holes in order to reflect a constancy of outcome relative to the physical edge of the hole, as traditionally edge distance is measured from the centre of a standard hole. The minima specified are based on past successful practice and relate to the expected edge roughness. They are similar to those in comparable specifications. The end distance may also be controlled by end plate tearout, hence the reference to Clause 9.3.2.4.

C9.6.3 Maximum pitch

The values specified are empirically based on successful past practice. Smaller pitches than the maximum may be preferred if corrosion between the connected plies may be a problem.

C9.6.4 Maximum edge distance

The values specified are empirically based on successful past practice, and are intended to provide for the exclusion of moisture between connected plies, thus preventing corrosion between the plies which might accumulate and force the plies apart. Lesser values should be considered in corrosive applications. The provisions are also intended to prevent any potential curling-up of plate edges.

C9.6.5 Holes

(No Commentary.)

C9.7 DESIGN OF WELDS

C9.7.1 Scope

Clause 9.7.1 concentractes solely on design matters. Other matters which are of interest to the design engineer but which are covered by AS/NZS 1554.1 include—

(a) welder qualification;

(b) weld procedure qualification;

(c) weld inspection;

(d) allowance weld imperfections for different weld categories; and

(e) level of weld inspection.

Note that under Clause 1.6.2, the categories of welds, the level of visual examination and the level of other non-destructive examination required should be identified on the drawings. The selection of weld category should reflect the level of examination to be used. A Commentary on AS/NZS 1554.1 may be found in Ref. 19.

C9.7.2 Complete and incomplete penetration butt welds

C9.7.2.1 *Definitions*

(No Commentary.)

C9.7.2.2 *Size of weld*

The intention of Clause 9.7.2.2 is shown in Figure C9.7.2.2.

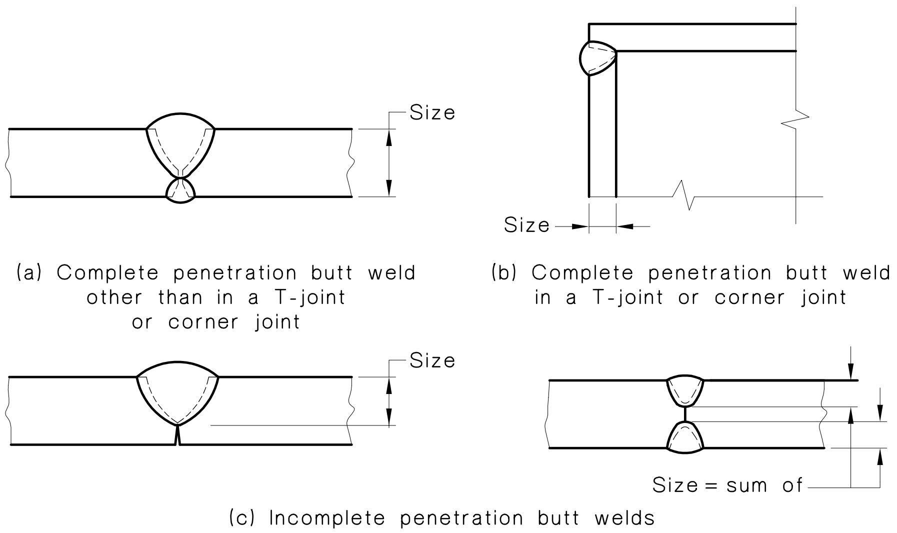

FIGURE C9.7.2.2 SIZE OF BUTT WELDS

AS/NZS 1554.1 requires the size of weld to be specified in the drawings. This presents no problem in respect of complete penetration butt welds where the term 'complete penetration butt weld' or the appropriate symbol from AS 1101.3 describes the desired result.

However, for incomplete penetration butt welds, the design engineer determines the design throat thickness by calculation using Clauses 9.7.2.3 and 9.7.2.7, while the size is a function of—

(a) the design throat thickness;

(b) the welding process; and

(c) the details of the weld preparation.

Rather than specifying the size of an incomplete penetration butt weld, the drawings should show the required design throat thickness. This then allows the fabricator to produce the required design throat thickness by selecting a suitable weld preparation, welding process and welding position. This is particularly important in the case where a fully automatic welding process is to be used, as Clause 9.7.2.3(b)(iii) permits some advantage to be gained due to the deep penetration usually achievable.

C9.7.2.3 *Design throat thickness*

The design throat thickness is the minimum dimension of the weld throat used for purposes of strength assessment in Clause 9.7.2.7.

For fully-automatic arc welding processes, Clause 9.7.2.3(b)(iii) permits advantage to be taken of the penetration achievable with such processes to reduce the size of the weld deposited, provided a macro test demonstrates the viability of the procedure (see Figure C9.7.2.3).

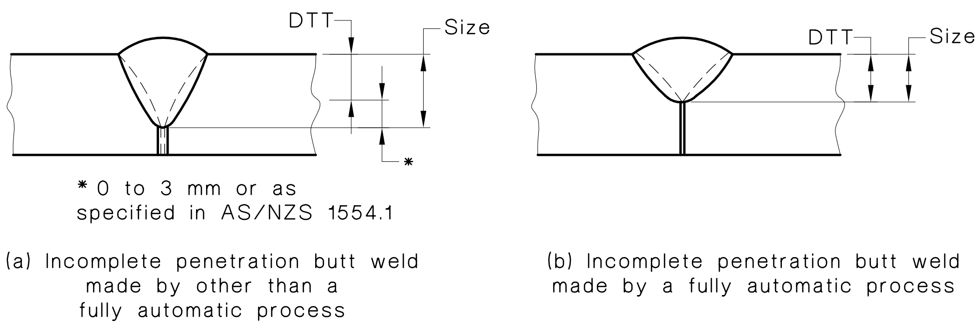

FIGURE C9.7.2.3 DESIGN THROAT THICKNESS

C9.7.2.4 *Effective length*

The length of a continuous full size weld is not necessarily the actual weld length. In certain cases, it is necessary to use run-on and run-off tabs to ensure that a full size weld is present at the ends of a weld. Otherwise the effective length may be reduced below the actual length.

C9.7.2.5 *Effective area*

(No Commentary.)

C9.7.2.6 *Transition of thickness or width*

Where parts subject to tension vary in thickness or width, or both, the required smooth transition can be made by the methods given in Figure 9.7.2.6. The maximum taper of 1:1 is a mandatory upper limit for either thickness or width transitions of parts in tension, although smaller tapers may be chosen, usually at some cost penalty. Some welded detail categories in Section 11 (Fatigue) require tapers no greater than 1:2.5, and Clause 9.7.2.6 makes clear that this lesser taper should be observed in such cases. In parts subject to compression, there is no need for a gradual transition, while for those subject to shear, a 1:1 maximum taper is recommended.

It is recommended that a taper less than 1:2.5 not be used, especially for thickness transitions, since in general the lesser the taper the greater the cost due to difficulties in preparation. Excessively low tapers on thickness transitions may need to be machined, which can be very costly.

The rationale for the 1:1 transition is related to the equivalent stress effect of weld defects and reinforcement permitted by AS/NZS 1554.1 for both GP and SP category welds. A more gradual transition is of little practical use if notches and stress concentration effects prevail adjacent to and in the weld.

Figure 9.7.2.6(a) illustrates the various methods of achieving the required thickness transition depending on whether the adjoining parts have centre-line or offset alignment. When a large difference in thickness exists, there is little option but to prepare the parts to be joined with a special edge preparation. This will usually require a flame-cut or machined edge with multiple faces as shown in Figure C9.7.2.6(a).

Where the offset or thickness differential is less than the thickness of the thinner part connected, the transitions may be achieved by tapering the weld to the top surface of the thinner part (see Figure C9.7.2.6(b) and Figure 9.7.2.6(a)(ii)).

Alternatively, the weld may be tapered to the chamfered face of the thicker part (see Figure C9.7.2.6(c)) with subsequent tapering of the unfused top edge. The methods illustrated in Figures C9.7.2.6(b) and (c) are practical and economic, since they permit conventional edge preparations to be cut on the parts prior to welding operations.

The recommended method for width transitions of butt joints in parts of unequal width is by chamfering the wider part with the taper of the chamfer not being steeper than 1:1 (see Figure 9.7.2.6(b)).

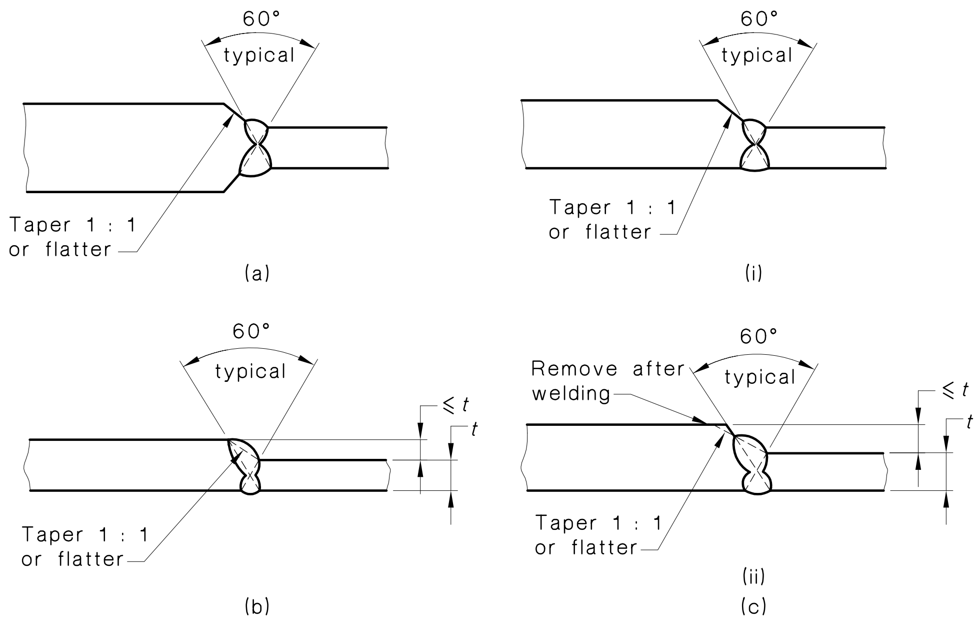

FIGURE C9.7.2.6 TRANSITION IN THICKNESS BETWEEN UNEQUAL MEMBERS

C9.7.2.7 *Strength assessment of a butt weld*

In a complete penetration butt weld, the throat thickness of the weld is equal to that of the thinner part joined, and since there is significant mixing of parent material and deposited weld metal, the design capacity is taken as that of the parts being joined provided that the consumables are qualified in accordance with AS/NZS 1554.1 and that they give a minimum strength at least equal to that of the parent metal given in Table 2.1. This becomes important for steels with a yield strength greater than 350 MPa.

Incomplete penetration butt welds are treated as fillet welds for design purposes, and accordingly the strength assessment is made using Clause 9.7.3.10.

C9.7.3 Fillet welds

C9.7.3.1 *Size of a fillet weld*

The definition of fillet weld size is shown in Figure 9.7.3.1, wherein t_w is the size (the leg length). Australian practice is to denote the size of a fillet weld by the leg length, while European practice is to use the throat dimension (t_t).

Preferred fillet weld sizes have the advantage of setting a standard size range for design engineers to work to, and are sizes measurable with the available fixed fillet weld gauges. There is no restriction implied on using non-preferred sizes.

C9.7.3.2 *Minimum size of a fillet weld*

The minimum sizes of fillet welds given in Table 9.7.3.2 can all be made as single run welds. It is recommended that the provisions of Table 9.7.3.2 also be used for the root run of multi-run welds, even though the Standard is not explicit in this regard.

The provisions of Clause 9.7.3.2 are intended to ensure that sufficient heat input is provided in order to reduce the possibility of cracking occurring in either the heat-affected zone or in the fillet weld itself, especially in restrained joints. Thick material and small welds may result in a rapid cooling of the weld metal, due to the thick material acting as a heat sink, and this may result in a loss of ductility or cracking in the weld metal.

C9.7.3.3 *Maximum size of a fillet weld along an edge*

Note that in Case (b) of Figure 9.7.3.3, the design throat thickness should be based on the size (t_w) that is less than thickness (t), while for Cases (a) and (c), the size (t_w) equals the thickness (t). The reason for the difference in Case (b) is that, if top edge melting occurs, it is difficult to determine the true size of the fillet weld.

C9.7.3.4 *Design throat thickness*

In a similar manner to butt welds, advantage may be taken of the increased penetration achievable with a fully automatic welding process, in order to reduce the size, but not the design throat thickness, of a fillet weld – 85% of the penetration being considered as part of the design throat thickness. The viability of the procedure should be demonstrated by means of a macro test.

C9.7.3.5 *Effective length*

It is important to note that the effective length is the overall length of the full-size fillet weld. No deduction is required at the ends since experience has proved that such a provision is unnecessary.

C9.7.3.6 *Effective area*

(No Commentary.)

C9.7.3.7 *Transverse spacing of fillet welds*

The requirements of Clause 9.7.3 are shown in Figure C9.7.3.7. The provisions are empirical, based on successful past practice.

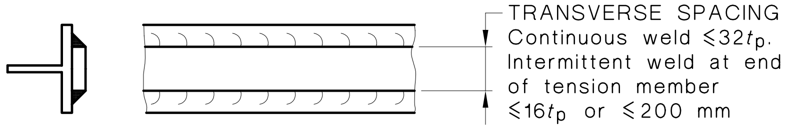

FIGURE C9.7.3.7 TRANSVERSE SPACING OF FILLET WELDS

C9.7.3.8 *Intermittent fillet welds*

The requirements of Clause 9.7.3.8 are summarized in Figure C9.7.3.8. The values specified are empirically based on successful past practice.

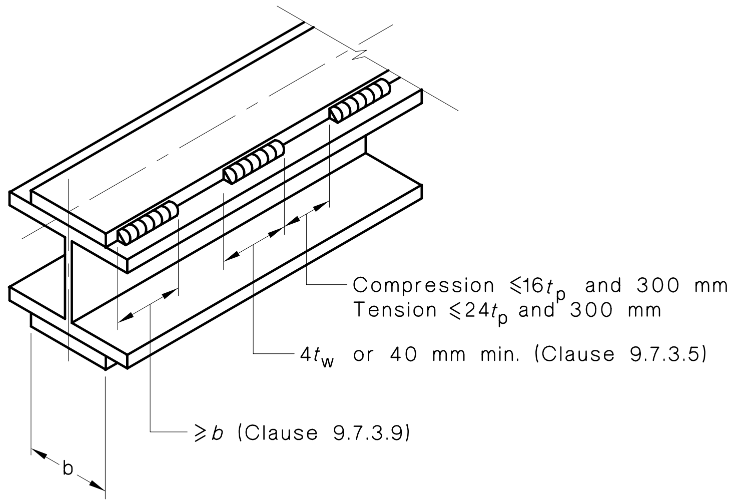

FIGURE C9.7.3.8 PROVISIONS FOR SPACING OF INTERMITTENT FILLET WELDS

C9.7.3.9 *Built-up members— intermittent fillet welds*

The requirements of Clause 9.7.3.9(a) are included in Figure C9.7.3.8. The remaining provisions are self-explanatory, generally being similar to the provision of Item (a). The provisions are empirically based on successful past practice.

C9.7.3.10 *Strength limit state for a fillet weld*

The nominal capacity is based on a failure stress of $0.6f_{uw}$ in shear on the weld throat (t_t) which is assumed to be the failure plane (see Figure C9.7.3.10(1)). Considering the design actions (v_n*, v_{vt}*, v_{v1}*) on the fillet weld throat shown in Figure C9.7.3.10(1), a general form of a failure criterion may be written as follows (Refs 20 and 21):

$$\sqrt{\left[v_n^{*2} + k_v\left(v_v^{*2} + v_{vt}^{*}\right)\right]} = k_w\left(0.6 f_{uw} t_t\right)$$

$$= \phi k_w v_w$$

where

v_n* = design force per unit length of weld normal to the plane of the fillet weld throat

v_{v1}* = design shear force per unit length of weld longitudinal to the plane of the fillet weld throat

v_{vt}* = design shear force per unit length of weld transverse to the plane of the fillet weld throat.

For previous editions of the Standard, the design criterion was based on either a k_v value of 1.0, which results in a vectorial addition method, or a k_v value of 3, which results in a von Mises combination criterion. For Clause 9.7.3.10, values of $k_v = 1.0$ and $k_w = 1.0$ were adopted based on the studies reported in Refs 20 and 21.

An alternative approach is to use a load-deformation method which recognizes that the weld has a finite deformation capacity, and attempts to obtain the load-deformation curve for fillet welds by test. This data is then used to predict the failure load of any fillet weld (see for example Ref. 22).

Tests reported in Ref. 23 indicate that the design rules are valid for rectangular hollow sections with wall thickness less than 3 mm, as contained in AS 1163, provided that a ϕ value of 0.7 rather than 0.8 is used for fillet welds subject to longitudinal shear force and attached to thin (<3 mm) RHS members.

The reduction factor (k_r) essentially reduces the effective weld length (l_w) determined in accordance with Clause 9.7.3.5 (see Figure C9.7.3.10(2)). The reduction in effective length applies to lap joints with long weld elements to account for non-uniformity in the stress distribution along the weld.

For fillet welded lap connections, there is no minimum length beyond that required by Clause 9.7.3.7.

Where longitudinal fillet welds are used alone in a connection, Ref. 5 requires the length of each weld to be at least equal to the width of the connecting material, because of shear lag (see Figure C9.7.3.10(3)). The transverse spacing of the longitudinal fillet welds should not exceed 200 mm nor 16t (see Figure C9.7.3.10(3), unless some alternative provision is made to prevent separation of the connected parts (Ref. 25). By providing a minimum lap of five times the thickness of the thinner part of a lap joint, the resulting rotation of the joint when pulled will not be excessive, as shown in Figure C9.7.3.10(4).

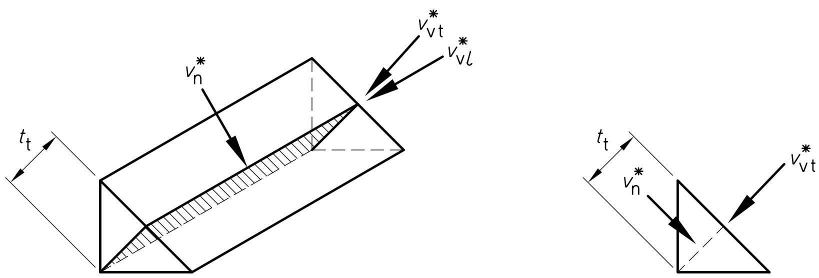

FIGURE C9.7.3.10(1) DESIGN ACTIONS ON A FILLET WELD

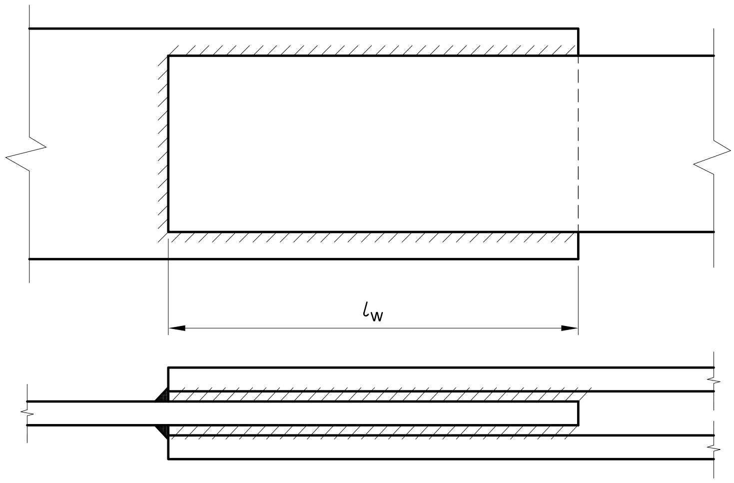

FIGURE C9.7.3.10(2) LAP JOINT WITH FILLET WELDS

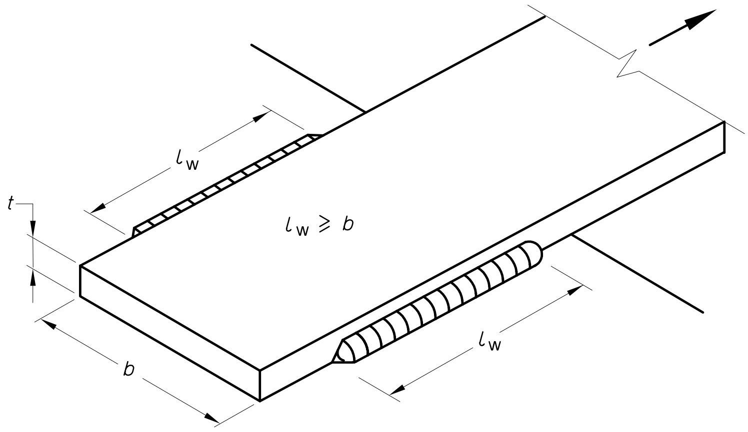

FIGURE C9.7.3.10(3) LONGITUDINAL FILLET WELDS

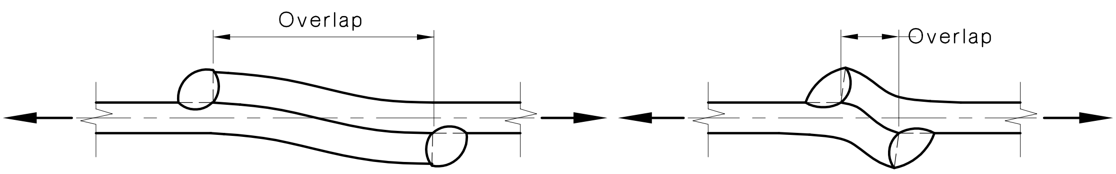

FIGURE C9.7.3.10(4) MINIMUM LAP

C9.7.4 Plug and slot welds

Typical uses for plug and slot welds are to transmit shear in a lap joint or to prevent the buckling or separation of the plates in a lap joint. Their use is not extensive for structural applications.

The provisions of Clause 9.7.4.2 are based on research reported in Ref. 24, which concluded that the traditional approach of using an average shear failure stress over the hole area is an acceptable design approach. The following detailing provisions are based on the provisions of the AWS Structural Welding Code (Ref. 25). AISC (US) provisions are identical (Ref. 5).

The diameter of the hole for a *plug weld* should be not less than the thickness of the part containing it plus 8 mm. The diameter should not exceed either the minimum diameter plus 3 mm, or 2.25 times the thickness of the part, whichever is the greater.

The minimum centre-to-centre spacing of plug welds should be 4 times the diameter of the hole.

The depth of the filling of plug welds in material 16 mm or less should be equal to the thickness of the material. For thicknesses over 16 mm, the depth should be at least one-half the thickness of the material, but not less than 16 mm.

The length of the slot for a *slot weld* should not exceed 10 times the thickness of the part containing it. The width of the slot should be not less than the thickness of the part containing it plus 8 mm. The width should not exceed either the minimum width plus 3 mm, or 2.25 times the thickness of the part, whichever is the greater.

The ends of the slot should be semicircular or should have the corners rounded to a radius not less than the thickness of the part containing it, except those ends that extend to the edge of the part.

The minimum spacing of lines of slot welds in a direction transverse to their length should be 4 times the width of the slot. The minimum centre-to-centre spacing in a longitudinal direction on any line should be 2 times the length of the slot.

C9.7.5 Compound weld

(No Commentary.)

C9.8 ASSESSMENT OF THE STRENGTH OF A WELD GROUP

C9.8.1 Weld group subjected to in-plane loading

C9.8.1.1 *General method of analysis*

In Clause C9.7.3.10, the strength and behaviour of an isolated element of weld was considered. A weld group may be considered as a collection of such elements, and it is necessary to consider how the nominal capacity of such a weld group may be assessed.

In the general method of analysis, the nominal capacity of a welded connection with a constant thickness weld group is assessed by treating that connection as a weld group of unit thickness in isolation from the attached elements or members.

If a connection at the end of a member is viewed as a weld group in isolation from that member (see Figure C9.8.1.1), then the nominal capacity of the weld group may be determined by either an elastic or an ultimate strength approach. Both methods are based upon assumptions in Items (a) and (b) of Clause 9.8.1.1, rotation being assumed about an instantaneous centre for the weld group.

The elastic or linear method is the traditional approach to the assessment of the load capacity of a weld group. The force per unit length of weld is considered to be linearly proportional to the distance from the instantaneous centre.

Derivations of the fundamental equations are given in Refs 1, 22 and 26.

Once the forces per unit length have been determined, the nominal capacity may be determined using the failure criteria of Clause 9.7.3.10.

This method has been adopted in the Standard because reliability studies reported in Refs 20 and 21 have indicated that the method is sufficiently reliable, while having the virtue of being simpler to apply than the alternative methods available and being amenable to hand calculation.

The ultimate strength analysis of a fillet weld group has been described in Ref. 22. For this type of analysis, the weld group is divided into short elements of fillet weld. The load-deformation relationships determined by testing are considered to describe the behaviour of each element. Although the weld forces are still considered to act normal to the radius from the instantaneous centre, the magnitude of the force is not proportional to the radius. The instantaneous centre should therefore be determined by trial and error. The ultimate load capacity corresponding to the achievement of an ultimate displacement condition at some point in the weld group can then be determined.

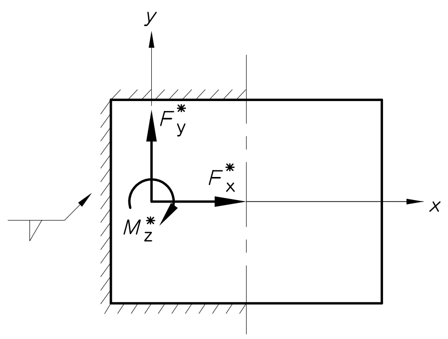

FIGURE C9.8.1.1 FILLET WELD GROUP LOADED IN-PLANE

C9.8.1.2 *Alternative analysis*

An alternative approach is offered in which a fillet weld group is designed as an extension of the connected member by maintaining a consistent distribution of forces so that equilibrium is satisfied at the interface between the weld element and the parent plate. For example, in a commonly adopted theory, only the web of the beam is assumed to resist vertical shear force whereas in weld group theory, the shear force may be considered to be uniformly distributed over the length of the weld (see Figure C9.8.1.2(a)). A similar difference in the assumed force distribution exists for a beam subjected to torsion as illustrated in Figure C9.8.1.2(b). This alternative analysis allows the assumptions made in member design also to be used for the design of the fillet weld group.