CHAPTER 9

STRUCTURAL WELDING

The following sections regarding the welded connections are applicable to structures loaded with predominantly static loads, while for fatigue loadings refer to Chapter 11.

9.1 WELDABILITY AND STEEL PROPERTIES

"Weldability "is the capacity of a metal to be welded under the fabrication conditions imposed, into a specific, suitably designed structure, and to perform satisfactorily in the intended service.

Weldability is enhanced by low carbon, fine grain size and restricted (low) thickness. Conversely, it is reduced by high carbon, coarse grain, and heavy thickness. Table 9.1 abstracts the requirements covering weldability related variables.

9.2 STRUCTURAL WELDING PROCESS, WELDING POSITIONS AND ELECTRODES REQUIREMENTS

9.2.1 Welding Positions

– The different welding positions are shown in Fig. 9.1 where:

a- In the flat position weld metal can be deposited faster because gravity is working with the welder, so large electrodes and high currents can be used.

b- In the vertical and overhead positions, electrodes diameters below 4 mm (or at most 5 mm) are to be utilized otherwise weld metal runs down.

c- For arc welding the weld metal is deposited by the electro-magnetic field, the welder is not limited to the flat or horizontal position.

d- The designer should avoid whenever possible the overhead position, since it is the most difficult one.

e- Welds in the shop are usually in the flat position, where manipulating devices can be used to rotate the work in a flat position.

f- Field welds that may require any welding position depending on the orientation of the connection have to meet welding inspection requirements of Section 9.9.

Table 9.1 Requirements for Properties Affecting Weldability of St
Sections, Plates, and Bars

Grade of Steel	Nominal Values of Yield Stress F_y and Ultimate Strength F_u — Thickness t				Maximum Thickness of Statically Loaded Structural Elements (mm)	Charp Tem
	t ≤ 40 mm		40 mm < t ≤100 mm			
	F_y (t/cm^2)	F_u (t/cm^2)	F_y (t/cm^2)	F_u (t/cm^2)		T_{cv} Test Temperature (^{o}c)
St 37	2.40	3.70	2.15	3.40	250	-20°
St 44	2.80	4.40	2.55	4.10	150	-20°
St 52	3.60	5.20	3.35	4.90	130	

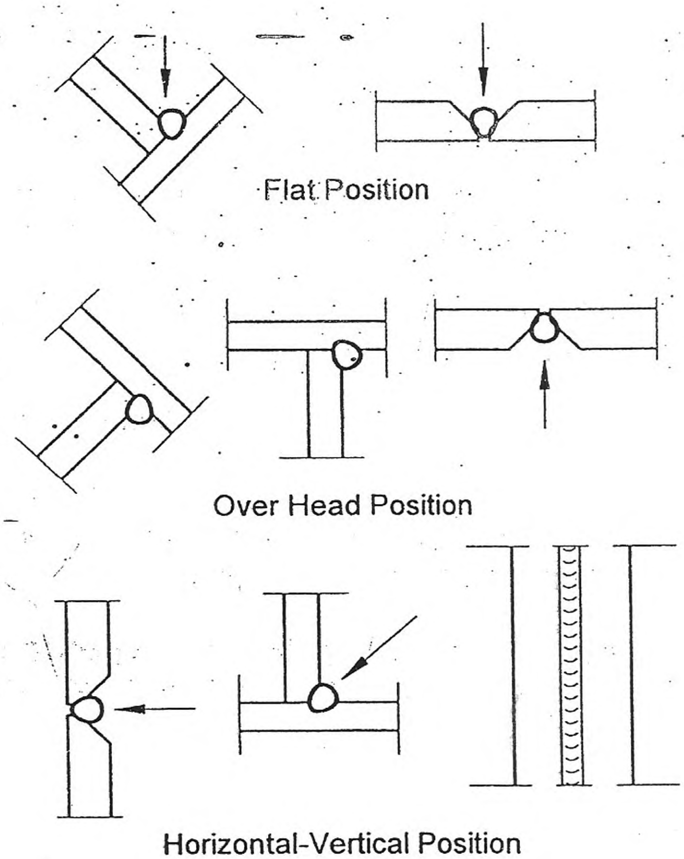


Figure 9.1 Welding Positions

9.2.2 Welding Processes

Weldable structural steels meeting the requirements of Tab... welded by one of the following welding processes:

- Shielded Metal Arc Welding (S.M.A.W.)
- Submerged Arc Welding (S.A.W.)
- Gas Metal Arc Welding (G.M.A.W.)
- Flux Cored Arc Welding (F.C.A.W.)
- Gas Tungsten Arc Welding (G.T.A.W.)

9.2.3 Electrode Requirements

a- The common sizes of electrodes for hand welding are 4 ... diameter. For the flat welding position 6 mm can be used.
b- 8 mm fillet weld size is the maximum size that can be made ... with 5 mm coated electrodes.
c- For large sizes several runs of electrode in arc welding are to ... while for gas processes any size can be made in one run.

The appropriate electrode type regarding the weld process as w... yield and maximum tensile strength are given in Table 9.2.

The following flow chart designates the electrode and flux symbo... Table (9.2).

9.3 THERMAL CUTTING

Two cutting systems are available:
a- Oxyfuel gas, which can cut almost any plate thickness used comm...
b- Plasma arc which will cut almost up to about 40 mm thickness a... faster than Oxyfuel.

9.4 DISTORTION

Non- uniform rate of cooling after welding causes shrinkage w... cause distortion in the welded steel elements. In order to minimize dis... the following recommendations are to be taken into consideration:
a- Use the minimum weld metal no larger than is necessary to ach... design strength.
b- Use symmetrical simultaneous welds.
c- Use minimum preheat. The rate of preheating must be slow and unif... is desirable to maintain the preheat temperature during the whole weld... process.
d- For welds requiring more than one pass of welding, the interp... temperature is to be maintained to the temperature of the deposited w... when the next pass is begun.
e- Use intermittent staggered welds.
f- Use clamps, jigs, etc., this forces weld metal to stretch as it cools.

Flowchart electrode and flux symbols designation

Shielded Metal Arc Welding (SMAW)

E A B C D

Electrode	Minimum tensile strength of deposit weld metal in imperical units = (60 ksi = 4.20 t/cm² or 70 ksi = 4.90 t/cm²)	Electrode welding position = 1 for all positions including vertical up = 2 for only flat and horizontal positions = 4 for all positions excluding vertical up	= 5,6 or 8 for low hydrogen electrodes (moisture content should be less than 0.2% of the volume) = 2,3,or 4 rutile electrodes = 1 or 0 for organic electrodes

Gas Metal Arc Welding (GMAW)

E R A B S C

Electrode if used for GMAW	Rod if used for GTAW	Minimum tensile strength of deposit weld metal in imperical units = (60 ksi = 4.20 t/cm² or 70 ksi = 4.90 t/cm²	Solid electrode	Express the operating characteristics of electrode such as penetration, polarity, current type, etc......

Submerged Arc Welding (SAW)

F A H I

Flux	Minimum tensile strength of deposit weld metal in imperical units = (60 ksi = 4.20 t/cm² or 70 ksi = 4.90 t/cm²)	= A for as welded = P post weld heat treatment	The temprature that gives impact strength of 27 joules = 3 for -30 C°, = 4 for -40 C°, etc.....

Flux Chord Arc Welding (FCAW)

E A C T

Electrode	Minimum tensile strength of deposit weld metal in imperical units = (60 ksi = 4.20 t/cm² or 70 ksi = 4.90 t/cm²)	Electrode welding position = 1 for all positions = 2 for only flat and horizontal positions	Usability Code = 2 for single pass CO_2 shielded only

Table 9.2 Metal / Filler Metal Combination for Mechanical Chemical Matching

Group	Material Code	Min. Tensile Strength (t/cm^2) *	Min. Yield Strength (t/cm^2) *	Welding Process	Electrode Classification	Min. Yield Strength (t/cm^2)	Min. Tensile Strength (t/cm^2)
I	ST 37	3.40-3.70	2.15-2.40	SMAW	E60xx	3.3	4.15
					ER70S	4.0	4.80
				GMAW	F6xx	4.00	4.80
				SAW	F7xx	3.30	4.15
					E6xT	4.00	4.80
				FCAW	E7xT	3.30	4.15
					E60xx	4.00	4.80
	ST 44	4.10-4.40	2.55-2.80	SMAW	E70xx	4.0	4.80
II	ST 52	4.90-5.20	3.35-3.60	GMAW	ER70S	4.00	4.80
				SMAW	F7xx	4.00	4.80
				FCAW	E7xT	4.00	4.80

* The minimum values are shown in Section 1.3.3.

9.5 DESIGN, STRENGTH AND LIMITATIONS OF BUTT (GRO... WELDED CONNECTIONS

9.5.1 Nomenclature of the Common Terms

Figure 9.2 shows the nomenclature of the common terms for gro... we...

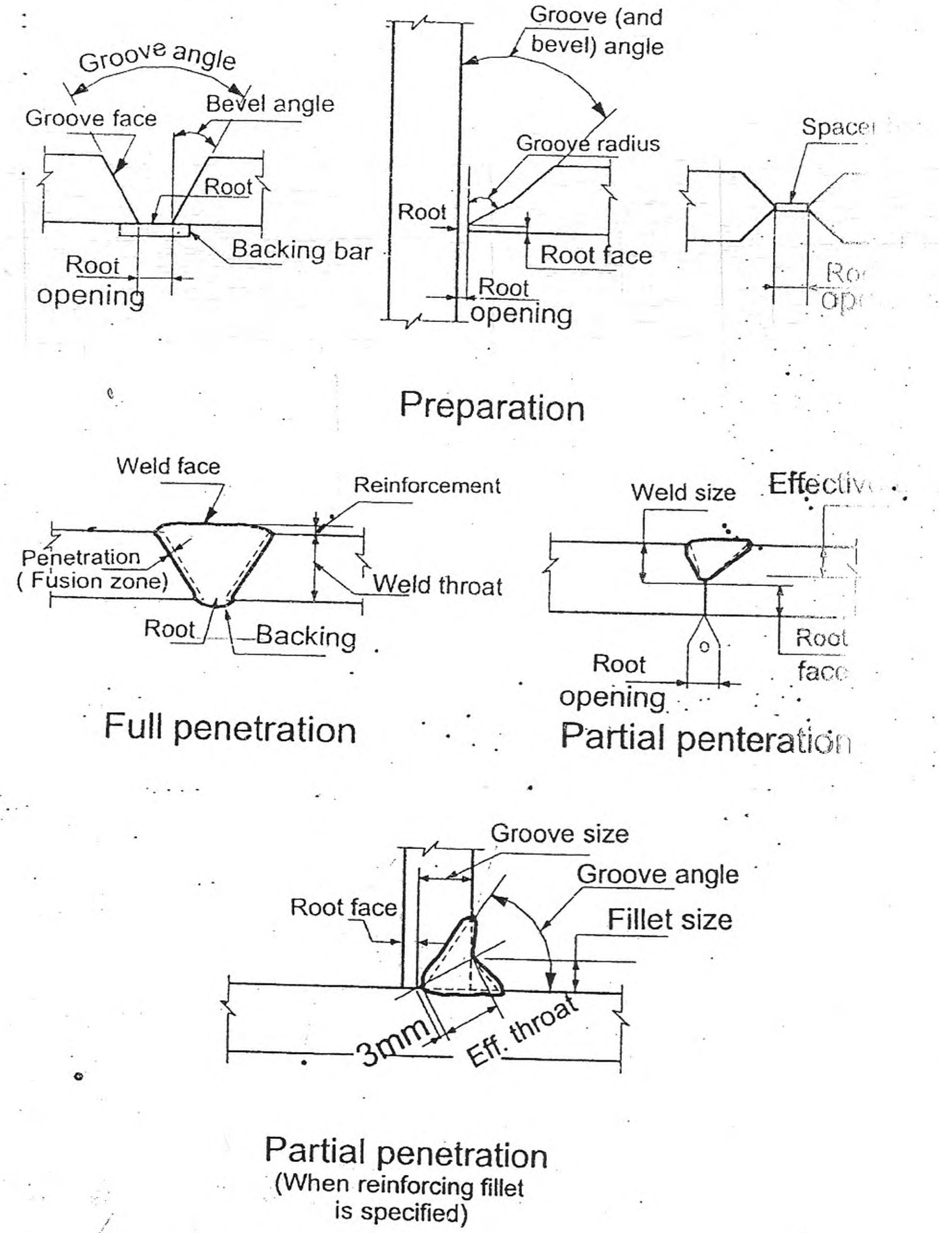
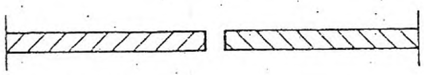
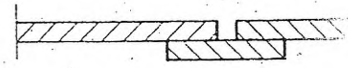
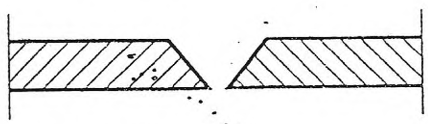
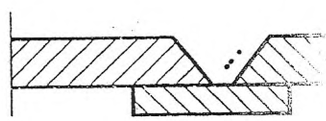
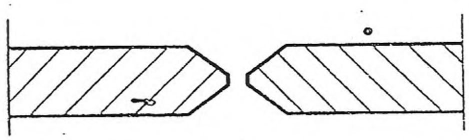
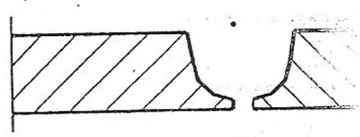
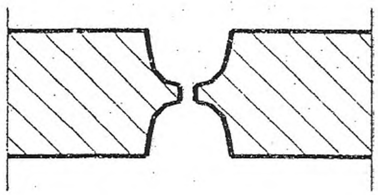


Figure 9.2 Butt (Groove) Weld Nomenclature

Table 9.3 Types of Groove Butt Welding

1.  Square - Butt • Welded from one side: up to 1.5 mm thick-no gap. • Welded from both sides using Normal Electrodes : up to 3 mm. thick-no gap. up to 5 mm. thick-take 1.5 mm gap. • Welded from both sides using deep penetration electrodes: up to 16 mm. -no gap.	2.  Square Butt with Backing Bar • Normal Electrodes : up to 5 mm. thick. 5mm gap up to 13mm. thick. 8mm ga… • Deep Penetration Electro… up to 13mm. thick. 6mm g…
3.  Single "V" Butt Weld • Included Angle: 60° for flat position . 70° for vertical position . 80° for over head position . • Root Thickness: 0-3 mm . • Thickness up to 25 mm . • Gap 1.5 mm - 3 mm .	4.  Single "V" Butt Weld With Backing Bar • Included angles as(3). • Gap 3 mm. - 5 mm . • Thickness up to 25 mm .
5.  Double "V" Butt Weld • Included angle gap and root thickness as(3) • Thickness 16 mm. - 50 mm.	6.  Single "U" Butt Weld • Inculded angle 20°-40° • Gap 3 mm. - 5 mm . • Root thickness 3mm.-5mm. • Root radius 3mm.-10mm. • Thickness 25mm.-50mm.

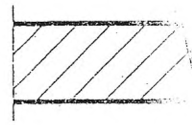
7.



Double "U" Butt Weld

- Dimensions as(6).
- Thickness 38 mm. upwards.

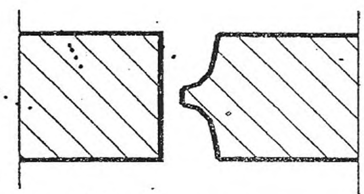
8.



Single "J" Butt W...

- Included angle 2...
- Gap 3mm. - 5m...
- Root thickness ...
- Root radius 5m...
- Thickness 25m...

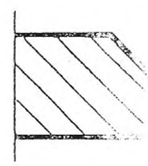
9.



Double "J" Butt Weld :

- Dimensions as(8).
- Thickness 38 mm upwards .

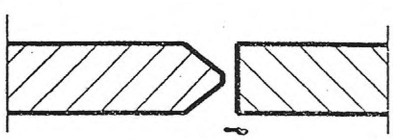
10.



Single Bevel B...

- Included angl...
- Gap 3 mm. - 6...
- Root thicknes...
- Thickness up t...

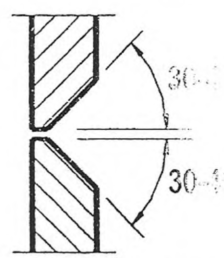
11.



Double Bevel Butt Weld

- Dimensions as 10 .
- Thickness 25 mm. upwards .

12.



Double Bevel Butt W...

- Angles as shown
- Gap 1.5 mm - 3 ...
- Root thickness 1...
- Thickness up to ...

Regarding the advantages, the economy, and the defects of ea... the following remarks are to be considered:

a- Double bevel, double V, double J and double U groove welds ... economical than single welds of the same type because of less ... volume.
b- Bevel or V grooves can be flame cut and therefore are less expens... J and U grooves which require planning or arc- air gouging.
c- Single V welding is achieved from one side, it is difficult to ... distortion, and this type is usually economical up to 25 mm thickn...
d- Single U welding is achieved from one side, the distortion is less ... single V and is not economical under 19 mm thickness.
e- Double V is a balanced welding with reduced distortion requires ...
f- Double U is a balanced welding with reduced distortion requires ... and is not recommended below 38mm thickness.
g- Groove welds joining plates of different thicknesses shall pref... made with a gradual thickness change not exceeding 1:4 as sho... 9.3a for tension members. In compression members there is no ... gradual thickness transition. The difference in thickness may be ... by a slope in the weld metal rather than machining the parent ... shown in Fig. 9.3b.
h- T-Groove welds are accepted even if they are not complete... achieving a partial penetration groove weld if the total weld th... greater than the parent metal thickness, see Fig.9.3c.

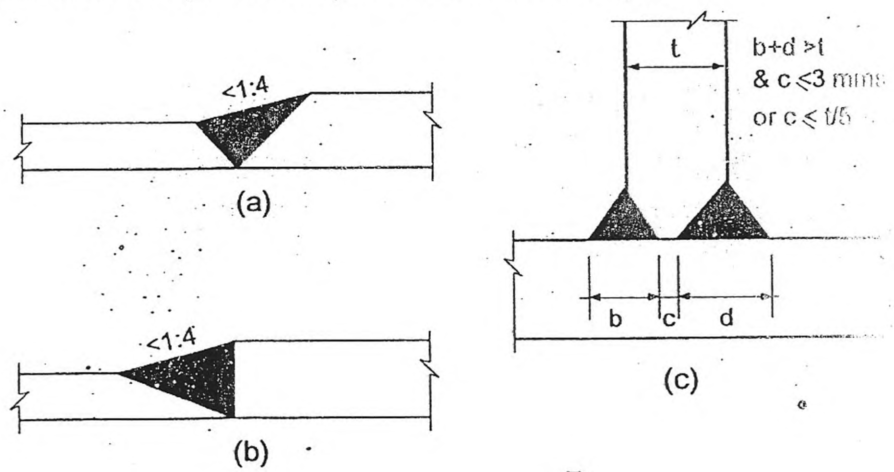


Figure 9.3 Groove Welds for Plates of Different Thicknes...

If the requirements of Fig. 9.3.c are not fulfilled the Tee-Gro... are to be analyzed as being fillet welds according to the provisions ... 9.6.

9.5.2 The Groove Weld Effective Area and Thickness Dimensio...

a- The effective area of groove welds shall be considered as th... length of the weld, times the effective thickness dimension.
b- The effective length of a groove weld shall be the width of the pa...
c- The effective thickness dimension of a full penetration groove weld is the thickness of the thinner part joined as shown in Fig. 9.4.a.

d- For incomplete (Partial) penetration groove welds and unsealed groove welds, the effective thickness, of weld is taken as the sum of the actual penetrated depths, as shown in Fig. 9.4 b, c and d.

e- For J or U partial joint penetration groove weld the effective thickness dimension shall be the depth of chamfer.

f- For bevel or V joint where the induced angle at the root of the groove is greater than 60° the thickness dimension shall be the depth of chamfer (D). While if the induced angle is less than 60° and greater than or equal to 45° the effective thickness dimension shall be the depth of the chamfer minus 3 mms (i.e. $t_g = D - 3$ *mms*) as shown in Fig. 9.4 e and f.

g- To insure fusion and minimize distortion for partial joint penetration groove weld the minimum thickness dimension is determined by the thicker of the two parts joined as given in Table 9.4.

h- Weld size is determined by the thicker of the two parts joined except that the weld size need not exceed the thickness of the thinner part joined when a larger size is required by calculated strength. For this exception particular care shall be taken to provide sufficient soundness of the weld.

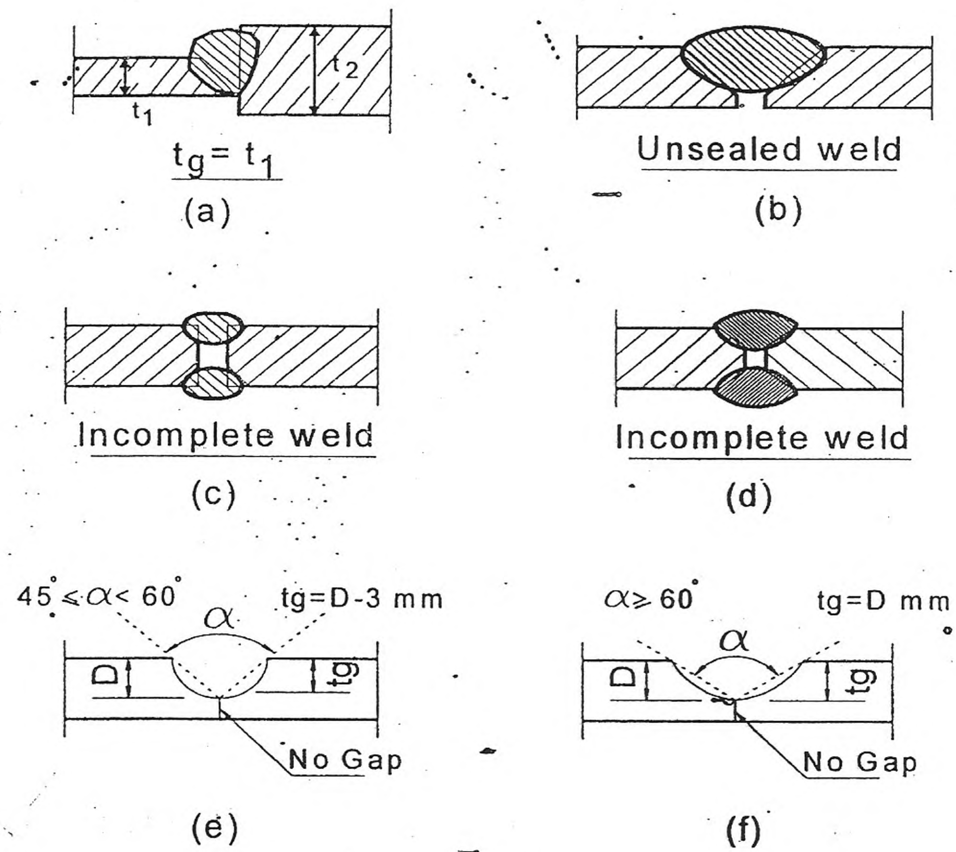


Figure 9.4 Details of Groove Weld

Table 9.4 Minimum Thickness Dimensions of Partial Joint Penetration Groove Weld

Material thickness of thicker part joined (greater of t_1 or t_2)	Up to 6 mm	Over 6 to 12	Over 12 to 18	Over 18 to 38	Over 38 to 56	Over 56 to 150	Over 150
Minimum effective thickness dimension (t_g) mm	3	5	6	8	9	12	16

9.5.3 Design Strength of Butt (Groove) Welds

9.5.3.1 Matching Filler Metal Requirements

The electrode material should have the properties of the base metal. When properties are comparable, the weld metal is referred to as "Matching" weld metal.

For complete and partial penetration groove welds, it is allowed to use weld metal with a strength level equal to "Matching" weld or one strength level stronger (see Table 9.2).

9.5.3.2 Design Strength of Butt (Groove) Welds

The Load and Resistance Factor Design concept which was previously given in Chapter (1), where Equation (1.7) gives the structural safety requirements for structural elements is also applicable to welds as follows:

$$\phi R_n \geq \gamma_i Q_i$$

Where:

ϕ = *shear*, tension or compression resistance weld reduction factor

R_n = *shear*, tension or compression nominal weld strength per unit length = R_{nw} for welds

γ_i = loads *factors*

Q_i = *service* loads such as bending moment, shearing force, axial force and torsional moment resulting from various loads

$\gamma_i Q_i$ = R_{uw} = factored load per unit length of weld which corresponds to the applied straining action

9.5.3.3 Tension, Compression and Shear Design Strength of Complete Penetration Groove Welds

a- Tension and compression normal to the effective area and ... compression parallel to axis of weld (per unit length) must ... relations below:

$$\phi \; R_{nw} = 0.85 \, t_b \, F_y \quad t/cm$$

Where:

ϕ = 0.85

t_b = base plate metal thickness

F_y = the yield stress of the base metal, t/cm^2
for Hybrid sections F_y is the smaller yield stress for the ... elements t/cm^2

b- The shear strength on the effective area per unit length shall be

$$\phi \; R_{nw} = 0.85 \, t_b \, (0.6 \, F_y)$$

9.5.3.4 Tension, Compression and Shear Design Strength of ... Penetration Groove Welds

Partial penetration groove welds are similarly treated ... penetration groove welds. Equation 9.1 and 9.2 shall be appl... below:

a- Tension and compression strength

$$\phi \; R_{nw} = 0.85 \, t_g \, F_y \qquad 3$$

b- Shear strength

$$\phi \; R_{nw} = 0.85 \, t_g \, (0.6 \, F_y) \qquad 4$$

Where:

t_g = the actual penetrated weld depth, cm

9.5.4 Constructional Restrictions and Remarks

a- Single V and U groove welds shall be sealed, whenever possible by depositing a sealing run of weld metal on the back of the joint. Where this is not done, the strength in the weld shall be not more than one half of the corresponding permissible design strength indicated in Section 9.5...

b- In the case of single and double V and U butt weld 18 mm ... and over in size, in dynamically loaded structures, the back of the first run shall be cut out to a depth of at least 4 mm , prior to the application of subsequent

runs. The grooves thus formed and the roots of single V and U groove welds shall be filled in and sealed.

c- When it is impossible to deposit a sealing run of weld metal on the back of the joint, then provided that backing material is in contact with the back of the joint, and provided also that the steel parts are bevelled to an edge with a gap not less than 3 mm and not more than 5 mm, to ensure fusion into the root of the V and the backing material at the back of the joint, strength may be taken as specified in Section 9.5.3.3.

d- Possible defects that may result in discontinuities within the weld are to be avoided. Some of the more common defects are: incomplete fusion, inadequate joint penetration, porosity, undercutting, inclusion of slag and cracks (refer to Section 9.8)

e- i- Butt welds shall be built up so that the thickness of the reinforcement at the center of the weld is not less than the following:

- Butt welds $\leq$ 30 mm in size reinforce by 10%
- Butt welds > 30 mm in size reinforce by 3mm

ii- Where flush surface is required, specially in dynamic loading, the butt weld shall be built up as given in (a) and then dressed flush.

9.6 DESIGN, STRENGTH AND LIMITATIONS OF FILLET WELDED CONNECTIONS

9.6.1 Nomenclature of the Common Terms

Figure 9.5 shows the nomenclature of the common terms for fillet welds.

9.6.2 Different Types of Fillet Welded Connections

Fillet welds are made between plates surfaces which are usually at right angles, but the angle between the plates may vary from 60^{o} to 120^{o}. Tee joints, corner welds and cruciform joints are all combinations of fillet welds and are as shown in Fig. 9.6.

The ideal fillet is normally of the mitre shape which is an isosceles triangle as shown in Fig. 9.7(h). The mitre and convex welds are stronger than a concave fillet weld of the same leg length when the weld is subject to static loadings, but the concave is stronger when subject to dynamic loadings.

Vertical welds made upwards in one run, are generally convex. Usually low currents produce the convex welds.

The penetration of the weld should reach the root where the contour of penetration is usually as shown in Fig. 9.7(g).

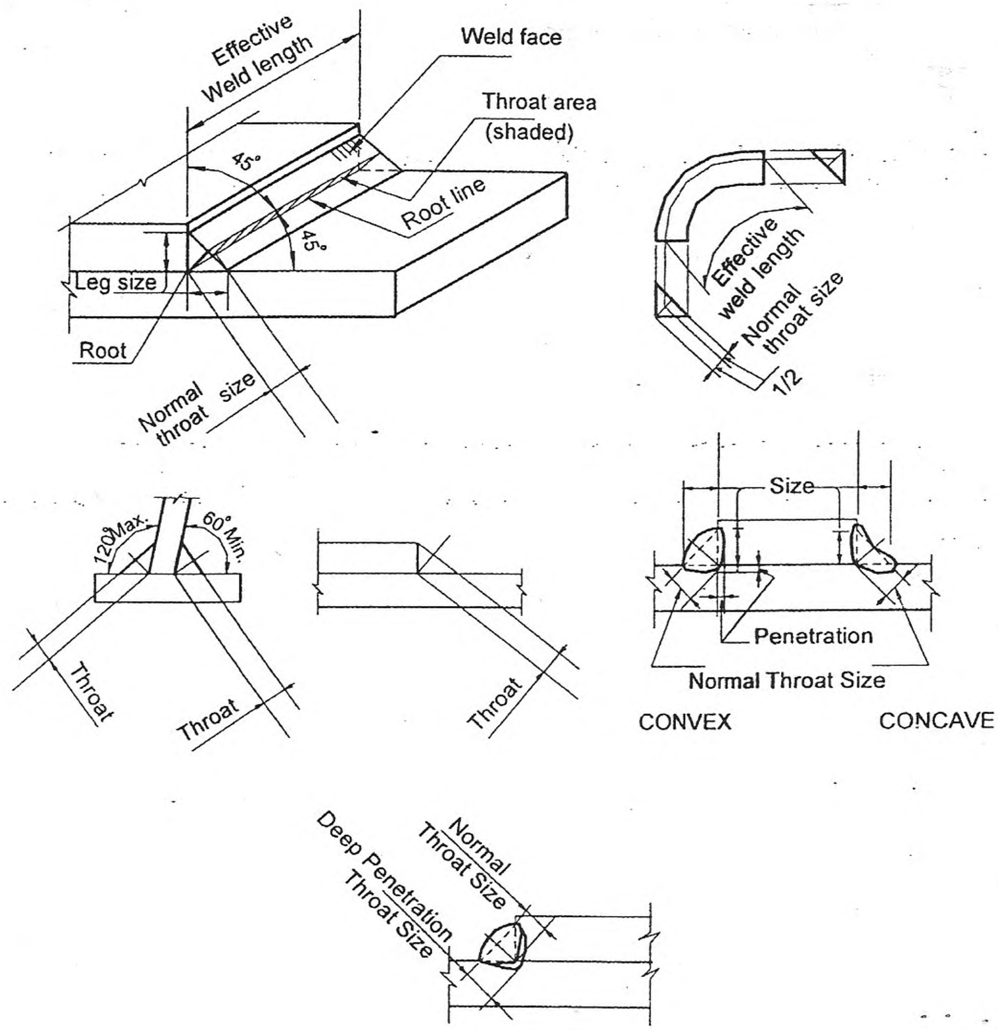


Figure 9.5 Fillet Weld Nomenclature

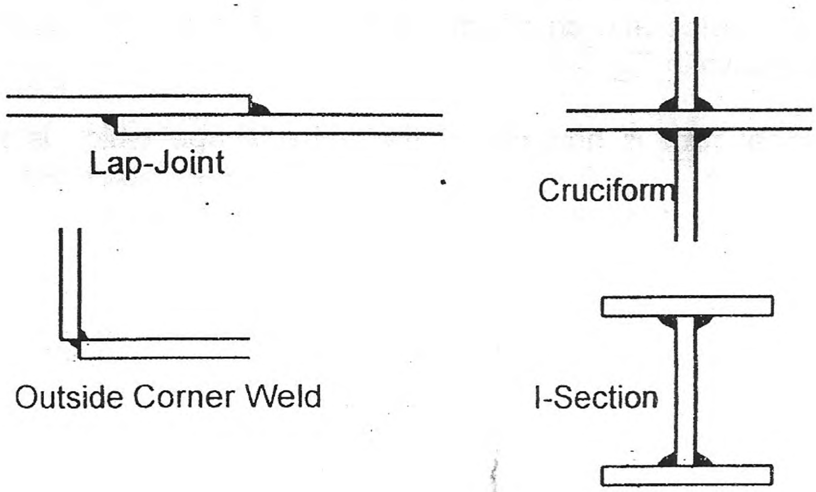


Figure 9.6 Combinations of Fillet Welded Connections

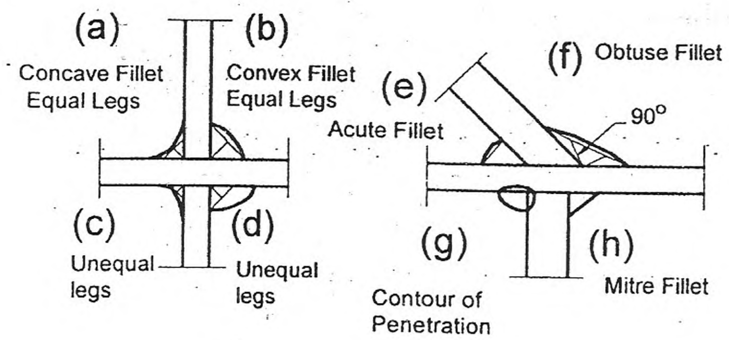


Figure 9.7 Fillet Weld Configurations

9.6.2.1 Effective Area of Fillet Welds

The effective weld section is equal to the largest triangle which can be inscribed between the fusion surfaces and the weld surface, provided there is a minimum root penetration, which is not taken into account. The effective throat (*a*) is then the distance from the root to the surface of the isosceles triangular weld along the line bisecting the root angle as shown in Fig. 9.8.

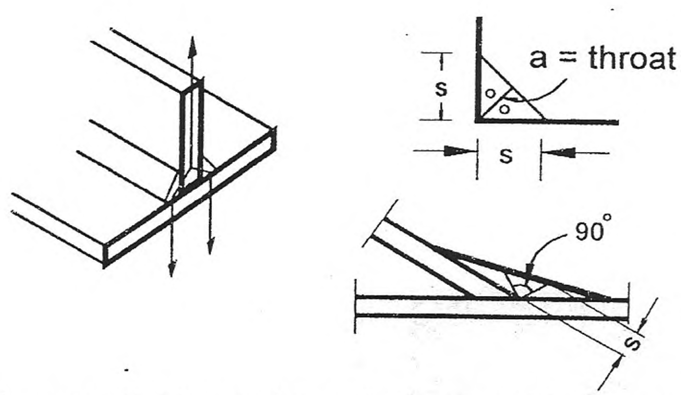


Figure 9.8 Dimensions of Size and Throat of Fillet Weld

Fillet welds are stressed across the throat of the weld, while their size (*s*) is specified by the leg length (*s*) where:

$a = K.s$ 9.5

The value of "*K*" depends on the angle between the fusion faces and it may be taken as follows:

Table 9.5 Values of K Relating Size and Throat of Weld

Degree	60° – 90°	91° – 100°	101° – 106°	107°– 113°	114°– 120°
K	0.7	0.65	0.6	0.55	0.5

9.6.3 Limitations

a- Deposited fillet weld metal is related to the limiting angles between the fusion faces that shall not be greater than 120 ° nor less than 60 ° for flat and down hand welding, 70 ° for vertical welding and 80 ° for overhead welding. The throat of a fillet weld as deposited shall be not less than 6/10 and 9/10 of the minimum leg length in the case of concave and convex fillets respectively as shown in Fig. 9.9.

b- The minimum size of fillet welds shall be not less than the size required to transmit calculated forces nor the size as shown in Table 9.6 which is based upon experiences and provides some margin for uncalculated stresses encountered during fabrication, handling, transportation and erection. The limitations of Table 9.6 are based upon the quench effect of thick material on small welds. Very rapid cooling of weld metal may result in a loss of ductility. Further, the restraint to weld-metal shrinkage provided by thick material may result in weld cracking.

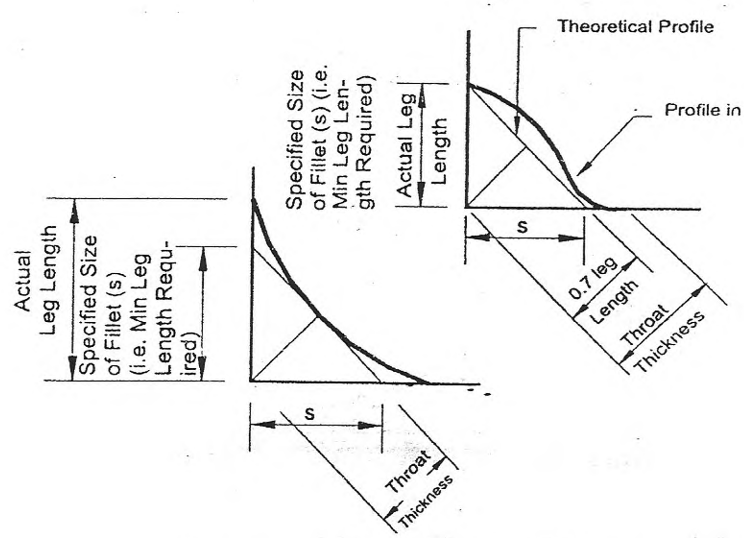


Figure 9.9 Deposited Fillet Weld Metal

Table 9.6 Minimum Size of Fillet Welds

Material thickness of thicker part joined (mms)	To 6 mm inclusive	Over 6 to 12	Over 12 to 18	Over 18
Minimum size of fillet weld (s) mms	4	5	6	8

- For flange-web welds and similar connections, the actual weld size need not be larger than that required to develop the web capacity and the requirements of Table 9.6 shall not apply.

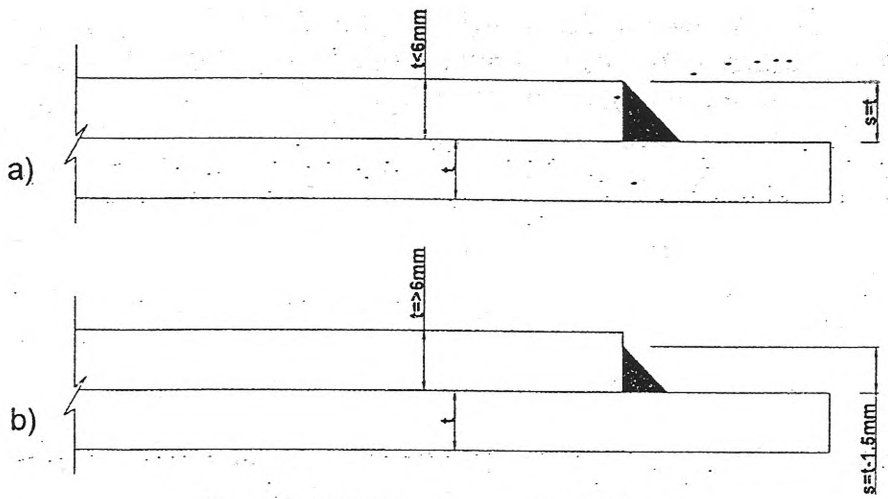


Figure 9.10 Maximum Weld Size

c- The Maximum size of fillet weld should be as follows:

i- The maximum size of fillet weld(s) should not exceed the thinner thickness of the connected plates for longitudinal and edge fillet weld.

ii- At long edges of material less than 6 mms thick the size (s) should not be greater than the thickness of the material (see Fig. 9.10 a).

iii- At long edges of materiel 6 mms or more in thickness, the size(s) should not be greater than the thickness of the material minus 1.5 mms, unless the weld is especially designated on the drawings to be built out to obtain full-throat thickness, (see Fig. 9.10(b)).

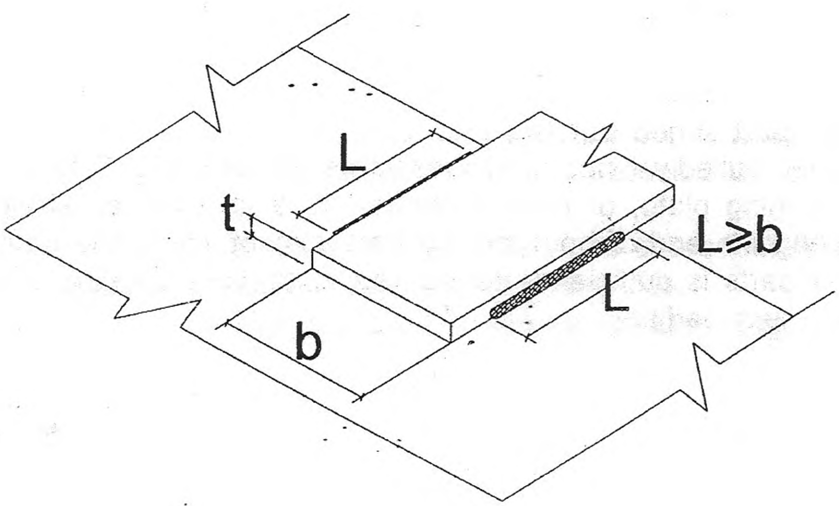


Figure 9.11 Longitudinal Fillet Weld

d- The minimum effective length of fillet welds designed on the basis of strength shall be not less than four times the weld size(s) or 5 cms whichever is largest.

e- When longitudinal fillet welds are used alone in a connection (see Fig. 9.11), the length of each weld should be at least equal to the width of the connecting material because of shear lag.

f- The maximum effective length of fillet weld loaded by forces parallel to the weld, such as lap splices and gusseted truss connections, shall not exceed

70 times the fillet weld size(s). A uniform stress distribution may be assumed throughout the maximum effective length. Generally in lap joints longer than 70s a reduction factor β-allowing for the effects of non-uniform distribution of stress along its length is to be utilized according to the following relation:

$$\beta = 1.2 - 0.2L / (70\ s) \qquad 9.6$$

Where,

L = overall length of the fillet weld

g- There are No limitations for the length of fillet weld for beam to column connections as well as for the flange to web weld in welded built up plate girders (see Fig. 9.12 (a) and (b)).

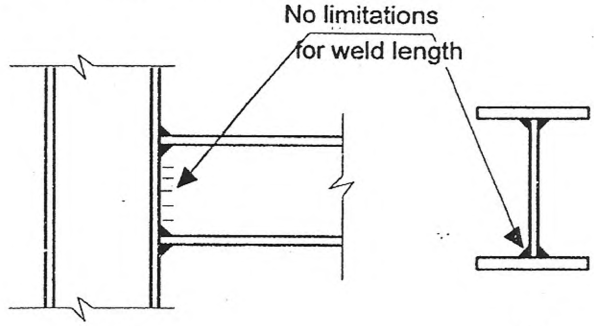


Figure 9.12 Different Locations with No Limitations

h- In lap joints, the minimum amount of lap shall be five times the thickness of the thinner part joined but not less than 5.0 cms, so that the resulting rotation when pulled will not be excessive as shown in Fig. 9.13. In addition lap joints joining plate, or bars subjected to axial stresses shall be fillet welded along the end of both lapped bars except where the deflection of the lapped parts is sufficiently restrained to prevent opening of the joint under maximum loading.

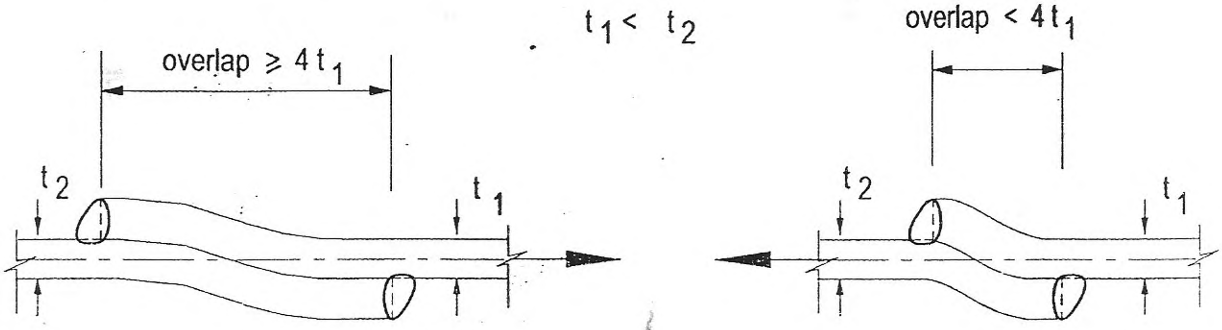


Figure 9.13 Minimum Lap to Minimize Excessive Rotation

i- Fillet weld terminations :

i- Fillet weld terminations shall not be at the extreme ends or sides of parts or members. They shall be:

- either returned continuously around the ends or sides respectively for a distance not less than two times the nominal weld size (see Fig. 9.14(a)).
- or shall terminate not less than two times the nominal weld size as shown in Fig. 9.14(b).

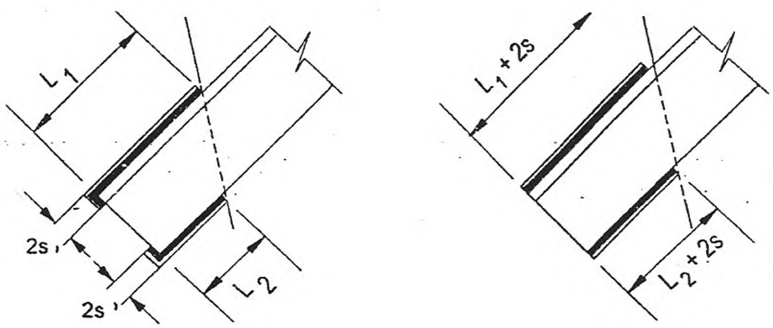


Figure 9.14 Fillet Weld Terminations

ii- For details and structural elements subject to cyclic (fatigue), out of plane forces and/or moments of frequency and magnitude that would tend to initiate a progressive failure of the weld, filler welds shall be returned around the side or end for a distance not less than two times the nominal weld size. The common connections where this limitation applies are: brackets, beam seats, framing angles, simple end plates and similar connections.

iii- For framing angles and simple end-plate connections which depend upon flexibility of the outstanding legs for connection flexibility, if end returns are used, their length shall not exceed four times the nominal size of the weld.

iv- Fillet welds which occur on opposite sides of a common plane shall be interrupted at the corner common to both welds.

v- End returns shall be indicated on the design and detail drawings.

j- Intermittent fillet welds may be used to transfer calculated stress across a joint of faying surfaces when the strength required is less than that developed by a continuous fillet weld of the smallest permitted size, and join components of built up members. The following limitations are to be satisfied:

i- Intermittent welds shall not be used in parts intended to transmit stresses in dynamically loaded structures.

ii- The effective length of any segment of intermittent fillet welding shall not be less than four times the weld size with a minimum of 4.0 mms.

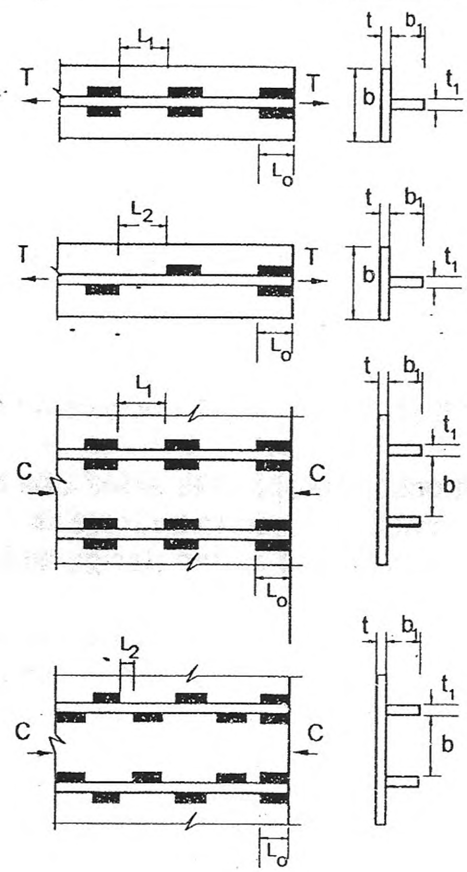
iii- The clear distance between effective lengths of consecutive intermittent fillets whether chained (L_1) or staggered (L_2) shall not exceed 12 times the thickness of the thinner part in compression or 16 times in tension and in no case shall it exceed 20 cms (see Fig. 9.15).

iv- In a line of intermittent fillet welds, the welding shall extend to the ends of the connected parts for staggered welds. This applies generally to

both edges but need not apply to subsidiary fittings or components such as intermediate stiffeners.

v- For a member in which plates are connected by means of intermittent fillet welds, a continuous fillet weld shall be provided on each side of the plate for a length (L_O) at each end equal to at least three quarters of the width of the narrower plate connected (see Fig. 9.15).

vi- Stiffeners and girder connections are permitted to be directly welded with the compression flange. In the case of the tension flange, intermediate plates (not welded to the flange) shall be inserted between the flange and the stiffener in order to prevent weakening of the flange by transverse welds. Where intermittent welds are used the clear distance between consecutive welds, whether chained or staggered shall not exceed 16 times the thickness of the stiffener. The effective length of such weld shall not be less than 10 times the thickness of the stiffener in the case of staggered welds and 4 times in the case of chained welds, or one quarter the distance between stiffeners whichever is smallest.



- $L_O \geq$ *0.75* ***b*** *or 0.75* $\boldsymbol{b_1}$ – whichever is smaller

- (L_1) or (L_2) $\leq$ *16* ***t*** *or 16* $\boldsymbol{t_1}$ *or 200 mm* - whichever is smallest (Tension)

- (L_1)or (L_2) $\leq$ *12****t*** *or 12*$\boldsymbol{t_1}$ *or 200 mm*-whichever is smallest (Compression)

Figure 9.15 Intermittent Fillet Welds

k- Single side fillet welds:

i- Single side fillet welds subjected to normal tensile stresses perpendicular to the longitudinal direction of the welds are not allowed.

ii- Single side fillet welds between the flanges and the web in I girder shall be made with a penetration of at least half the web thickness.

iii- For the single side fillet flange – to – web weld, thin fillet weld shall be completed on the other side of the web and made symmetrical at supports, and at the positions of concentrated loads where the web is not stiffened by vertical stiffeners.

9.6.4 Design Strength and Matching Weld Metal of Fillet Weld

9.6.4.1 Matching Filler Metal Requirements

For fillet welded connections the electrode material used must have at least the properties of the base metal, Table 9.2 is to be utilized for the choice of the "MATCHING" electrode. The use of weld metal with a strength less than "matching" weld metal is not allowed while the use of electrode one strength level greater than Matching may be used.

9.6.4.2 Design Strength of Fillet Weld

The factored load per unit length of weld ($R_u = \gamma_l \phi_i$) in a fillet weld loaded in an arbitrary direction can be resolved into the following components:

$(R_{uw})_{f\perp}$ = the normal factored load perpendicular to the axis of weld per unit length of weld.

$(R_{uw})_{q//}$ = the shear factored load parallel to the axis of weld per unit length of weld.

$(R_{uw})_{q\perp}$ = the shear factored load perpendicular to the axis of weld per unit length of weld.

These factored loads shall be related to the size(s) of the legs of the isosceles triangle inscribed in the weld seam if the angle between the two surfaces to be welded is between 60° and 90°. When this angle is greater than 90° the size of the leg of the inscribed right angle isosceles triangle shall be taken.

The design strength per unit length of fillet weld for all kinds of factored loads is as follows:

$$\phi \; R_{uw} = 0.7\, s\, (0.4\, F_u) \qquad \text{.......... 9.7}$$

Where:

ϕ = shear, tension or compression resistance weld reduction factor = 0.7

R_{uw} = shear, tension or compression nominal weld strength per unit length, t/cm

s = leg dimension of fillet weld (size), cm

F_u = ultimate tensile strength of the base metal, t/cm^2
for Hybrid sections F_u is the smaller ultimate strength for the connected elements

In case where welds are subjected simultaneously to normal and shear factored loads, they shall be checked for the corresponding principal stresses. For this combination of stresses, an effective factored load value $(R_{uw})_{eff}$ per unit length may be utilized and the corresponding design weld strength is to be increased by 10% as follows:

$$(R_{uw})_{eff} = \sqrt{(R_{uw})^2_{f\perp} + 3[(R_{uw})^2_{q//} + (R_{uw})^2_{q\perp}]} \leq 0.77s(0.4F_u) \text{.....9.8}$$

The effective length of a fillet weld is usually taken as the overall length of the weld minus twice the weld size(s) as deduction for end craters.

9.7 PLUG AND SLOT WELDS

The stress transfer of plug and slot welds is limited to resisting shear loads in joints at plane parallel to the faying surface. The strength capacity is calculated as the product of the area of the hole or slot times the ultimate shear stress as follows:

$$\phi\ R_{nw} = 0.7\,(\text{Area of hole or slot}).(0.6\,F_u) \text{ .... 9.9}$$

The proportions and spacing of holes and slots and the depth are illustrated in Fig. (9.16) and the corresponding limitations are as given in Table (9.7).

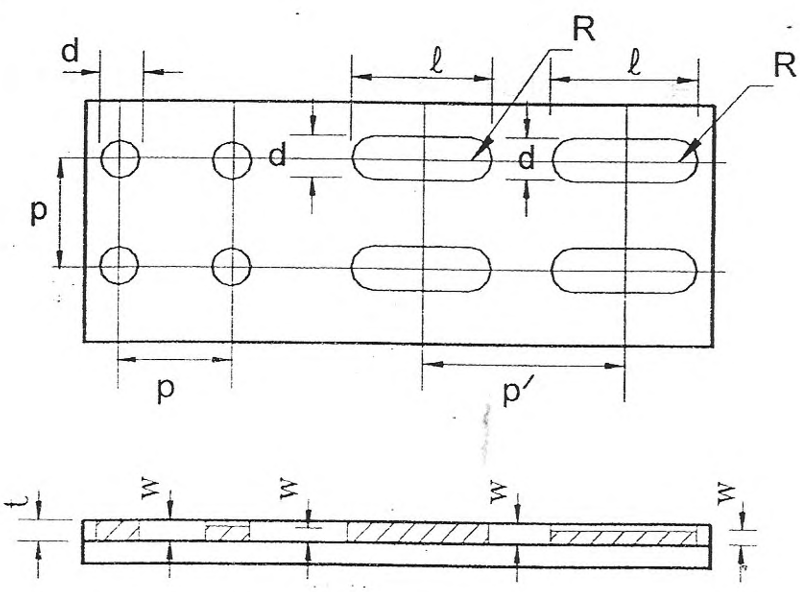


Figure 9.16 Definitions of Plug and Slot Welds

Table 9.7 Plug and Slot Welds Limitations

<table>
<tr><th>Plate Thicknes t (mm)</th><th>Min. Hole diameter or Slot width d_{min} (mm)</th><th colspan="2">Hole and Slot Proportions Spacing and Depth of Weld</th></tr>
<tr><td>5 & 6</td><td>14</td><td colspan="2">$d \geq (t+8)$mm preferably rounded to next higher even number; also $d \leq 2.25\,t$ or d_{min} +3mm whichever is greater</td></tr>
<tr><td>7&8</td><td>16</td><td rowspan="6">$p \geq 4d$
$p/ \geq 2\ell$
$\ell \leq 10\,w$
$R = d/2$
$R \geq t$</td><td rowspan="6"><u>Depth of filling of plug and slot welds (w):</u>
Where $t \leq 16$ mm, $w = t$
Where $t > 16$ mm, $w > t/2$
but not less than 16 mm.</td></tr>
<tr><td>9 &10</td><td>18</td></tr>
<tr><td>11 & 12</td><td>20</td></tr>
<tr><td>13&14</td><td>22</td></tr>
<tr><td>15 &16</td><td>24</td></tr>
</table>

N.B. There are no limitations for the edge distances.

9.8 GENERAL RESTRICTIONS TO AVOID UNFAVOURABLE WELD DETAILS

9.8.1 Lamellar Tearing

Lamellar tearing is a separation (or crack) in the base metal, caused by through – thickness weld shrinkage strains. The probability of this failure can be minimized by:

a- Using small weld size providing the shrinkage to be accommodated.
b- The welding procedure should also establish a welding sequence such that the component restraint and the internal restraints in the weldment are held to a minimum.
c- The use of a welding procedure with low hydrogen weld and an effective preheating minimize lamellar tear.

Some joints susceptible to lamellar tearing can be improved by careful detailing as shown in Fig. 9.17.

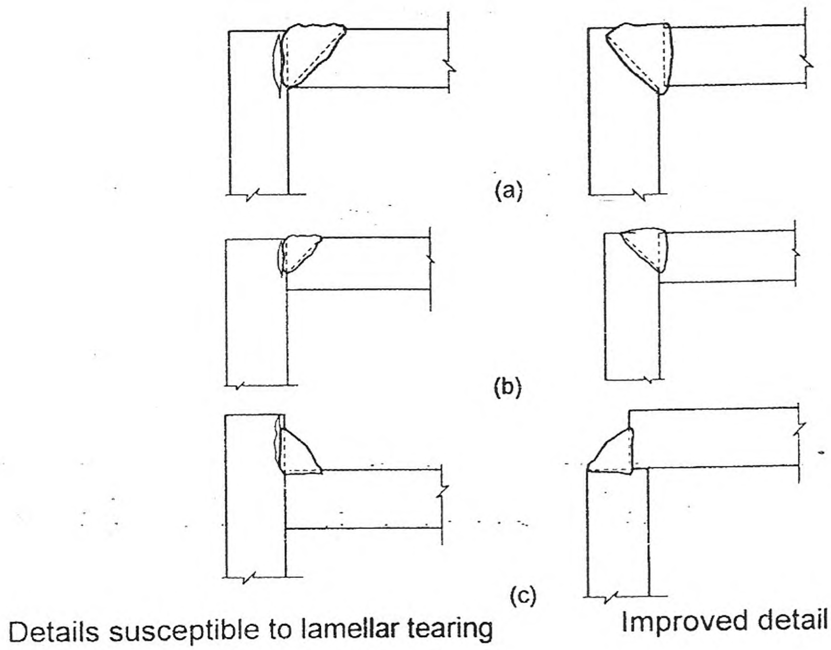


Figure 9.17 Improved Welded Connections to Reduce Lamellar Tear

9.8.2 Notches and Brittle Fracture

a- The one sided fillet welds can result in severe notches as shown in Fig. 9.18(a). The remedy is to use two fillets one on each side. A similar condition arises with partial penetration groove welds.

b- Backing bars can cause a fatigue weld notch if they are welded as shown in Fig. 9.18(b). A remedy would be to weld in the groove as in Fig. 9.18(c), where any undercut would be filled, or at least backed up by the final weld joint. The backing bars should also be continuous throughout its length.

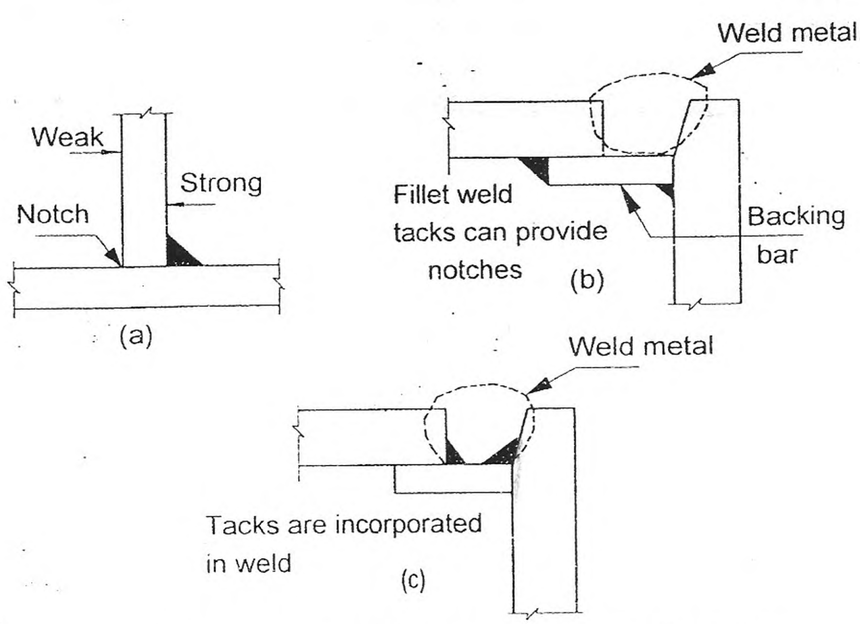


Figure 9.18 Notches and Brittle Fracture

9.9 WELD INSPECTION METHODS

The designer must specify in the contract document the type of weld inspection required as well as the extent and application of each type of inspection. Table 9.8 summarizes the characteristics and capabilities of the five most commonly used methods for welding inspection.

Table 9.8 Characteristics of Common Weld Inspection Methods

Inspection Method	Characteristics and Applications	Limitations
Visual (VT)	Most common, most economical. Particularly good for single pass.	Detects surface imperfections only.
Dye Penetrant (DPT)	Will detect tight cracks, open to surface.	Detects surface imperfections only. Deep weld ripples and scratches may give false indications.
Magnetic Particle (MT)	Will detect surface cracks and subsurface cracks to about 2 mm depth with proper magnetization. Indications can be preserved on clear plastic tape.	Requires relatively smooth surface. Careless use of magnetization prods may leave false indications.
Radiographic (RT)	Detects porosity, slag, voids, irregularities, lack of fusion. Film negative is permanent record.	Detects must occupy more than about 1.20% of thickness to register. Only cracks partial to impinging beam register. Radiation hazards Exposure time increases with thickness.
Ultrasonic (UT)	Detects cracks in any orientation, Slag, lack of fusion, inclusions, lamellar tears, voids. Can detect a favorably oriented planar reflector smaller than 1mm. Regularly calibrate on 1½ mm dia. drilled hole. Can scan almost any commercial thickness.	Surface must be smooth, Equipment must be frequently calibrated. Operator must be qualified. Exceedingly coarse grains will give false indications. Certain geometric configurations give false indication of flaws.