SECTION 2 WELDING CONNECTIONS FOR STEEL

1 General

1.1 Application

1.1.1 The requirements of this Section apply for the preparation, execution and inspection of welded connections in steel hull structures of yachts.

They are to be complemented by the criteria given in [2], to which reference is made. These criteria being given as recommendations, minor departures may be accepted by the Society, on a case by case basis.

The general requirements relevant to fabrication by welding and qualification of welding procedures are given in the Rule Note NR216 Materials and Welding, Chapter 5.

1.1.2 Weld connections are to be executed according to the approved plans. Any detail not specifically represented in the plans is, if any, to comply with the applicable requirements.

1.1.3 It is understood that welding of the various types of steel is to be carried out by means of welding procedures approved for the purpose, even though an explicit indication to this effect may not appear on the approved plans.

1.1.4 The quality standard adopted by the shipyard is to be submitted to the Society and applies to all constructions unless otherwise specified on a case by case basis.

1.2 Base material

1.2.1 The requirements of this Section apply for the welding of hull structural steels of the types considered in the Rule Note NR216 Materials and Welding, or other types accepted as equivalent by the Society.

1.2.2 The service temperature is intended to be the ambient temperature, unless otherwise stated.

1.3 Welding consumable and procedures

1.3.1 Approval of welding consumable and procedures

Welding consumable and welding procedures adopted are to be approved by the Society.

The requirements for the approval of welding consumable are given in the Rule Note NR216 Materials and Welding, Ch 5, Sec 2.

The requirements for the approval of welding procedures for the individual users are given in the Rule Note NR216 Materials and Welding, Ch 5, Sec 4 and Ch 5, Sec 5.

The approval of the welding procedure is not required in the case of manual metal arc welding with approved covered electrodes, except in the case of one side welding on refractory backing (ceramic).

1.3.2 Consumable

The minimum consumable grades to be adopted are specified in Tab 1 depending on the steel grade.

Consumable used for manual or semi-automatic welding (covered electrodes, flux-cored and flux-coated wires) of higher strength hull structural steels are to be at least of hydrogen-controlled grade H15 (H). Where the carbon equivalent Ceq is not more than 0,41% and the thickness is below 30 mm, any type of approved higher strength consumable may be used at the discretion of the Society.

Especially, welding consumable with hydrogen-controlled grade H15 (H) and H10 (HH) shall be used for welding hull steel forgings and castings of respectively ordinary strength level and higher strength level.

Table 1 : Consumable grades

Steel grade	Consumable minimum grade	
	Butt welding, partial and full T penetration welding	Fillet welding
A	1	1
B - D	2	
E	3	
AH32 - AH36 DH32 - DH36	2Y	2Y
EH32 - EH36	3Y	

Note 1:
Welding consumable approved for welding higher strength steels (Y) may be used in lieu of those approved for welding normal strength steels having the same or a lower grade; welding consumable approved in grade Y having the same or a lower grade.

Note 2:
In the case of welded connections between two hull structural steels of different grades, as regards strength or notch toughness, welding consumable appropriate to one or the other steel are to be adopted.

1.4 Personnel and equipment

1.4.1 Welders

Manual and semi-automatic welding is to be performed by welders certified by the Society in accordance with the Rule Note NR476 “Approval testing of welders”, unless otherwise agreed with the Society. The welders are to be employed within the limits of their respective approval.

1.4.2 Automatic welding operators

Personnel manning automatic welding machines and equipment are to be competent and sufficiently trained.

1.4.3 Organisation

The internal organisation of the shipyard is to be such as to ensure compliance in full with the requirements in [1.4.1] and [1.4.2] and to provide for assistance and inspection of welding personnel, as necessary, by means of a suitable number of competent supervisors.

1.4.4 NDE operators

Non-destructive tests are to be carried out by qualified personnel, certified by the Society, or by recognised bodies in compliance with appropriate standards.

The qualifications are to be appropriate to the specific applications.

1.4.5 Technical equipment and facilities

The welding equipment is to be appropriate to the adopted welding procedures, of adequate output power and such as to provide for stability of the arc in the different welding positions.

In particular, the welding equipment for special welding procedures is to be provided with adequate and duly calibrated measuring instruments, enabling easy and accurate reading, and adequate devices for easy regulation and regular feed.

Manual electrodes, wires and fluxes are to be stored in suitable locations so as to ensuring their preservation in proper condition. Especially, where consumable with hydrogen-controlled grade are to be used, proper precautions are to be taken to ensure that manufacturer's instructions are followed to obtain (drying) and maintain (storage, maximum time exposed, re-backing, ...) hydrogen-controlled grade.

1.5 Documentation to be submitted

1.5.1 The structural plans to be submitted for approval, according to Ch 1, Sec 3, are to contain the necessary data relevant to the fabrication by welding of the structures and items represented as far as class is concerned.

1.5.2 Where several steel types are used, a plan showing the location of the various steel types is to be submitted at least for outer shell, deck and bulkhead structures.

1.6 Design

1.6.1 General

For the various structural details typical of welded construction in shipbuilding and not dealt with in this Section, the rules of good practice, recognised standards and past experience are to apply as agreed by the Society.

1.6.2 Plate orientation

The plates of the shell and strength deck are generally to be arranged with their length in the fore-aft direction. Possible exceptions to the above will be considered by the Society on a case by case basis.

1.6.3 Prefabrication sequences

Prefabrication sequences are to be arranged so as to facilitate positioning and assembling as far as possible.

The amount of welding to be performed on board is to be limited to a minimum and restricted to easily accessible connections.

1.6.4 Distance between welds

Welds located too close to one another are to be avoided. The minimum distance between two adjacent welds is considered on a case by case basis, taking into account the level of stresses acting on the connected elements.

2 Type of connections and preparation

2.1 General

2.1.1 The type of connection and the edge preparation are to be appropriate to the welding procedure adopted, the structural elements to be connected and the stresses to which they are subjected.

2.2 Butt welding

2.2.1 General

In general, butt connections of plating are to be full penetration, welded on both sides.

Connections different from the above may be accepted by the Society on a case by case basis; in such cases, the relevant detail and workmanship specifications are to be approved.

2.2.2 Welding of plates with different thicknesses

In the case of welding of plates with a difference in thickness equal to or greater than:

- 3 mm, if the thinner plate has a thickness equal to or less than 10 mm
- 4 mm, if the thinner plate has a thickness greater than 10 mm

a taper having a length of not less than 4 times the difference in thickness is to be adopted for connections of plating perpendicular to the direction of main stresses. For connections of plating parallel to the direction of main stresses, the taper length may be reduced to 3 times the difference in thickness.

When the difference in thickness is less than the above values, it may be accommodated in the weld transition between plates.

For large thicknesses (e.g. 25mm), other criteria may be considered on a case by case basis, when deemed equivalent.

2.2.3 Edge preparation, root gap

Typical edge preparations and gaps are indicated in Tab 2 and Tab 3.

The acceptable root gap is to be in accordance with the adopted welding procedure and relevant bevel preparation.

Table 2 : Typical butt weld plate edge preparation (manual welding) - See Note 1

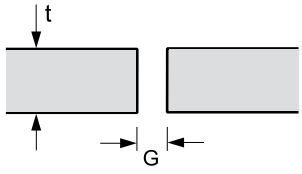
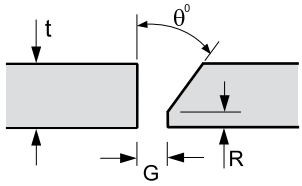
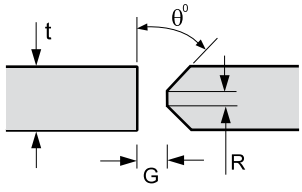
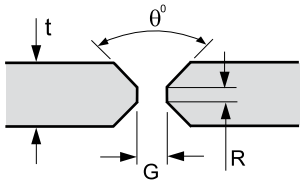
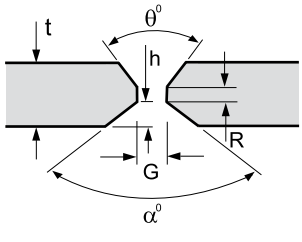
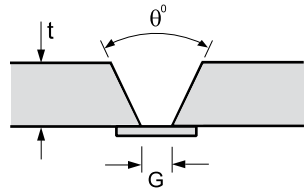
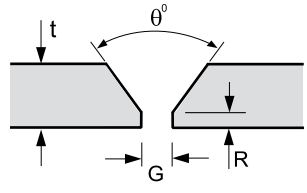
Detail	Standard
Square butt 	t ≤ 5 mm G = 3 mm
Single bevel butt 	t > 5 mm G ≤ 3 mm R ≤ 3 mm 50° ≤ θ ≤ 70°
Double bevel butt 	t > 19 mm G ≤ 3 mm R ≤ 3 mm 50° ≤ θ ≤ 70°
Double vee butt, uniform bevels 	G ≤ 3 mm R ≤ 3 mm 50° ≤ θ ≤ 70°
Double vee butt, non-uniform bevels 	G ≤ 3 mm R ≤ 3 mm 6 ≤ h ≤ t/3 mm θ = 50° α = 90°
Note 1: Different plate edge preparation may be accepted or approved by the Society on the basis of an appropriate welding procedure specification.	

Table 3 : Typical butt weld plate edge preparation (manual welding) - See Note 1

Detail	Standard
Single vee butt, one side welding with backing strip (temporary or permanent) 	3 ≤ G ≤ 9 mm 30° ≤ θ ≤ 45°
Single vee butt 	G ≤ 3 mm 50° ≤ θ ≤ 70° R ≤ 3 mm
Note 1: Different plate edge preparation may be accepted or approved by the Society on the basis of an appropriate welding procedure specification.	

2.2.4 Butt welding on permanent backing

Butt welding on permanent backing, i.e. butt welding assembly of two plates backed by the flange or the face plate of a stiffener, may be accepted where back welding is not feasible or in specific cases deemed acceptable by the Society.

The type of bevel and the gap between the members to be assembled are to be such as to ensure a proper penetration of the weld on its backing and an adequate connection to the stiffener as required.

2.2.5 Section, bulbs and flat bars

When lengths of longitudinals of the shell plating and strength deck within 0,6 L amidships, or elements in general subject to high stresses, are to be connected together by butt joints, these are to be full penetration. Other solutions may be adopted if deemed acceptable by the Society on a case by case basis.

The work is to be done in accordance with an approved procedure; in particular, this requirement applies to work done on board or in conditions of difficult access to the welded connection. Special measures may be required by the Society.

2.3 Fillet welding

2.3.1 General

In general, ordinary fillet welding (without bevel) may be adopted for T connections of the various simple and composite structural elements.

2.3.2 Fillet welding types

Fillet welding may be of the following types:

- continuous fillet welding, where the weld is constituted by a continuous fillet on each side of the abutting plate
- intermittent fillet welding, which may be subdivided into:
  - chain welding
  - scallop welding
  - staggered welding.

2.3.3 Continuous fillet welding

Continuous fillet welding is to be adopted:

- for watertight connections
- for connections of brackets, lugs and scallops
- at the ends of connections for a length of at least 75mm
- where intermittent welding is not allowed, according to [2.3.4].

Continuous fillet welding may also be adopted in lieu of intermittent welding wherever deemed suitable, and it is recommended where the spacing p, calculated according to [2.3.4], is low.

2.3.4 Intermittent welding

The spacing p and the length d, in mm, of an intermittent weld, shown in:

- Fig 1, for chain welding
- Fig 2, for scallop welding
- Fig 2, for staggered welding

are to be such that:

$$\frac{p}{d} \leq \varphi$$

where the coefficient φ is defined in Tab 4 for the different types of intermittent welding, depending on the type and location of the connection.

In general, staggered welding is not allowed for connections subjected to high alternate stresses.

In addition, the following limitations are to be complied with:

- chain welding (see Fig 1):

  $d \geq 75$ mm

  $p\text{-}d \leq 200$ mm

- staggered welding (see Fig 2):

  $d \geq 75$ mm

  $p\text{-}2d \leq 300$ mm

  $p \leq 2d$ for connections subjected to high alternate stresses.

Figure 1 : Intermittent chain welding

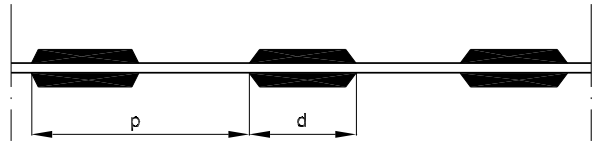
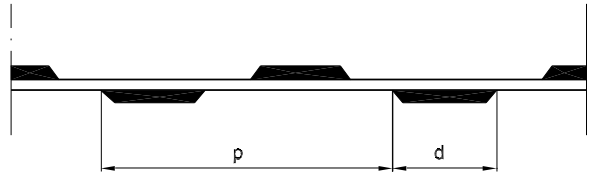


Figure 2 : Intermittent staggered welding



2.3.5 Throat thickness of fillet weld T connections

The throat thickness of fillet weld T connections is to be obtained, in mm, from the following formula:

$$t_T = w_F t \frac{p}{d}$$

where:

w_F : Welding factor, defined in Tab 4 for the various hull structural connections; for connections of primary supporting members and not mentioned in Tab 4, w_F is defined in Tab 6

t : Actual thickness, in mm, of the structural element which constitutes the web of the T connection

p, d : Spacing and length, in mm, of an intermittent weld, defined in [2.3.4].

For continuous fillet welds, p/d is to be taken equal to 1.

In no case may the throat thickness be less than:

- 3,0 mm, where the gross thickness of the thinner plate is less than 6 mm
- 3,5 mm, otherwise.

The throat thickness may be required by the Society to be increased, depending on the results of structural analyses.

The leg length of fillet weld T connections is to be not less than 1,4 times the required throat thickness.

2.3.6 Throat thickness of welds between cut-outs

The throat thickness of the welds between the cut-outs in primary supporting member webs for the passage of ordinary stiffeners is to be not less than the value obtained, in mm, from the following formula:

$$t_{TC} = t_T \frac{\varepsilon}{\lambda}$$

where:

t_T : Throat thickness defined in [2.3.5]

ε, λ : Dimensions, in mm, to be taken as shown in Fig 3, for continuous welding.

Table 4 : Welding factors w_F and coefficient φ for the various hull structural connections

Hull area	Connection			w_F **(1)**	φ **(2) (3)**	
	of	to			CH	ST
General, unless otherwise specified in the table	watertight plates	boundaries		0,35		
	webs of ordinary stiffeners	plating		0,13	3,5	4,6
Bottom and double bottom	longitudinal ordinary stiffeners	bottom and inner bottom plating		0,13	3,5	4,6
	centre girder	keel plate		0,25	1,8	
		inner bottom plating		0,20	2,2	
	side girders	bottom and inner bottom plating		0,13	3,5	4,6
		floors (interrupted girders)		0,20	2,2	
	floors	bottom and inner bottom plating	in general	0,13	3,5	4,6
			at ends (20% of span) for longitudinally framed double bottom	0,25	1,8	
		inner bottom plating in way of brackets of primary supporting members		0,25	1,8	
		girders (interrupted floors)		0,20	2,2	
	partial side girders	floors		0,25	1,8	
Side	ordinary stiffeners	side plating		0,13	3,5	4,6
Deck	ordinary stiffeners	deck plating		0,13	3,5	4,6
	strength deck	side plating		Partial penetration welding		
	non-watertight decks	side plating		0,20	2,2	
Bulkheads	ordinary stiffeners	bulkhead plating	in general **(5)**	0,13	3,5	4,6
			at ends (25% of span), where no end brackets are fitted	0,35		
	tank bulkhead structures	tank bottom	plating and ordinary stiffeners (plane bulkheads)	0,45		
		boundaries other than tank bottom		0,35		
	watertight bulkhead structures	boundaries		0,35		
	transverse bulkheads between floats of catamarans	boundaries		0,35		
Structures located forward of 0,75 L from the AE	bottom longitudinal ordinary stiffeners	bottom plating		0,20	2,2	
	floors and girders	bottom and inner bottom plating		0,25	1,8	
	side frames	side plating		0,20	2,2	
	side girders	side plating		0,25	1,8	
After peak	internal structures	each other		0,20		
	side ordinary stiffeners	side plating		0,20		
	floors	bottom and inner bottom plating		0,20		
Machinery space of motor yachts	girders	bottom and inner bottom plating	in way of main engine foundations	0,45		
			in way of seating of auxiliary machinery	0,35		
			elsewhere	0,20	2,2	
	floors (except in way of main engine foundations)	bottom and inner bottom plating	in way of seating of auxiliary machinery	0,35		
			elsewhere	0,20	2,2	
	floors in way of main engine foundations	bottom plating		0,35		
		foundation plates		0,45		
	floors	centre girder	single bottom	0,45		
			double bottom	0,25	1,8	

Hull area	Connection			w_F (1)	φ (2) (3)	
	of	to			CH	ST
Superstructures and deckhouses	external bulkheads	deck		0,35		
	internal bulkheads	deck		0,13	3,5	4,6
	ordinary stiffeners	external and internal bulkhead plating		0,13	3,5	4,6
Pillars	pillars	deck	pillars in compression	0,35		
			pillars in tension	Full penetration welding		
Ventilators	coamings	deck		0,35		
Rudders	horizontal and vertical webs directly connected to solid parts	each other		0,45		
	other webs	each other		0,20		
	webs	plating	in general	0,20		
			top and bottom plates of rudder plating	0,35		
		solid parts or rudder stock		According to Ch 10, Sec 2, [6]		

(1) In connections for which $w_F \geq 0,35$, continuous fillet welding is to be adopted.

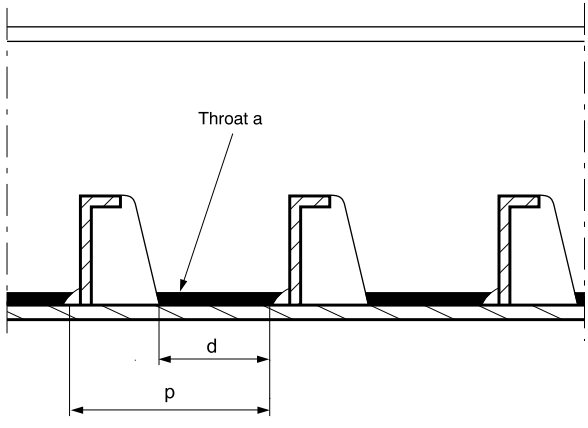
(2) For coefficient φ, see [2.3.4]. In connections for which no φ value is specified for a certain type of intermittent welding, such type is not permitted and continuous welding is to be adopted.

(3) CH = chain welding, ST = staggered welding.

(4) Ends of ordinary stiffeners means the area extended 75 mm from the span ends. Where end brackets are fitted, ends means the area extended in way of brackets and at least 50 mm beyond the bracket toes.

(5) In tanks intended for the carriage of ballast or fresh water, continuous welding with $w_F = 0,35$ is to be adopted.

Figure 3 : Continuous fillet welding between cut-outs



2.3.7 Throat thickness of welds connecting ordinary stiffeners with primary supporting members

The throat thickness of fillet welds connecting ordinary stiffeners and collar plates, if any, to the web of primary supporting members is to be not less than $0,35t_W$, where t_W is the web thickness, in mm.

In general, the resistant weld section A_W, in cm^2, connecting the ordinary stiffeners to the web of primary members, is not to be less than:

$$A_W = \varphi \cdot p \cdot s \cdot \ell \cdot \left(1 - \frac{s}{2 \cdot \ell}\right) K \cdot 10^{-3}$$

where:

φ : Coefficient as indicated in Tab 5

p : Design pressure, in kN/m^2, acting on the secondary stiffeners, as defined in Ch 7, Sec 1 and Ch 7, Sec 2

s : Spacing of ordinary stiffeners, in m

ℓ : Span of ordinary stiffeners, in m

K : Greatest material factor of ordinary stiffener and primary member, as defined in Ch 4, Sec 3, [3].

Table 5 : Coefficient φ

Case	Weld	φ
1	Parallel to the reaction exerted on primary member	100
2	Perpendicular to the reaction exerted on primary member	75

2.4 Lap-joint welding

2.4.1 General

Lap-joint welding may be adopted for:

- peripheral connection of doublers
- internal structural elements subjected to very low stresses.

Elsewhere, lap-joint welding may be allowed by the Society on a case by case basis, if deemed necessary under specific conditions.

Continuous welding is generally to be adopted.

2.4.2 Gap

The surfaces of lap-joints are to be in sufficiently close contact.

Table 6 : Welding factors w_F and coefficient φ for connections of primary supporting members

Primary supporting member	Connection			w_F **(1)**	φ **(2) (3)**		
	of	to			CH	SC	ST
General	web, where A < 65 cm²	plating and face plate	at ends	0,20			
			elsewhere	0,15	3,0	3,0	
	web, where A ≥ 65 cm²	plating		0,35			
		face plate	at ends	0,35			
			elsewhere	0,25	1,8	1,8	
	end brackets	face plate		0,35			
In tanks, where A < 65 cm² **(5)**	web	plating	at ends	0,25			
			elsewhere	0,20	2,2	2,2	
		face plate	at ends	0,20			
			elsewhere	0,15	3,0	3,0	
	end brackets	face plate		0,35			
In tanks, where A ≥ 65 cm²	web	plating	at ends	0,45			
			elsewhere	0,35			
		face plate		0,35			
	end brackets	face plate		0,45			

(1) In connections for which $w_F \geq 0,35$, continuous fillet welding is to be adopted.

(2) For coefficient φ, see [2.3.4]. In connections for which no φ value is specified for a certain type of intermittent welding, such type is not permitted.

(3) CH = chain welding, SC = scallop welding, ST = staggered welding.

(4) For primary supporting members in tanks intended for the carriage of ballast or fresh water, continuous welding is to be adopted.

(5) In tanks intended for the carriage of ballast or fresh water, continuous welding with $w_F = 0,35$ is to be adopted.

Note 1: A is the face plate sectional area of the primary supporting member, in cm².

Note 2: Ends of primary supporting members means the area extended 20% of the span from the span ends. Where end brackets are fitted, ends means the area extended in way of brackets and at least 100 mm beyond the bracket toes.

2.4.3 Dimensions

The dimensions of the lap-joint are to be specified and are considered on a case by case basis. Typical details are given in Tab 7.

2.5 Slot welding

2.5.1 General

Slot welding may be adopted in very specific cases subject to the special agreement of the Society.

In general, slot welding of doublers on the outer shell and strength deck is not permitted within 0,6L amidships. Beyond this zone, slot welding may be accepted by the Society on a case by case basis.

Slot welding is, in general, permitted only where stresses act in a predominant direction. Slot welds are, as far as possible, to be aligned in this direction.

2.5.2 Dimensions

Slot welds are to be of appropriate shape (in general oval) and dimensions, depending on the plate thickness, and may not be completely filled by the weld.

Typical dimensions of the slot weld and the throat thickness of the fillet weld are given in Tab 7.

The distance between two consecutive slot welds is to be not greater than a value which is defined on a case by case basis taking into account:

- the transverse spacing between adjacent slot weld lines
- the stresses acting in the connected plates
- the structural arrangement below the connected plates.

2.6 Plug welding

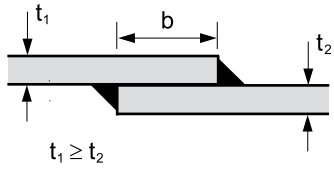
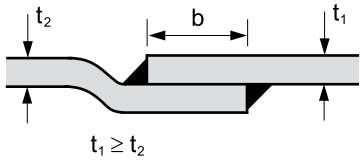
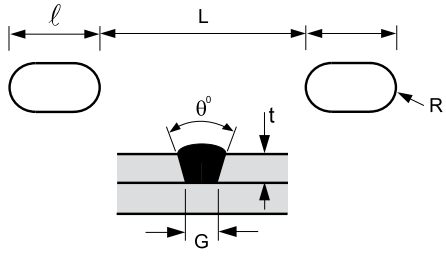
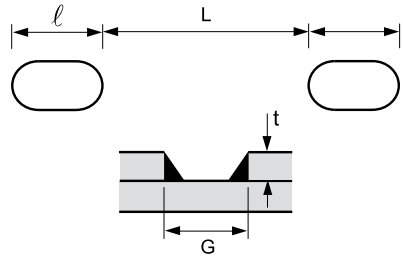
2.6.1 Plug welding may be adopted only when accepted by the Society on a case by case basis, according to specifically defined criteria. Typical details are given in Tab 7.

3 Workmanship

3.1 Welding procedures and consumable

3.1.1 The various welding procedures and consumable are to be used within the limits of their approval and in accordance with the conditions of use specified in the respective approval documents.

Table 7 : Typical lap joint, plug and slot welding (manual welding)

Detail	Standard	Remark
Fillet weld in lap joint 	b = 2 t_2 + 25 mm	location of lap joint to be approved by the Society
Fillet weld in joggled lap joint 	b ≥ 2 t_2 + 25 mm	
Plug welding 	• t ≤ 12 mm ℓ = 60 mm R = 6 mm 40° ≤ θ ≤ 50° G = 12 mm L > 2 ℓ • 12 mm < t ≤ 25 mm ℓ = 80 mm R = 0,5 t mm θ = 30° G = t mm L > 2 ℓ	
Slot welding 	• t ≤ 12 mm G = 20 mm ℓ = 80 mm 2 ℓ ≤ L ≤ 3 ℓ, max 250 mm • t > 12 mm G = 2 t ℓ = 100 mm 2 ℓ ≤ L ≤ 3 ℓ, max 250 mm	

3.2 Welding operations

3.2.1 Weather protection

Adequate protection from the weather is to be provided to parts being welded; in any event, such parts are to be dry.

In welding procedures using bare, cored or coated wires with gas shielding, the welding is to be carried out in weather protected conditions, so as to ensure that the gas outflow from the nozzle is not disturbed by winds and draughts.

3.2.2 Butt connection edge preparation

The edge preparation is to be of the required geometry and correctly performed. In particular, if edge preparation is carried out by flame, it is to be free from cracks or other detrimental notches.

Recommendations for edge preparation are given in the "Guide for welding".

3.2.3 Surface condition

The surfaces to be welded are to be free from rust, moisture and other substances, such as mill scale, slag caused by oxygen cutting, grease or paint, which may produce defects in the welds.

Effective means of cleaning are to be adopted particularly in connections with special welding procedures; flame or mechanical cleaning may be required.

The presence of a shop primer may be accepted, provided it has been approved by the Society.

Shop primers are to be approved by the Society for a specific type and thickness according to the Rule Note NR216 Materials and Welding, Ch 5, Sec 3.

3.2.4 Assembling and gap

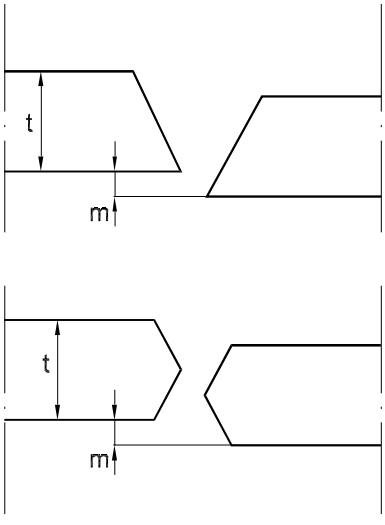
The setting appliances and system to be used for positioning are to ensure adequate tightening adjustment and an appropriate gap of the parts to be welded, while allowing maximum freedom for shrinkage to prevent cracks or other defects due to excessive restraint.

The gap between the edges is to comply with the required tolerances or, when not specified, it is to be in accordance with normal good practice.

3.2.5 Plate misalignment in butt connections

The misalignment m, measured as shown in Fig 4, between plates with the same gross thickness t is to be less than 0,15t, without being greater than 3 mm.

Figure 4 : Plate misalignment in butt connections

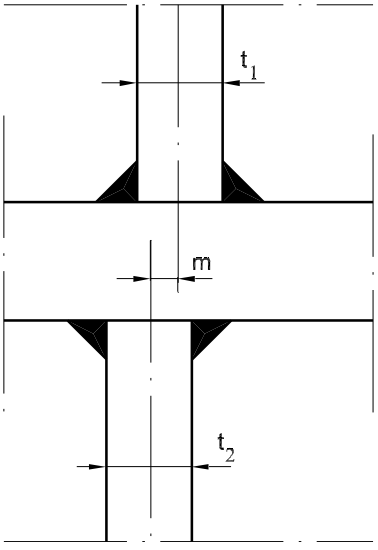


3.2.6 Misalignment in cruciform connections

The misalignment m in cruciform connections, measured on the median lines as shown in Fig 5, is to be less than:

- t/2, in general, where t is the gross thickness of the thinner abutting plate.

Figure 5 : Misalignment in cruciform connections



The Society may require lower misalignment to be adopted for cruciform connections subjected to high stresses.

3.2.7 Welding sequences

Welding sequences and direction of welding are to be determined so as to minimise deformations and prevent defects in the welded connection.

All main connections are generally to be completed before the ship is afloat.

Departures from the above provision may be accepted by the Society on a case by case basis, taking into account any detailed information on the size and position of welds and the stresses of the zones concerned, both during ship launching and with the ship afloat.

3.2.8 Interpass cleaning

After each run, the slag is to be removed by means of a chipping hammer and a metal brush; the same precaution is to be taken when an interrupted weld is resumed or two welds are to be connected.