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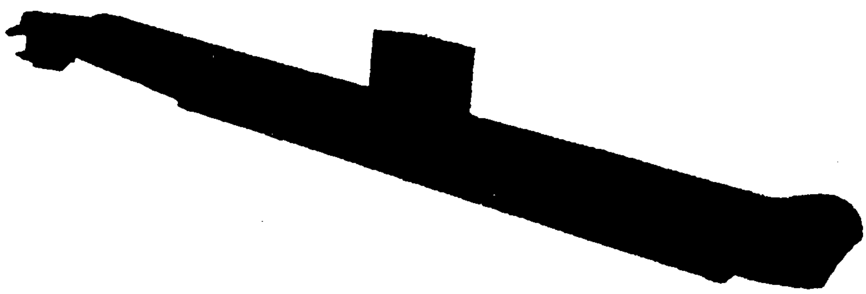

RENEWAL OF THE PLATING IN WAY OF THE ENGINE ROOM CLOSURE PLATE OF HMAS OTWAY DURING THE SUBMARINES THIRD REFIT

BY

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OVER THE TWO YEARS THE AUTHOR SPENT AT COCKATOO DOCKYARD PTY LTD IN THE POSITION OF SENIOR NAVAL ARCHITECT, PRINCIPAL NAVAL OVERSEERS THE AUTHOR RECEIVED A GREAT DEAL OF ASSISSTANCE AND ADVICE FROM MANY OF THE PERSONNEL IN THE PRODUCTION AND TECHNICAL DEPARTMENTS OF THE DOCKYARD FOR WHICH HE IS VERY APPRECIATIVE. IN PARTICULAR THE FOLLOWING THREE PEOPLE HAVE BEEN OF GREAT ASSISSTANCE IN THE SUCCESSFULL COMPLETION OF THE MAJOR STRUCTURAL REPAIRS UNDERTAKEN ON HMAS OTWAY. THESE PEOPLE ARE,

MR R. TOWNDROW - WELDING ENGINEER

MR N. MACMILLAN - SUBMARINE REFIT SUPERINTENDENT

MR P. DEMOVIC - BOILERMAKER FOREMAN.

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1. Summary

HMAS OTWAY is an Oberon Class submarine built by Scotts Shipbuilding & Eng Co Ltd of Greenock Scotland and was commissioned in April 1968 The submarine therefore is almost twenty years old and is currently undergoing her third refit.

The engine room closure plate of an Oberon Class Submarine, as built by Scotts, is a segment of pressure hull plating approximately twenty six feet long 100 inches wide incorporated into which there are twenty six in number thick insert pads which are reinforcement for various openings/penetrations through the pressure hull and fittings mounted to the hull. It included the very large forged pads for the engine group exhaust valves. This plate had to be renewed during HMAS OTWAY's third refit due to extensive corrosion and wastage over a large proportion of the plate.

This paper discusses many of the technical aspects of the work involved in renewing this large segment of pressure hull plating, the problems encountered, the standards involved in submarine structural work, and the importance of a close working relationship between the Contractor and the Customer to ensure satisfactory workmanship and methods within the bounds of the applicable standards.

2. Hull Construction

The normal method of construction of submarine hulls, particularly in British ship yards is as described in Ref 1. The construction of the hull commences with the manufacture of bulkheads and the frame sections, the frames being produced by either trammel-burning the webs and welding them to strip cut tables or by cold bending of extruded frame sections. A complete ring frame may be made from several segments of formed/welded section, the number of segments depending on the physical restrictions of the equipment used and the fabrication shop. "To maintain the stringent requirements of circularity and boost the production rate, the hull is usually formed from 20 plus pressure hull 'hoops' which incorporate several frames plus the pressure hull plate. The frames, and bulkheads where required, are assembled in jigs with frame circularity being maintained within the jig by radial struts. The frames are supported horizontally at the required spacing, whilst segments of pressure hull plating, pre shaped by cold rolling, are wrapped round the jigged framing. The pressure hull plates are butt welded to each other and then welded to the frames"*. The length of the pressure hull 'hoop' is therefore governed by the maximum width of quench and tempered plate available as well as the usual crane lifting capacity. A pressure hull 'hoop' therefore normally is approximately 10ft to 12ft long and includes 3 to 4 frames.

The construction method used by Scotts in building our Oberon hulls

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* Extracted from Reference 1

differed from this method in that they incorporated a larger number of frames in the jig and instead of wrapping the cold rolled plating around the hull they rolled it and layed it length wise. Therefore a pressure hull hoop was approximately 40 feet long. In this case the length of the pressure hull `hoop' is governed by the length of plating available together with crane capacity, and the width of the plating available governs the number of plates required to complete the hoop and therefore the number of longitudinal butt welds. This has a significant influence on the amount of localised distortion induced into the hull.

The normal operation of a set of large plate rolls for forming plate involves three rollers, as shown in sketch 2 ; the lower two rollers having horizontal movement and the top roller applying the bending pressure by vertical movement. The desired shape is achieved by regulating the gap between the lower two rolls. When the plate passes through the rolls no shape is put into the plate once the trailing edge passes the tangent point on the lead roll as shown in sketch 3. The reverse applies initially. Normal practice when rolling plates is to allow for extra length/width of material to provide roll on/roll off tabs so that any flat sections which occur in way of the leading edge and trailing edge can be cut off.

The standard width of quenched and tempered pressure hull plating as supplied by the steel works to Scott's for use in the construction of the RAN Oberon hulls is 8ft, which by modern standards is a narrow plate. To reduce the number of plates required, and therefore the amount of welding, for the pressure hull hoops, Scotts appear to have rolled the pressure hull plates as is with no, or very little, provision for roll on/ roll off tabs. Therefore every pressure hull plate segment has flat sections approximately 6 to 8 inches wide at the trailing edge and leading edge. This has resulted in noticeable peaking of the pressure hull plating at the longitudinal weld seams, the degree of peaking varying with the effects of localised welding induced distortion at the longitudinal seams. (see sketch 4). This will be discussed in greater detail in a later later section of the paper in relation to the method of circularity measurement.

For the Oberon hulls built at Scott's the pressure hull `hoop' in way of the engine room was not pre-outfitted with the diesel engines before it was consolidated to the adjacent hull units. The principal structural unit in way of the engine room of the submarine was initially fabricated with a mild steel plate in the crown position so that circularity of the unit could be established. To install the engines this mild steel plating together with the segments of frames underneath were cut away to provide the required access opening. The final size of the opening after removal of all parent plate in the welding heat affected zones was 26ft long and 100 inches wide. The width therefore was greater than that of the standard width plate available. Also the opening spanned the junction of two pressure hull `hoop' units. To achieve the required width several segments of plate had to be welded together as shown in sketch 5, unless an extra wide plate was available. The plate segments were rolled, welded to the frame segments and, after installation of the engines welded back into the hull. The submarine builder had the option of installing into the pressure hull the large number of insert pads required before the plate was consolidated back into the submarine or after consolidation.

3. <u>The Corrosive Environment</u>

As mentioned previously, the segment of pressure hull plating immediately above the engines in a deisel-electric submarine is prone to having a large number of insert pads which are reinforcement for the various openings and penetrations through the pressure hull for systems such as diesel exhaust and the engine cooling water systems. Also the external space above the engine room, confined by the pressure hull plating and the light casing fairing structure, becomes a jumble of large bore exhaust pipe work, fluid system pipe work together with a collection of heat exchangers, cable runs,and stowages. The various discharge systems involve the removal of heated fluids and gases from the submarine into a corrosive medium sea water. As a result the temperature of the plate and insert pads surrounding the point of discharge becomes elevated above ambient temperature. This coupled with the limited access to the external surface of the pressure hull plating for preventative maintenance during a commission, results in this area of any design of diesel electric submarine being subjected to a high level of corrosion activity.

As a result of survey, the engine room closure plate of HMAS OTWAY had to be renewed during her third refit due to extensive wastage of the pressure hull plating. The corrosion present included general heavy wastage and pitting of the plate immediately around the group exhaust valves and clusters of very deep sharp pitting spread over the entire length of the closure plate, particularly where the temperature of the pressure hull plate becomes slightly elevated as a result of heat input from some of the fluid/gas systems discharging overboard, such as the engine fresh water cooling system heat exchangers and associated pipe work.

4. <u>Method of Fabrication Chosen</u>

<u>Initial Factors to be Considered</u>

The size of plate to be renewed was approximately 26 ft long and 9 ft wide and, as the width of this new plate exceeded the width of standard plate available, there was no alternative other than to fabricate the new closure plate from four segments of plating joined together to achieve the dimensions. Installation of the new plating by any method would therefore involve 2 longitudinal weld seams and 5 transverse butt joints. The positioning of the transverse butt joints is critical in this region due to the stringent requirements of the welding code aimed at minimizing areas of weld induced stress concentration.

Due to the close proximity of a pressure hull frame and also the engine room hatch coaming, which therefore is an area of localised high stress concentration as per any large hull opening, the new aft butt joint had to be positioned in way of the existing butt joint to minimize the stress concentration.The new aft butt was positioned by splitting the existing butt such that when the weld preparation for the new joint was made all old weld metal and a minimum of 5mm of the old parent metal aft of the existing weld was removed. Removing this amount of parent material removes the fusion zone of the old weld, and allowing for the new fusion zone penetrating further into the parent material, will minimize the risk of forming hard brittle martensitic grains adjacent to the weld. The parent plate in way of the weld preparation was then Non Destructively Examined for evidence of porosity and lamellar tearing so that the position could be finalized.

The other transverse butt joints were positioned to avoid or intersect any future welds for insert plates or foundations for external fittings in a manner acceptable to the welding code. The maximum possible separation between the butt welds being only 8 ft (the width of plating available) placed severe limitations on the number of feasible locations.

Further difficulty was experienced in locating the positions of the required transverse butts as a result of the poor condition of the available stocks of pressure hull plate material. All available stocks of plate were drawn from the Stores system so that the best plate could be utilized.The plates were found to be of inconsistent thickness in sound ares and also some portions of the plate had been ground to remove surface defects from manufacture. They also had a variety of roll marks and gouges from manufacture, as well as varying degrees of pitting resulting from poor storage. In order to get four plate segments of suitable thickness and condition in the sizes required, three 40 ft by 8 ft plates had to be cut up. The unused portions of the plates were largely unsuitable for use. This highlights the need for adequate quality assurance procedures when any purchase of equipment or stock is made regardless of the place of origin, and also highlights the responsibility of any Naval Stores organisation to maintain stock in an immediately usable condition. In this instance degradation of the repair to the submarine hull was avoided by luck in that the segments of plate could just be nested into regions of sound plate. The margin to spare was minimal. Approximately 2,500 ultrasonic thichkness readings were taken in surveying these plates.

There are two other initial factors to be considered which have a big influence on the method of fabrication chosen. The first is the need to maintain circularity of the repaired vessel within the design requirements, and the second is the accuracy of the positioning of the renewed insert pads into the new plate.

Maintaining adequate circularity in the repair of any pressure vessel is not just a matter of rolling the new plating to the correct radius. As a result of fabrication procedures, a pressure vessel has considerable residual stresses locked into its structure which will be released to some extent during any cutting or burning operation. Also when a large pressure vessel is initially fabricated from several structural units it is impossible to obtain two units with exactly the same mean radius, out of circularity away from the mean circle, and the same phase relationship for the deviation from the mean circle. Therefore the adjacent units are worked together with the constraint that localised stress concentrations from the working of the plates to meet each other and from any plate edge misalignment have to be kept within acceptable levels. If the repair area straddles the junction of two units it is possible to be dealing with two distinctly different levels of out of circularity for the units but both units are within the appropriate circularity tolerance. The larger the variation the greater the residual stresses built into the hull and therefore the greater the likelihood of localised distortion during subsequent cutting or burning operations. Yet the repairer is obligated to meet the circularity requirements for the complete structure along the entire length of repair and also in the sound structure at either end of the repair which may have varied with distortion post cutting.One of the nice features of having a build out of circularity tolerance lower than the design out of circularity tolerance is that it provides some margin for repairs undertaken through life of the pressure vessel. In the worst case if adjacent structural units are accepted and consolidated at build with measured out of circularity approaching the design limits but at opposing ends of the tolerance range it may prejudice the effective life of the vessel or the operating pressure of the vessel at some stage in service life because it will be exceedingly difficult for the repair yard to maintain the circularity tolerance post repairs.

In regards to the accuracy required for the positioning of the hull insert pads two factors had to be considered. Several of the large insert pads, such as those for the `engine group exhaust valves' are coupled to complex fluid/gas discharge systems internally which have very little flexibility and marry up to pieces of equipment for which the locations were fixed at build, and the cost of relocation is prohibitive. Therefore the pad must be located in the original orientation. It must also be remembered that in way of the internal surface of the pressure hull plating in the crown position there is a conglomeration of major pipe, cable and ventilation runs which have been positioned with various constraints and needs. There is very little unused space. The incorrect positioning of an insert pad or different orientation of the fitting attached to the pad could result in that fitting fouling other pieces of equipment etc thereby necessitating costly re-runs of systems or rectification action which ultimately could prejudice the refit completion date. For all these reasons it was important to match the longitudinal, transverse, and vertical positions of the old pads together with the alignment of the face of the pad and the orientation of any bolt holes into the pad so that after completion of all structural work the engine room systems could be refitted to the vessel without any delays.

Before discussion continues on the method of fabrication the following details on existing work practices for submarines repaired at Cockatoo Dockyard, the refit dockyard for submarines in Australia, should be noted. There are two work practices related to welding which have a detrimental effect on the overall manhours required for the job and the time to complete the repair. These are;

a) all weld preparations for pressure hull plate were obtained by grinding the plate to the required profile.

b) all pressure hull welding is conducted in accordance with Naval Engineering Standard (NES) 706 and using consumables approved for welding the pressure hull steel in accordance with specification DGS 234 B, as specified by the Department of Defence. The only consumable currently approved for welding Oberon submarine pressure hull steel is a Manual Metal Arc process electrode.

The reason for only grinding weld preparations and not using a combination of bevel cutting and grinding is lost in antiquity. At build the plate edges were prepared by a combination of flame cutting and light grinding of the surface. A contributing factor to this practice is that most pressure hull inserts undertaken by CODOCK have been relatively small i.e. cutting out redundant insert pads or consolidating small inserts such as for SWUP which was about 6ft x 4ft. Burning operations for removing redundant material has been a manual operation therefore necessitating extensive grinding to straighten the edge and prepare the weld profile. It is interesting to note that at the early planning stages it was intended by CODOCK to follow this existing practice on an insert of very large proportions.

In regards to the approved electrodes the availability of only a 'stick electrode' has occurred because of the stringent approval requirements which cannot be relaxed and the relatively small quantity of electrodes required against general industry usages. Therefore there has been a reluctance by industry to fund the approval of an electrode for a small financial return. Similarly the Department could not justify the funding of expensive research and development for approving a GMA consumable with a small usage rate, particularly as throughout most of the life of the RAN Oberon's there has been no capability in Australia to undertake 'bulge explosion tests' necessary to qualify the welding consumable. With local manufacture of quench and tempered plate in Australia for military purposes bulge explosion tests are now available in country.

5. **Method Chosen**

There were two possible methods, with some variations, of fabricating and consolidating the renewed pressure hull plate and installing all insert pads.

The first method involved largely a single stream approach. A schematic of the best variation of the method is given as Appendix B. The basic steps in this method are:

A) Mark out and cut away the existing corroded and wasted pressure hull plate.

B) Repair any damage to the tops of the pressure hull frames from removing old plate.

C) Prepare plate edges on the submarine to the required welding profile and NDE to check for defects

D) Repair frames to adjust for any shape imperfections

Concurrently with A B C and D and away from the submarine

E) Mark out and cut new plate segments to the required dimensions

F) Prepare plate edges, for joining of the four flat plates by welding to form one plate, to the required weld profile and NDE to check for defects

G) Install individual plates in a jig to restrict distortion during welding operations , (see sketch 5).

H) Weld plates together in accordance with weld procedure to extent that weld is just below surface. Total length of weld 27 ft

I) Non destructively examine welds and repair as necessary.

J) Remove plate from jig and roll to correct radius

K) Install rolled plate in a jig to maintain shape during subsequent lifting and welding operations

L) Non destructively examine plate edges in way of longitudinal seams and butts for joining plate to submarine

As single stream action

M) Fit new plate to opening in submarine, trimming to size

N) Prepare plate edges of new plate for welding adjusting where necessary weld profile to match that of existing plate of vessel

O) Non destructively examine plate edges after preparation for welding to check clear of defects

P) Preheat all plating in way of proposed welding to the required temperature

Q) Weld new plate to hull in accordance with an approved welding sequence to limit distortion , (approximately 70 ft of class 1 welding)

R) Non destructively examine the welds from step O to check for defects, and repair as necessary

S) Weld plate to frames in accordance with an approved sequence

T) Non destructively examine welds

U) Weld required capping runs to transverse butts joining plate segments, (approximately 27 ft of welding six runs each side)

V) Non destructively examine welds repair as required

W) In accordance with an approved sequence individually cut plating, prepare edges to required weld profile, non destructively examine edge, fit insert pad, re-orientate heating elements around insert and apply heat, weld insert pads into hull using overhead and downhand welding as required. This step is repeated for twenty six in number insert pads, which in total requires 100ft of welding, 50% overhead in a hot confined space.

X) Prepare welds for X-raying i.e carefully grinding to remove ridges and valleys in the capping runs which can mask defects deep in the weld

Y) On completion of installing all insert pads non destructively examine welds for defects and repair as necessary

Z) Replace any inserts in pressure hull frames required for access for welding longitudinal seams and any insert pads which cross over a frame.

This method has several advantages, these being

1) For consolidation of the new plate to the hull it only required a relatively light uncomplicated jig to hold the plate in shape until it had been pulled down and tack welded to the pressure hull frames

2) It enables jigging to be attached to the pressure hull frames for the positioning and orientation of all insert pads, thereby reducing the complexity of the jig holding the plate to the rolled shape, and more importantly reduces the risk of incorrect positioning of the new insert pads when they are installed. The jigging on the frames would be used to hold the insert pad in place.

3) The welding of the insert pads onboard would utilize existing welding procedures with a known pattern of distortion and with the pressure hull framing supplying a known level of restraint against buckling.

Overall it involves the least risk in terms of purely fabrication aspects. This was the method favoured by Devonport Dockyard when they were consulted by the author and CODOCK in June 1986. The Devonport Dockyard Welding Engineer particularly stressed that they preferred to install the major insert pads after the new plate had been consolidated to the hull, particularly the group exhaust valve hull pads, some of the smaller insert pads were installed ashore.

This method of fabrication however has several major disadvantages. These are;

1) To a large extent, in overall time scale, it is single stream fabrication predominantly involving one trade - Boilermaking/ Welding. While all fabrication work is taking place onboard the submarine it precludes access to the engine room of the submarine to all other trades and refit work.

2) This therefore results in an imbalance in the work load / manpower distribution of the various trades.

3) To overcome this imbalance a higher proportion of overtime would have to be utilized by the other trades to complete all the normal refit work in way of the engine room, engines, and auxiliary equipment and systems, engine room tanks.

4) This can be further exacerbated if their are extensive weld repairs required for the main butt and seam welds as well as the insert pad welds.

5) Therefore their is a higher risk that the refit key dates such as installation of the battery, system functional tests and engine trials will be delayed and therefore increasing the risk that the overall refit schedule could be jeopardized which ultimately increases the cost of the refit.

The second method involves the fabrication of a very heavy female supporting jig to allow for a major proportion of the welding to be undertaken away from the submarine, therefore it is a two stream approach. A schematic of the method is given in Appendix C. The basic steps in this method are;

A) Mark out and cut away the existing corroded and wasted pressure hull plate

B) Repair any damage to the tops of the pressure hull frames from removing the old plate.

C) Prepare plate edges on the submarine to the required welding profile and NDE to check for defects.

D) Repair frames to adjust for any shape imperfections.

Concurrently with A B C and D and away from the submarine

E) Mark out and cut new plate segments to the required dimensions

F) Prepare plate edges, for joining of the four flat plates by welding to form one plate, to the required weld profile and NDE to check for defects.

G) Install the individual plates in a jig to restrict distortion during welding operations

H) Weld plates together in accordance with the weld procedure to extent that weld is just below the surface. Total length of weld 27 ft.

I) Non destructively examine welds and repair as necessary

J) Remove the plate from jig and roll to the required radius

K) Install the rolled plate in a jig that has been specially design to maintain shape during subsequent welding operations in particular for support at the installation of the numerous thick insert pads. The jig must also provide adequate access for all welding operations and be able to be lifted and turned over to permit all welding to be undertaken down hand.

L) Preheat all plating in way of proposed welding to the required temperature

M) Weld required capping runs to main transverse joining butts approx 6 runs per side

N) Non destructively examine welds

O) In accordance with an approved sequence, individually cut plating, prepare edges to the required weld profile, non destructively examine edge, fit insert pad, re-orientate heating elements around insert and apply heat, weld insert pads into the hull using downhand welding turning the entire jig over at an appropriate time to complete the reverse side welding in the downhand position. Continually monitor weld induced distortion and adjust weld sequence if required. Step O is repeated for twenty six in number inserts or until it has been decided to replace the plate to the hull

P) Prepare welds of insert pads for X-raying i.e. carefully grinding to remove valleys and ridges in the capping runs which can mask defects deep in the weld. The insert pads should be X-rayed at convenient times to enable as many inserts as possible to be totally cleared of defects before the plate is consolidated to the submarine.

Q) Non destructively examine plate edges in way of proposed locations of the longitudinal and transverse weld seams

As single stream action on the submarine

R) Fit new plate to opening in the submarine trimming to size

S) prepare plate edges of the new plate for welding adjusting where necessary the weld prep profile to match that of the existing plate on the vessel

T) Non destructively examine plate edges after preparation for welding to check clear of defects

U) Pre heat all plating in way of proposed welding to the required temperature

V) Weld new plate to hull in accordance with an approved welding sequence to limit distortion , (approximately 70 ft of class 1 welding)

W) Non destructively examine the welds from step V and any insert plate welds that have not been X-rayed

X) Weld plate to frames in accordance with an approved sequence

Y) Non destructively examine all welds

Z) Replace any inserts in pressure hull frames required for access for welding longitudinal seams and any insert pads which cross a frame.

This method has several major advantages, these being

1) The majority of welding is done in a more comfortable environment therefore encouraging higher productivity. This is extremely important as the productivity of the welders must deteriorate with constant working in confined spaces with elevated temperatures from preheating of the plating to avoid hydrogen embrittlement.

2) No overhead welding required for installation of all hull insert pads. This greatly reduces the risk of defects and improves productivity

3) This method enables the production manager to balance the work load for all trades as it gives access to the engine for key trades such as fitters and plumbers. The start time of the boilermaker work on the submarine in removing the old plate and the preparatory work for the new plate can be varied or work interrupted because there is considerable float time particularly if flame cutting is used for the weld preparation.

4) The Production manager has more flexibility in organising workload and the sequence of events. The program of consolidating the crown plate can be varied as the need arises. If he so wishes he can put the crown plate back on the submarine early before all insert pads are installed, or if the jig is proving unsuccessful in resisting distortion of plate due to welding of the insert pads

5) With the large majority of welding and Non Destructive examination of welding being done before the closure plate is installed on the submarine it reduces the risk of extensive delays at the final stages of the consolidation program due to weld repairs, noting that even minor repairs consume as much time as the time for the original weld

There are several disadvantages to this method, these being;

1) Requires heavier jig to provide adequate distortion restraint along the whole of plate due to welding of insert pads

2) The jigging for the positioning and orientation of the pads has to be built into the main jig structure and therefore there is a slightly higher risk that the inserts could be set in the wrong positions as the jigging needs to be removable to provide access, disorientaion is the contributing factor.

3) The most important disadvantage is that with this method there is an unknown distortion pattern. The restraint against buckling will be from localised point supports not from the hull frames. This disadvantage can be offset by the fact that the method has flexibility of when the plate is consolidated to the submarine . Therefore if unacceptable levels of distortion occur it is a simple matter of reverting to the single stream method.

After extensive discussions between all parties it was decided to use the second method. A jig was therefore fabricated based on the design shown on sketch 6 - 11. The method of attachement of the plate to the hull adopted was similar to that for holding the plates in position during build. Small ferrules were welded to the hull plating. The ferrules were cup shaped with an internal thread. Large bolts were screwed into the ferrules to locate the plating into the jig frames. On completion of the entire job the ferrules can be ground down to a level just proud of the plate. This minimises risk of damage to the to the plate.

7. **Statement of Work**

Once the method of fabrication had been agreed to between the Customer and the Contractor the 'Statement of Work', Ref 2 , was written by the author detailing the methods and general procedures to be used, the preliminary action to be undertaken, the circularity readings required, the testing and certification of procedures required, the standard of workmanship and specifications to be adhered to, and the Quality Assurance requirements. This document was approved and issued. It is important to realise that a statement of work is only a major overview document. It acts as a staring point as it lays down the basic/ essential requirements. From this point there must be constant interaction between the Customer and the Contractor to dissect and interpret each aspect of the statement of work and referenced specifications there in so that the work when completed meets all the requirements of the Customer. This is particularly important as many specifications, such as welding codes, to a large extent are guidance documents. It is very easy for a Customer and Contractor to have different interpretations of the requirements of a document. It is far too late to argue over an interpretation when the job is complete. This should be noted for all aspects of a project. Quality Assurance is an interactive process between the Customer and the Contractor and must be applied to all phases of a project.

8. Preliminary Work

Apart from the preliminary survey work and non destructive examination of plating etc. required by the statement of work there were three principal pieces of preliminary work which had to be undertaken before fabrication could commence. These were approval of a welding consumable for cold working of weldments, verification of the shape of the vessel before cutting of plating, and fabrication of the jigs required to assist fabrication.

8.1 Approval of a Welding Consumable for Cold Working Weldments Joining Pressure Hull Plating.

As part of the fabrication method involved the joining of four segments of flat pressure hull plate and, after completion of welding, rolling the entire plate as one unit to get uniformity of radius, this involved cold working of weldments. In accordance with the general fabrication specification, NES 706 (ref 4), Oberon submarine pressure hull plate may be cold worked 'provided the amount of cold working does not exceed a strain of 3.3% and provided that the fabricator demonstrates by mechanical testing that the weld metal properties for the particular consumable used, continues to meet the approved weld metal properties detailed in NES 769, (ref 5).

To meet these requirements two flat plates were prepared, and welded together following the exact procedure that would be used on the real welds including overhead welding. The plate was X-rayed for evidence of defects which were repaired, rolled to the required radius , X-rayed again for evidence of defects caused by rolling , and then capped. The necessary test pieces were cut from the plate. All tests proved satisfactory.

9. Verification of Shape of Vessels Subject to External Pressure

The verification of the shape of any pressure vessel following fabrication or repair is of prime importance as the amount of deviation from the mean circle (extent of shape imperfection) ultimately determines the safe operating pressure of the vessel. Also of extreme importance is the phase relationship of the out of circularity as

a) it is critical to compare the phase relationship of the pressure vessel as built against the theoretically determined worst modal buckling shape

b) the phase relationship determines the suitability of consolidating adjacent structural units without inducing high localised stress concentrations at the joint, and as mentioned previously for this reason the phase relationship is of critical importance when contemplating a repair crossing two structural units.

There are three acceptable methods of determining out of circularity of a large pressure vessel to a high level of accuracy. These are;

1) Using a swing arm or trammel gauge.

In this method radii or differences from a constant internal radius are measured at an even number of equally spaced intervals around the circumference sufficient to define the profile of the section being considered but not fewer than 24 The axis of rotation of the internal swing arm should approximate the true centre of circularity of the section under consideration but it does not have to be exactly in the centre as the calculation method corrects for the deviation of the assumed centre from the true centre. However the centre used should remain constant for the full set of readings. The method of calculation is given in `Case No 5500/33 August 1981 to BS 5500 1976 Method 2 .

2) The second method is a variation of the first where instead of using a swinging arm the hole unit is rotated in a lathe about its axis and the deviations measured to the external surface from a fixed indicator on the lathe tool post. This method is only practical at build or for very small structures

3) External Ring

The third method is also a variation of the first method in that a fixed ring of known radius greater than that of the vessel under consideration is positioned around the hull and the deviations at an equal number of points (no less than 24) is measured from the ring to the external surface. Again the centre of the fixed ring should approximate the true centre. The results are then transferred into radii and the same method of calculation is used as per method 1.

4) Chord Gauge

The fourth method involves the use of a chord (or bridge if preferred) gauge. See sketchs 12-14. With this method chord gauge measurements at no fewer than 24 equally spaced positions on the circumference should be taken to give values of the rise of ** termed chord gauge readings, or differences from a constant rise. The readings shall be measured to a precision of 0.1mm. The steps required for taking circularity measurements by this method are fully described in Annex A which is an extract from references 2 and 3. The departure from the mean circle can be calculated from the readings using the following equation equation and influence coefficients as given in Case No 5500/33 August 1981 to Bs 5500 1976 Method 3

$$\epsilon_r = \sum_{i=0}^{N=1} \delta_i \, I_{(i-r)} \qquad \text{Note } I_{-s} = I_{N-s}$$

Or alternatively the departure from the mean circle can be calculated using the method described in `Kendrick - Shape Imperfections in Cylinders and Spheres Their Importance and Methods (J. Strain Analysis For Eng. Design 12 No 2 Apr 1977) which is a full Fourier Analysis method.

Regardless of the method of calculation used for the chord gauge method the total acceptance of the chord gauge readings as giving an accurate representation of the deviations from the mean circle, is dependent on the closure distance after stepping the gauge around the hull being within the tolerance of $\pm$ 3/8 ths of an inch.

<u>Method of Circularity Measurement Chosen</u>

The first method (internal trammel) is an excellent means of measuring the shape of a nearly circular section when the trammel has an uninterrupted sweep right around the circumference, and was the method used at build. Continual breaking down and resetting of the trammel bar to avoid obstacles increases the inaccuracy of the method to an unacceptable level. This method is not feasible in a refit situation for the main hull. Use of an external ring is best suited to a build application prior to any saddle tanks being attached to the vessel. Also cost of fabricating the ring with a machined internal surface is prohibitive in a refit situation for a limited number of readings. Therefore the only feasible method for taking circularity readings on HMAS OTWAY was the chord gauge method which is the least accurate. This method is considered not as accurate as the other methods as;

a) it is more prone to operator error

b) uses the external surface of the vessel which has a proportion of surface defects, such as pitting of the plate, which will give a distorted reading

c) is more prone to inaccuracy due to the effects of localised plate distortion.

d) also access openings had to be cut into the main ballast tanks and keel structure so that the gauge can be stepped round the hull. This is an expensive exercise.

e) the calculation/analysis method only computes deviations from the mean circle, it does not give mean radius or location of the centre.

A Chord Gauge was manufactured at Cockatoo Dockyard Pty Ltd from a verbal explanation of the operation of the gauge by the author to dockyard personnel and from photographs of a gauge given to the author by Devonport Dockyard. The gauge manufactured by Codock was an improvement on that possessed by Devonport as it incorporated features such as a digital displacement reader instead of a clock dial, and also it had the capability of remote readout and printing. This had obvious benefits for working in confined spaces such as the main ballast tanks of an Oberon submarine.

Chord readings were taken before any cutting of the pressure hull occurred. This was so that a known datum existed and any initial circularity problems would be known. The chord readings taken this time differed from those taken at build in that more readings were taken around the hull, 48 instead of the original 24. This is the current UK practice as it gives better definition of the shape.

Lessons Learnt In Use of a Chord Gauge

The submarine was prepared for taking the circularity readings at the nominated locations in accordance with the instructions detailed in Annex A. Experience from operation of the chord gauge in a real environment highlighted two factors, (factors b and c as listed above), which contribute to the inaccuracy of the method but can be partially overcome by an extensive visual survey of the actual points where the gauge has touched the hull.

In regards to the condition of the external surface of the steel, local imperfections did have an effect on individual readings. This does not occur only when the surface imperfection is immediately in way of the point of measurement (pointer No 2 on sketch) but also whenever either of the end pointers was in way of the surface imperfections. The type of surface imperfections encountered was not just confined to pitting and corrosion of the plate. Other types of surface imperfections encountered included various roll marks / ridging in the plating, gouges, nicks and lumps of excess metal. These naturally can be allowed for by a survey of the immediate point of contact of all three pointers of the gauge and making a judgement of the extent of correction required.

The other significant factor which contributed to inaccuracies was the effect of the areas of local distortion in the plating, particularly the peaking of the plate at the longitudinal weld seams as described previously. The operation of the chord gauge follows the basic steps detailed below.

Step 1 The starting point is marked on the hull. The gauge is placed on the hull such that pointer 1 is placed accurately on the starting line.

Step 2 The other end of the gauge is lowered onto the hull and pointer 3 is used to scribe a mark on the hull.

Step 3 With pointer 1 and pointer 3 sitting on the hull the measuring pointer (pointer 2) is then released from its restraining clip and is lowered onto the hull.

Step 4 The chord reading is then taken.

Step 5 The gauge is lifted off and the procedure repeated for the next reading with pointer 1 being placed on the hull exactly where pointer 2 has taken the reading. Pointer 3 is then again used to scribe a mark on the hull to locate reading point 4.

This procedure is repeated for all 24 or 48 points around the hull. In theory the location where pointer 2 takes a reading should exactly coincide with the scribe mark defining the reading location as defined by pointer 3 as it has progressed around the hull.In practice this does not always occur, particularly when the gauge is straddling a peaked longitudinal weld seam and/or for one or two readings after, or similarly when the gauge pointers are landing in way of localised distortion such as occurs around insert pads. In these cases the mid point (pointer 2) did not always coincide with the with the scribe mark where pointer 3 had been, the deviation being up to 1/8 th of an inch for a badly peaked weld seam. As can be seen from examination of the calculation formula the deviation from mean circle is influenced by the chord reading at every location around the hull. If when this deviation in location occurred pointer 1 was placed where pointer 2 had landed all correlation between the readings would be progressively lost and the required closure distance would not be achieved. In most cases the deviation was only a 1/64 th or 1/32 nd of an inch and progressively disappeared until another imperfection was encountered. Therefore the end pointer 1 was always placed exactly on the scribed mark left from pointer 3, the discrepancy in location of pointer 2 from the marks was recorded and a visual survey of each point was made so that if the readings also occurred in an area of surface imperfection, such as pitting, an adjustment could be made to the reading when analysis of the results was carried out. However, regardless of whether an adjustment is made to the reading or not a level of inaccuracy still exists in the readings.

10. <u>ACTUAL FABRICATION WORK</u>

As described in a previous section, work on replacing the corroded/wasted engine room closure plate on HMAS OTWAY progressed along two paths. Path one involved the fabrication in jigs of the new engine room closure plate with the large majority of the insert pads fully installed prior to fitting the new plate to the submarine. Path two involved the removal of the corroded wasted plate from the submarine, the preparation of the plate edges for welding, and the repair of the frames.

Also as previously mentioned the new closure plate had to be fabricated from four segments to gain the correct width and length. Based on the understanding of Dockyard Management that a 26ft long plate of pressure hull grade material could be rolled to the required shape by the plate rolls in the dockyard, which were government owned/ installed and maintenance supported and had been acquired with a view to this type of rolling task, the decision was made jointly by the author and the Submarine Refit Superintendent to weld the segments together to form one long flat plate prior to rolling, with welding distortion controlled in a jig. This had the advantages that the edge misalignment between the plate segments could be kept to the minimum and, more importantly, could be rolled to one radius. The flat plate jig is shown in sketch 5 .

The 25 ft of class 1 welding was carried out in accordance with the welding procedure written by the Welding Engineer and approved by the authur. Preheating of the plate in way of the welds and for all subsequent welding of the quench and tempered plate was by means of the equipment detailed in Appendix E.

With the assistance of the jig, welding distortion **was successfully controlled and all welding was conducted with a high level of productivity. The welding was 100% radiographically examined and no defects were found.**

Attempts were then made to roll the complete plate, however it proved to be beyond the capacity of the plate rolls. This was either because it was totally beyond their design capacity, or due to the poor maintenance state of the rolls. The small guide rolls above the top main roller were overheating and the plate was seizing when passing through the rolls. Two of the completed butt welds therefore had to be split to enable the plate to be rolled by a subcontractor, Transfields Pty Ltd, which was successfully completed.

At this stage,and in the following stage , a major breakdown in Quality procedures occurred and they are discussed here to highlight the fact that Quality Assurance and Control are the responsibility of all parties involved in a project, from the Customer to the Contractor's management, down to the tradesmans assistant.

A proven welding procedure, for the reweld of the transverse butts, deviced to limit distortion to the minimum, was written by Codocks Welding Engineer based on the requirements of the welding code. It was discussed and assessed by the Welding Engineer and the Customers Representative and then approved for issue. The quality system was working along the path it should with interaction between the Customer and the Contractor, an assessment of all the variables and risks and the issue of approved procedures. The breakdown occurred when the shaped plates were set up in the main jig with the wrong weld prep. It should be stressed that it was done with good intent as there was concern that the splitting of the welds had reduced the total length of plate leaving inadequate `green' and the approved weld prep would reduce it further. However other action had been taken onboard the submarine to eliminate this problem. The weld prep used had a greater risk of higher weld induced distortion. This highlights a problem that exists in all shipyards in that it is difficult for all information to filter down to all levels. But this is why written procedures must be followed. Quality Assurance,Quality Control systems can only function when there is total commitment to follow all procedures.

It was not possible to remove the plate segments from the main jig, correct the weld preparation, and reinstall the plates in the jig without damaging the plates. Welding of the butts then commenced under close supervision by the Welding Engineer to a modified procedure. Distortion was closely monitored, and the number of runs each side per sequence adjusted accordingly. At this stage the second major breakdown in Quality procedures occurred. As the Welding Engineer and the Customers Representative would be absent from the dockyard attending a welding seminar , a signed set of instructions detailing when welding on the first side was to be stopped and the depth and width of the backgouging for the reverse side weld preparation was issued. Prior to approval and issue it had been discussed between the Welding Engineer and the Customers Representative, advice taken from other interested parties, the risks and alternatives assessed, and it was ultimately approved and issued. In other words the quality system was working. However the issued instructions were disregarded. The depth and width of the backgouging was not carried out in accordance with the issued instructions. As welding on the reverse side had commenced the Welding Engineer and the author were presented with a `fait accompli' situation on there return. The deviation from the procedure was done with good intentions, but the key factor is that that profile had been assessed and rejected due to higher risk of distortion. Recovery procedures were immediately commenced altering the number and size of the capping runs to balance the welding distortion. It is imperative to note that this is not a unique problem to this dockyard. The author has seen the same thing occur in all four dockyards he has worked in, and it occurs world wide in every industry. It can not be stressed too highly that Quality is the responsibility of all personnel whether it be the designers or the production department. Don't be naive and think it does not apply to a new shipyard or to your own quality system. Every one is fallible and makes errors. The more aware of the total commitment to following procedures the less errors occur.

As a result of the recovery action distortion of the plate in the jig due to welding stresses was successfully controlled with only minimal distortion occurring, usually outwards not inwards. The welds were 100% radiographically examined and again **no defects were found.** Installation of the twenty six in number insert pads was then commenced with each pad positioned correctly by use of the templates built into the jig which matched the exact orientation and position of the pads as built. Any deviation from these positions was discussed and assessed by all parties concerned before installation.

In general, work on installing the insert pads progressed very well with the Dockyard personnel being highly motivated with their work and taking extra care and time to avoid weld defects by thoroughly grinding out all stop start porosity clusters and slag inclusions. The extra time spent in this preventative work was recovered by increased efficiency and productivity, particularly on weekends. The large majority of welding being in the downhand position was also a contributing factor to the higher productivity. Distortion surrounding the insert pads was minimal. When the new crown plate was ready for fitting to the submarine all insert pads had been installed, though seven pads had welding to complete. Sixteen in number insert pads had been 100% radiographically examined for weld defects and again non were found. This was a very high success rate and is a credit to all those concerned with the welding from the supervision at all levels down to the trades assistants who did the grinding. The standard of welding was far above the minimum acceptance standards and was achieved with no time penalty, which justified the method chosen.

Therefore prior to fitting to the submarine we had a new plate which was straight along its length, rolled to the moulded radius and very rigid.

Looking now at the events which occurred on the submarine, prior to the removal of the corroded/ wasted pressure hull plate, the female main jig was placed on top of the submarine to install in the jig the templates of all the insert pads as previously mentioned. The jig was levelled and was sitting hard on top of the pressure hull at frames 79 and 90; the frames immediately fwd and aft of the existing transverse butts of the closure plate. At each frame between the frames 79 and 90, a gap was found between the top of the pressure hull plate and the relevant jig frame. The results are detailed below.

FRAME	GAP DIMENSIONS
79	0
80	> 8mm
81	> 8mm
82	8mm
83	7mm
84	7mm
85	> 8mm
86	> 8mm
87	5mm
88	0
89	3mm
90	0

A visual survey of the pressure hull plate in this area revealed the following;

a) At the centreline of the butt midway between frames 80 and 79 the closure plate had been severely pulled up to meet the opposing plate. Even with this there was still misalignment of the plate edges (4 mm approx) with the closure plate on the low side. This misalignment continued, with some variation, towards the longitudinal seams port and stbd.

b) At the butt welds 9 inches fwd of frame 90 the closure plate had also been pulled up to meet the opposing plate. At the centreline there was very little misalignment of the plate edges with the closure plate edges slightly below the opposing plate. However the misalignment increased progressing towards the longitudinal seams port and stbd to approx 4mm.

c) Along the longitudinal seams there was misalignment of plate edges with the closure plate being lower than the opposing plate particularly on the starboard side. misalignment varied between zero and 5 mm.

The above deficiencies have resulted in a very high level of fabrication induced stress in the original closure plate. They therefore had to be allowed for and eliminated at installation of the new closure plate. For comment I refer you back to section 4. In this case we had one plate that had been badly installed, which was crossing the junction of two structural units of adequate circularity.

This high level of fabrication induced stresses was illustrated when the existing transverse butt 9 inches forward of frame 90 was split for removal of the plate. Cutting progressed from the stbd corner moving to port. As the corner of the closure plate was released by cutting the closure plate locally moved significantly upwards. When the centreline area was released the closure plate plate locally moved downwards approximately 4 to 5 mm and the pressure hull plating between the cutline and frame 90 locally rotated upwards. The port aft corner behaved as per the stbd aft corner. This posed some concern as the age old saying of what goes up must come down does not always apply to submarine pressure hull plating following release of locked in stresses. In this case what goes down is easy to jack back up again using the frames as a strong point, but what goes up may stay there. The locked in fabrication stresses at the forward butt were utilized to assist in pulling down the plate fwd of the fwd butt. The plate was first cut adjacent to frame 80. The locked in stresses therefore caused the plate to rotate down about frame 79, which partially relieved the discrepancy in height.

A survey of the frames under the engine room closure plate revealed that on installation at build the extreme fibres of the frame flanges were aligned very accurately with the opposing frame segments. However the frame segments had been formed to a shallower radius. This had been the cause of the deviations along the centreline between the jig frames and the pressure hull plating. This was also confirmed by the circularity readings.

Concern was felt that if there were high levels of stresses in the plating the same might apply to the frames, with the result that when the plate was removed the frames may rotate to relieve any stresses. The engine room monorail is welded to the underside of the frame flanges at the centreline from frames 80 to 89. This was extended to the next frames which were outside the plate opening thereby holding in place one edge of the frame. The frame spacing for each pair of frames was measured at five locations across each frame as close as possible to the hull plating as a reference if the frames did rotate. On removal of all the old plating the frame spacings were again checked and no deviation was found.

Therefore in general what should have been a relatively straight forward job with known risks applicable more to the fabrication of the new plate had become quit a big undertaking with repair action to the frames having to be undertaken when it was not originally anticipated unless they buckled on release of the plate or were damaged.

When the plate was removed from above the frames using carbon arc air gouging to wash away the welds it was noted that the original installation weld preps on the frames was varied to allow closing of any gap by weld metal. This made it difficult to maintain any reference heights

The decision was therefore made by the author after evaluating all alternatives;

a) not to try to relieve the plate edge misalignment at the longitudinal seams by frame repair but to leave the correction of this to control of weld distortion on installation of the new plate. and to

b) to selectively repair the frames to achieve a gentle easy longitudinal curve to reduce the stress levels at the forward and aft butts.

To assess the extent of frame repair required, piano wires were set up over the top of the frames at five locations, see sketch . Three sets of readings were taken;

Set 1

Each wire was set at an even height above the plate at frame 79 and 90. Measurements were taken from the underside of the wire to the top of the frame . The nominal plate thickness was subtracted. These showed some variation from those measurements taken between the jig and the plate due to the movement of the freed plate at either end.

Set 2

The wires were pushed down so that they touched 5mm thick blocks placed on top of frames 80 and 89. These measurements were taken to determine if the frames between the end butt joints were in the same plane, particularly as the engine room closure plate crosses two structural units. The readings confirmed this.

From analysis of the data of set 1 and 2 it was obvious that the most suitable shape to achieve was a slight sag along the centreline which would then open up the radius of the new plate to match the shallower radius of the frames. However naturally there is a concern for circularity of the finished product. Therefore using the data from the analysis of the circularity readings, reformulating it into radii from an assumed centre, verifying that these radii gave the same deviations from mean circle as originally achieved with the analysis of the chord gauge readings, and then adjusting the data for the extent of frame repair contemplated, it was found that the repairs were feasible within the circularity tolerance limits. The frames were then repaired. A final set of readings (set 3) were taken to confirm the shape. Obviously there is a risk in performing theoretical projections of circularity shape and the author recommends that the only be undertaken with extreme caution.

Simultaneously with the repair of the frames the weld preparations on the the plate edges on the submarine were prepared. The weld preparations used involved a major departure from standard practice . The normal weld preparation and sequence of welding operations is as shown in sketch . This involves;

a) a 2/3 to 1/3t weld preparation

b) welding of the root run and subsequent overhead runs of weld to a depth where sufficient strength is achieved to permit backgouging.

c) Backgouging on the outboard side removing the root run and achieving a 1/2 x 1/2t weld profile.

d) completing down hand welding to just below the surface and

e) capping runs on both side to a sufficient height to temper the main weld runs.

This method while it has proved very successful over the years is a slow and costly method for the following reasons:

a) Firstly as the trade unions will not permit carbon arc air gouging in confined spaces (i.e. submarine internally), due to the high noise levels and smoke fumes, the dockyard is therefore committed to a large overhead weld for the first runs so that all backgouging can be done external.

b) Secondly backgouging the reverse side weld preparation involves the removal of a considerable amount of good weld metal which is time consuming and non productive.

c) The overall result is a weld profile larger than necessary hence greater welding time and cost.

After investigations by the Company Welding Engineer and the author, and following some research and development work it was decided to use a ceramic tile backing strip for the initial root runs and to adjust the weld profile accordingly. The use of the ceramic tile backing strip has the following advantages;

1. It is more tolerant to poor fit up as a root gap is required .

2. No backgouging is required only light grinding, slag tends to fuse to the ceramic tile.

3. Less weld metal required as no backgouge and weld profile is not as large.

4. Better distortion control.

5. Faster deposition of first run as in general a 5mm rod is used. With the normal weld preparation you are committed to a 4mm rod to get good penetration.

6. Reduced risk of cracking of the root run as more metal initially deposited hence a stronger root.

The weld preparation profile is shown in sketch 16. The ceramic backing tile is triangular in cross section with radius corners. The included angles are 90 , 60 , and 30 . The tile is mounted on an adhesive backing tape with the desired corner of the tile required for the inboard weld prep shape pointing upwards. The tile is held in place in the weld profile by the adhesive tape being pushed onto and adhered onto the internal plate surface.

As mentioned earlier in the paper it had been provided in the original plan network to prepare the weld preparation by grinding. This is a total of 140ft of grinding of weld preparation. The total planned time for this was 8 weeks.This was considered to be an unnecessary cost and could be improved by of flame cutting the weld preparation, and to use semi-automatic processes if possible.

After investigations by the author and by the CODOCK Welding Engineer and with the help of 'Linde Gas Pty Ltd' representatives, Mr P. Madden and Mr. D. Northcott, semi automatic tracked burning equipment was purchased to cut the old corroded plate off the submarine as accurately as possible and to flame cut the weld preparation, principally the large bevel. The details of the equipment are included at the end of the paper.

The semi automatic tracked burning equipment was used to prepare the large bevel for the weld preparation of the port longitudinal seam. Some problems were experienced due to the unevenness of the plating caused by slight distortion between the frames. The weld preparation was of a very good appearance requiring only light grinding to remove any scale. In general it tended to be slightly hollow.

In comparison the large bevel for the weld preparation on the stbd longitudinal weld seam was flame cut using hand held equipment. While the cut was of good quality and had been performed in about the same time as the total semi-automatic process time, (set up + cut , the preparation required extensive grinding to remove gouges etc. in the bevelled surface. The resultant weld preparation was of an inferior quality to that obtained using the semi-automatic burning equipment. The small inboard bevels were prepared by chipping and grinding.

The new closure plate was then removed from the shop lifted above the submarine with the aid of the floating crane TITAN and attached to support posts at the four corners of the opening. The plate could be raised and lowered by means of block and tackle. Then began the process of fitting the plate to the opening.

The plate was lowered onto the top of the hull and the outline of the opening marked. The plate was then raised slightly above the opening and burning operations commenced to remove excess metal. The plate was then flame cut from inboard the submarine to outboard at a slight bevel, to gradually work the plate down into the opening. When this had been satisfactorily achieved the plate was lifted by the block and tackle further above the hull and the large external bevel burnt using hand held torches. The inboard bevel was prepared by chipping. Extensive grinding was necessary to get the weld preparation to a satisfactory profile and condition. Though it was not to the standard of the semi automatic flame cut weld profile, utilization of the the ceramic backing strip and hence a weld prep providing for a root gap, allowed some tolerance of poor weld prep condition and misalignment of the root face. The total time to fit the plate and prepare the new plate edges was approximately 2 weeks, (7 day weeks).

An alternative method of fitting the new plate involves the taking of accurate measurements of the opening from the centreline of the vessel, and if necessary placing the plate immediately above the opening and scribing a line. The plate could then be removed from the vessel and using the semi-automatic cutting equipment the plate could be cut close to the correct size and then the large bevel flame cut. The plate could then have been placed back on the support structure, checked against the opening and the small amount of green provided removed by grinding. The ceramic backing strip is tolerant to a 4mm root gap. This method in the authors opinion had the potential to give a higher quality weld preparation but involves a higher risk of error.

When the plate was finally lowered onto the hull and pulled down onto the frames it was found that it took the intended slight sag easily. There was only one frame where the plate did nit rest solidly on the top of the frame. At this frame the gap was approximately 1mm on average. The plate in this area could not be pulled down further onto the frame even though the plate was being worked over a span in excess of 4 ft. The weld preparation on top of this frame was adjusted to accommodate the gap. The plate was further attached to the frames by widely spaced block tack welds. The plating was then preheated for 24 hours before welding commenced.

Welding of the transverse end butts and the longitudinal seams then commenced. An approved welding sequence for the installation of the plate had been written by the Welding Engineer and approved by the author at a very early stage prior to removing the old plate and choosing the preferred weld preparation. It is included at the end of this paper as Annex D. It generally followed the guidelines of the fabrication code,NES 706, in the order of sequencing the welds. The principal deviation being the use of heavy block tacks in a sequence to hold the plate in place and to give adequate strength to assist in preventing root cracking while the main weld steps were being performed. The block tacks could be removed later or incorporated into the correct weld steps in accordance with the sequence. Refering to Annex D it can be seen that using the old style weld preparation and using a standard pattern welding sequence, it was intended to place the first block welds, (approx 2 ft long), on the centreline of the fwd and aft transverse butts, weldin the blocks in the overhead position. The second block welds were to be on the longitudinal seams port and stbd at mid length. Opposing corners of of the overall plate would be then block welded, and then the rest of the longitudinal seams would be progressively block welded moving out from the mid position as shown on sheet 6 of Annex D.

As originally there was significant levels of distortion at the fwd and aft transverse butts which could largely be relieved by frame repair but never totally eliminated, it was decided by the author , the Welding Engineer, and the Boilermaker / Welding foreman responsible for the shipboard structural work to alter the sequence of the weld steps to concentrate heavily initially on the fwd and aft butts, the areas of distortion. These areas naturally also had the greater potential for plate edge misalignment, particularly the aft butt. The block welds were first placed on the centreline of the fwd and aft transverse butts as previously intended, and were of approximately 2ft in length. However they were welded from the outboard side welding down hand onto the ceramic backing strip. The block welding of the aft butt was then progressed with the beginning of the second pair of block welds positioned approximately 1 1/2 ft outboard of the centre block weld, and were less than 2ft in length. Examination of the welds by the author and the Welding Engineer revealed that the amount of plate edge misalignment obtained was excessive. It was decided to then split the second pair of block welds and also part of the centreline block weld to releive the edge misalignment. Welding was then recommenced to a different sequence with block welds progressing outboard from the centreline with no spacing between them. All welding was conducted using the back step method. The length of the blocks was adjusted to suit the local distortion and allow for gentle corrction of edge misalignment. Welding was stopped short of the radius corners which were left free to move. By this method edge misalignment was kept well within permisable levels. The forward butt was then treated similarly. The block welds were welded to approximately 1/16 th of an inch below the external surface.

Throughout this operation the longitudinal seams and the entire plate were monitored for evidence of distortion. Non was detected.

After the outboard block welding of the transverse butts had been completed the block welding of the longitudinal seams was then commenced following a sequence which involved block welding at the mid length positions and then stepping along the seams fwd and aft at varying intervals to further block weld. The length of block welds was adjusted to suit the plate edge misalignment being permitted. In some cases block welds of 4 ft in length were used. Very little plate edge misalignment occured at any of the welds, and the existing peaking at the longitudinal weld seams was eliminated by adjusting of the weld locally to pull the plate edges slightly down.

The important thing to appreciate here is that as a result of continual interaction between the Customer and representatives of the Contractors Technical, Production and Quality departments a difficult task was successfully undertaken and the resulting fit and installation of the plate was achieved within the standards to the best level that could be achieved.

Concurrently with the block welding of the longitudinal seams the fwd and aft transverse butts were prepared for overhead welding. More extensive grinding than anticipated was required at the fwd and aft butts to remove any slag and to prepare an acceptable weld prep. This was mainly due to misalignment of the opposing noses of the weld prep caused mainly by the way the plate had been trimmed down into the opening and also by the pre existing distortion. A better fit up less grinding was required on the overhead weld prep of the longitudinal seams. No visual evidence of root cracking was noted. The amount of work required on the inboard weld prep using the ceramic strip was far less than would have been required using the old style weld preparation.

Welding was then commenced inboard with the aft and fwd butts first and then the longitudinal seams port and stbd following the same sequence. On completion of these welds the outboard capping runs were undertaken.

It is interesting to note that the welding sequence subsequently used was very similar to that recommended in DNC 2, which is a fabrication code which long preceded NES 706 and had a specific section regarding installation of closure plates to submarines.

Once the butts and seams had been fully welded the plate was welded to the frames following a set sequence. As the plate fitted the shape very well there was no problems experienced with distortion or high stress levels.

Any outstanding welding on the insert pads was then completed. The butts and longitudinal seams were then X-rayed and approximately 5% to 7% of the total length of weld contained defects, which is a relatively low defect percentage for stick welding under non ideal conditions.

The defects ranged from linear slag inclusions to scattered porosity on the capping runs inboard. There was no evidence of root cracking or of lack of root fusion. In some instances the linear slag inclusions were at the root runs onto the ceramic strip. This was always at an area where the original preparation profile had not been correctly shaped , i.e the root faces did not align correctly, and in most cases occured at the forward and aft butts. All other linear inclusions were adjacent to other later runs of weld. In most cases the presence of the linear inclusions occured because the slag had not been properly ground out. They were in general very thin faint lines of slag. The main contributing factor to this was that the during the consolidation of the plate to the submarine it was announced that the dockyard would be closed at an unknown future date. Hence it was difficult to maintain a high level of motivation with all men involved on the job. All weld defects were repaired.

On completion of all weld repairs the final set of circularity readings were taken. When the author left the dockyard on being transferred back to Navy Office , the dockyard had commenced the arduous task of repairing the tops of the main ballast tanks, and the keel box structure due to all the access openings cut for taking the circularity readings. On completion of this task they will then commence to replace all the foundations and settings for the equipment mounted on the hull externally above the engine room.

The standard of workmanship over all was of a very high quality, and is a credit to all the tradesmen and supervisors involved in the work.

CONCLUSION

In conclusion it can not be stressed to highly that major military and commercial projects can only be successfully completed in Cost, Time, and meeting all the specified requirements of the Customer if there is close interaction between all parties concerned in the project.

It is particularly important for the Customer to fully understand the contents and intent of the documents they have specified in the contract and the standard of workmanship and specific material / mechanical properties required for the contracted work. The Designer/ Customer must ensure that the specifications quoted are in the content of ` Fitness for Purpose'. Far too often in both military and commercial projects a standard of workmanship or a particular physical property or production requirement is specified far in excess of what is actually required for the application because the Designer / Customer has chosen documents and standards without proper investigation of the the contents of these documents and there suitability. Over specification should be avoided. This does not mean that an attitude of " She'll be right mate, do it how ever you want" is the correct approach. The designer / customer must understand and investigate all aspects of the documents he intends to specify and determine exactly what are the mandatory requirements to fit the function and factors of safety of the piece of equipment or structure to be fabricated. It is then the responsibility of the Customer to interact actively with the Contractor to pass on this information so that all parties are working to a common interpretation. This is vitally important where documents which are part specfication part guidance document are used.

This does not mean that the Contractor is absolved from all responsibility in interpretation of documents. The Contractor has equal responsibility with the Customer in reaching a common interpretation of the requirements. The Contractor should always question the Customer when their is any possibility of miss interpretation of the details of a specification, or even in some cases the overall design philosophy if from their experience some factors appear deficient or over specified. Once a common interpretation has been achieved it is the Contractors responsibility to ensure that the necessary information filters down to all levels of personnel involved in the project as required and that the Quality Control system can actively assure the Customer that the specified requirements have been met.

It is far to late after a job has been completed or unneccessary cost overruns have occured for both parties to realise thta there has been a difference of interpretation or too high/ low a standard has been specified.

In the renewal of the pressure hull plating in way of the Engine Room Closure plate of HMAS OTWAY every effort was made by various representatives of the Production Department of the Contractor and the author, who was acting as the representative of the Design Authority and the Quality Assurance Representative, to ensure that a common interpretation and understanding was acheived. It did not always occur, but it showed what can be achieved when difficult problems have to be surmounted and also, in this case the work undertaken was the largest submarine pressure hull repair undertaken in Australia. To achieve a high level of interaction between the Customer and the Contractor takes a lot of hard work and time but it is a form of active Quality Assurance which should be aimed for in all military and commercial projects big or small.

REFERENCES

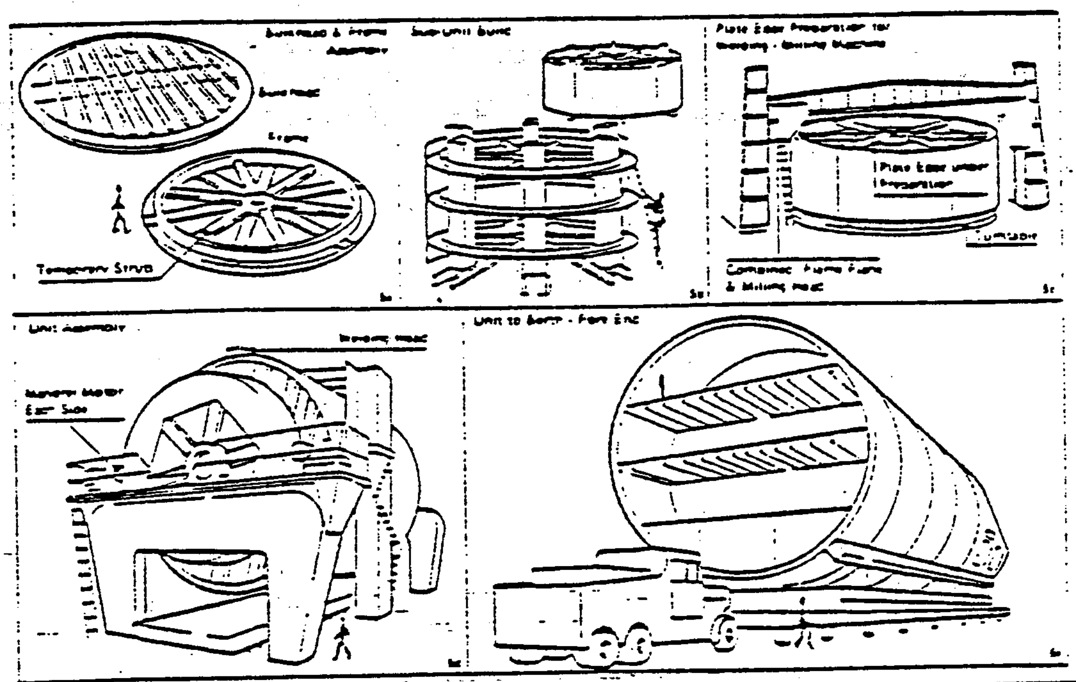
1. MODERN SUBMARINES - SHIPBUILDING ASPECTS by Mr W. RICHARDSON CBE, DL, C.ENG, FRINA, CBIM, F. INST. D. DEPUTY CHAIRMAN BRITISH SHIPBUILDERS

2. STATEMENT OF WORK FOR THE REPAIR/RENEWAL OF THE ENGINE ROOM CLOSURE PLATE - HMAS OTWAY.

3. ENQUIRY CASE No 5500/33 AUGUST 1981 TO BS 5500 1976 - THE VERIFICATION OF SHAPE OF VESSELS SUBJECT TO EXTERNAL PRESSURE

4. NAVAL ENGINEERING STANDARD 706 - WELDING AND FABRICATION OF SHIP STRUCTURE

5. NAVAL ENGINEERING STANDARD 769 - WELDING CONSUMABLES FOR STRUCTURAL STEELS APPROVAL SYSTEMS

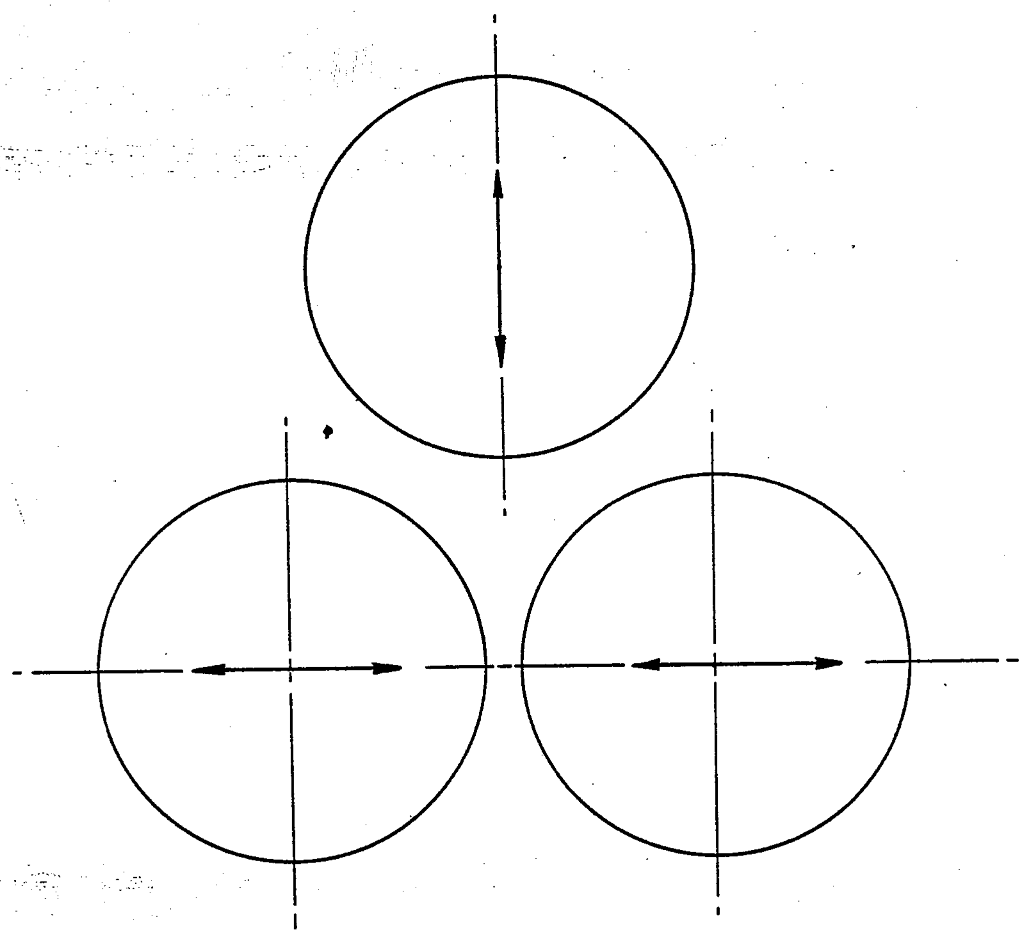


SKETCH 1

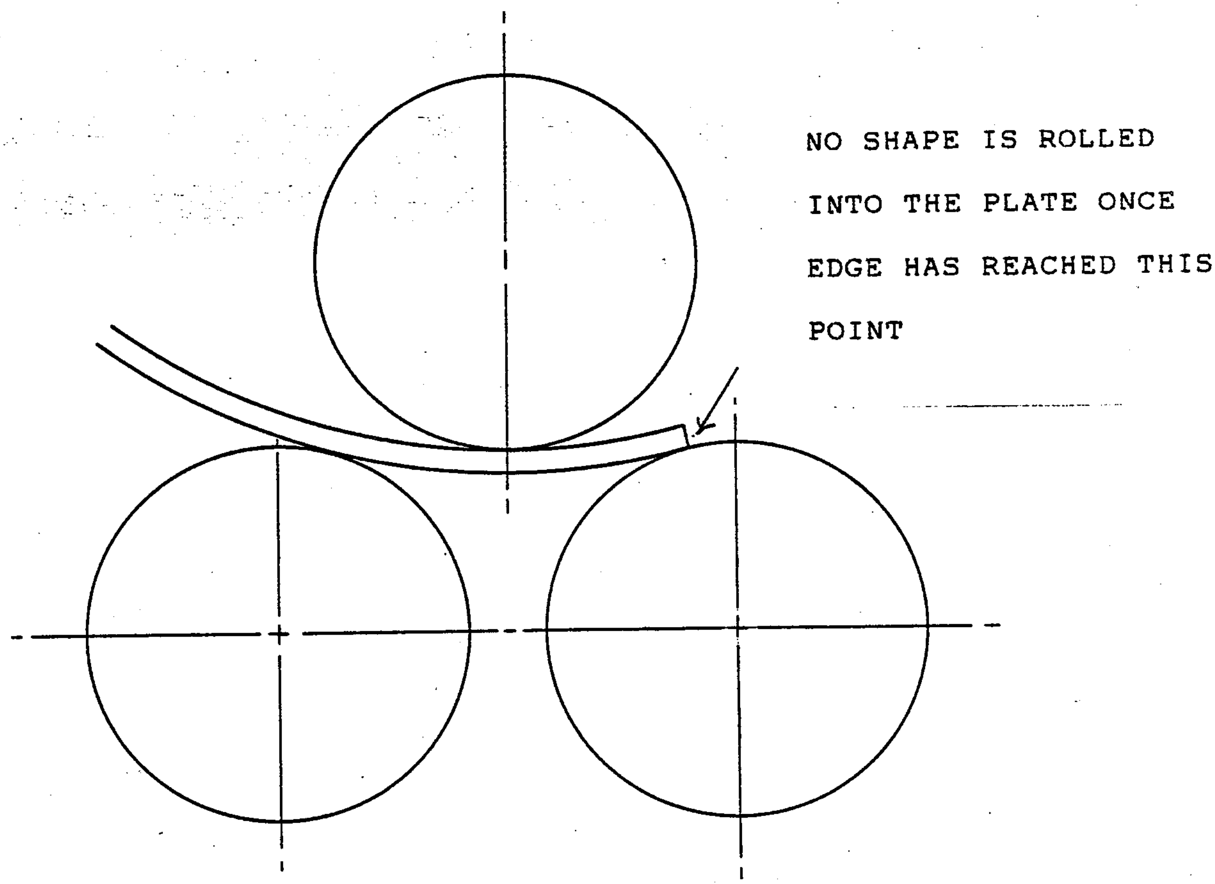
NORMAL METHOD OF PRESSURE HULL 'HOOP' FABRICATION

IN BRITISH SHIPYARDS

Extracted from Reference 1

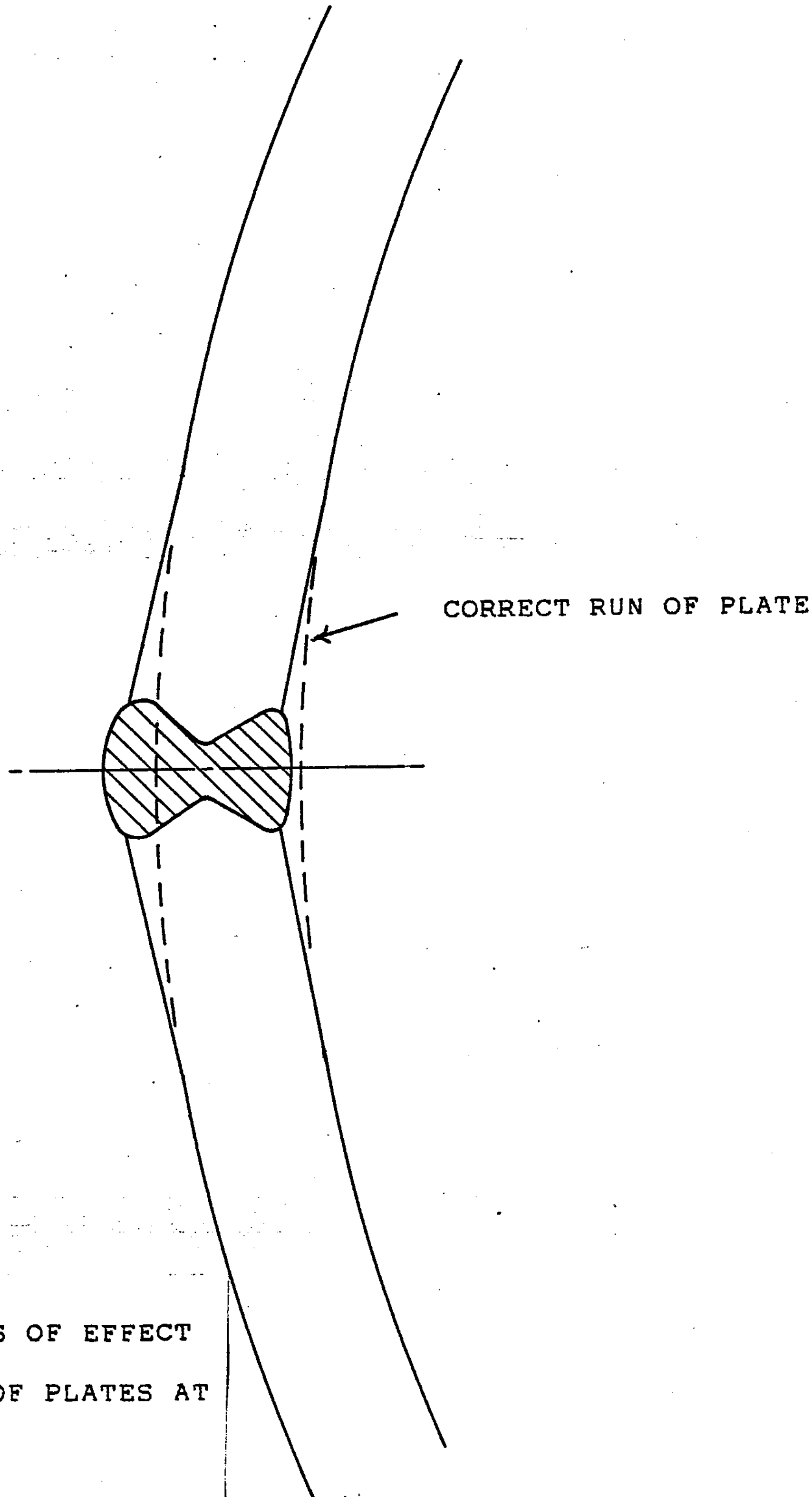


SKETCH 2 - NORMAL OPERATION OF A SET OF PLATE ROLLS TOP ROLLER CAN MOVE VERTICALLY, BOTTOM ROLLERS MOVE HORIZONTALLY.

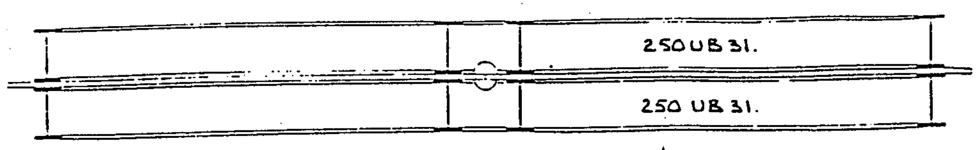


SKETCH 3 OPERATION OF PLATE ROLLS

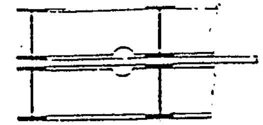
SHOWING HOW FLATS OCCURED IN PLATE



SKETCH 4 DETAILS OF EFFECT OF FLATS IN EDGES OF PLATES AT LONGITUDINAL SEAMS

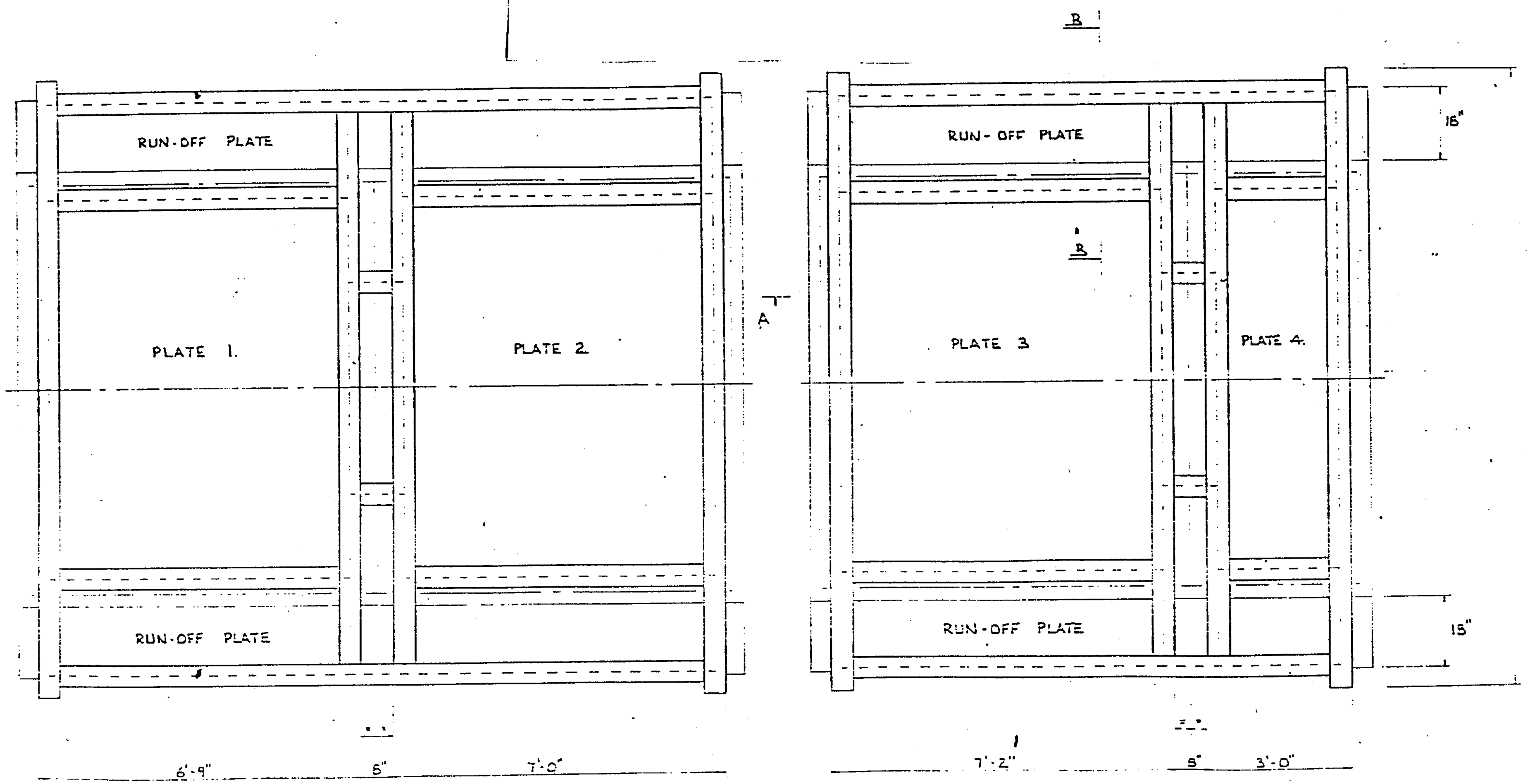


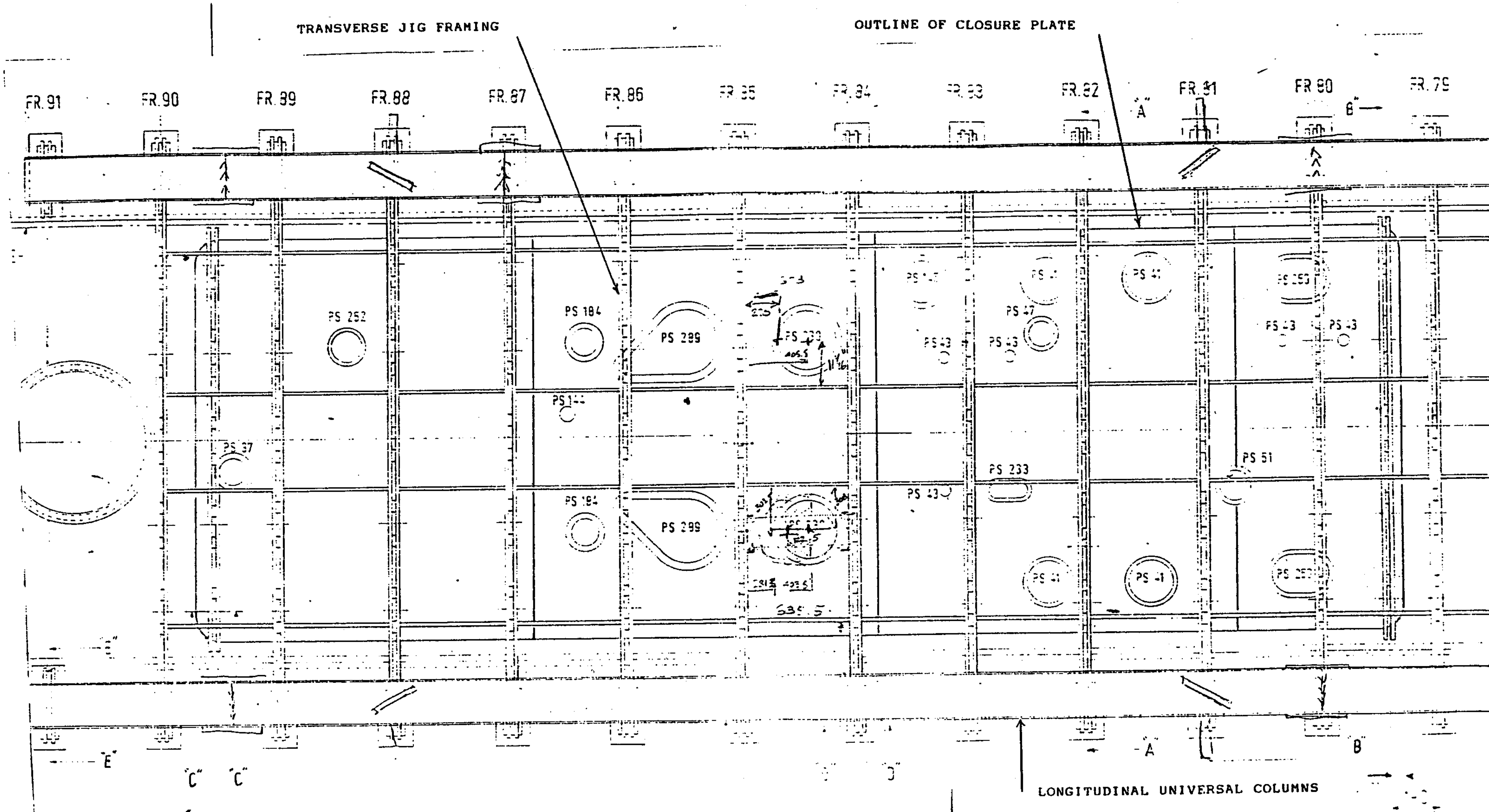
ELEVATION 'A-A'



SECTION 'B-B'

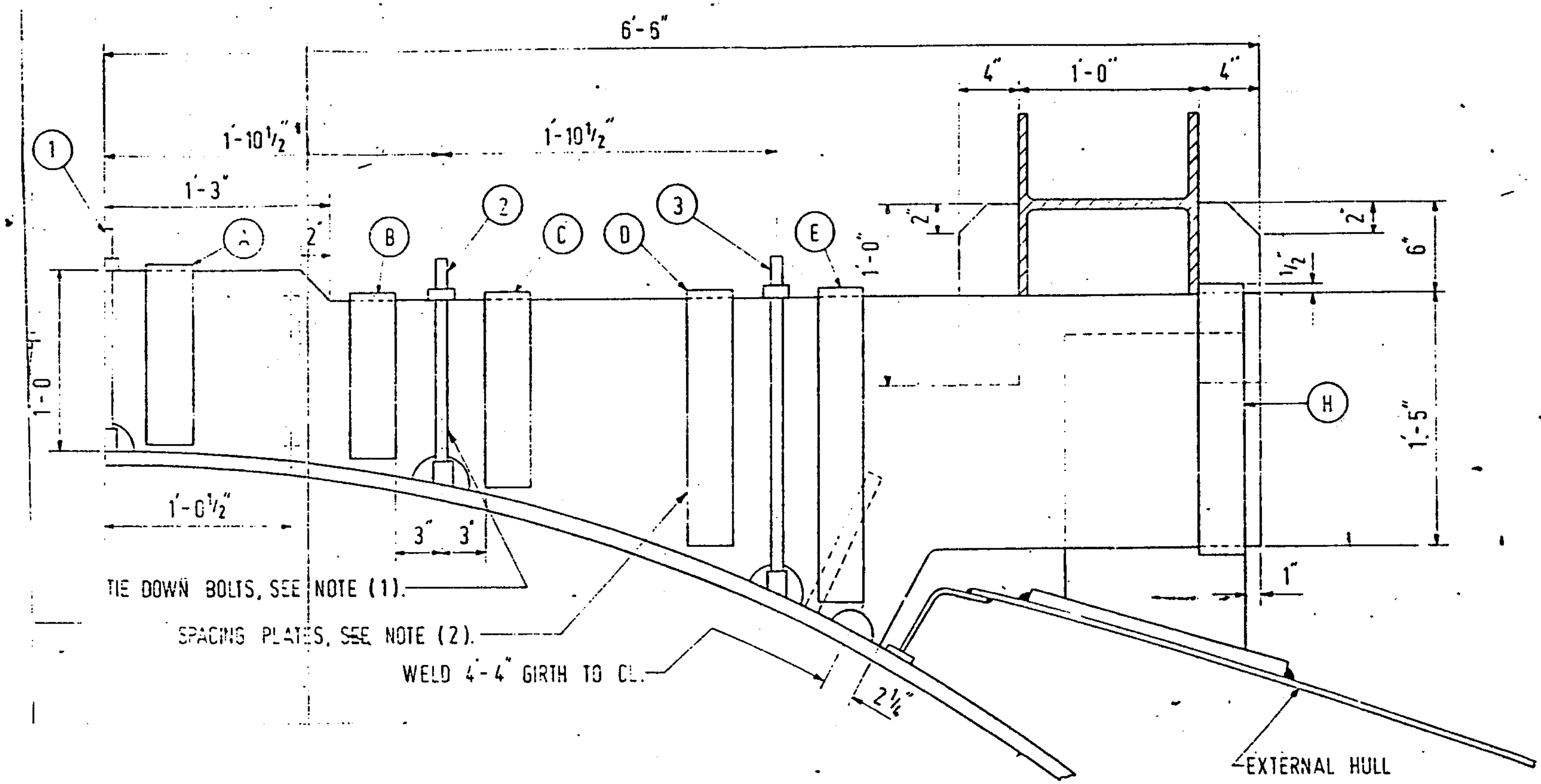
SKETCH 5 DETAILS OF JIG MANUFACTURED TO KEEP PLATE FLAT DURING WELDING OF PLATE SEGMENTS



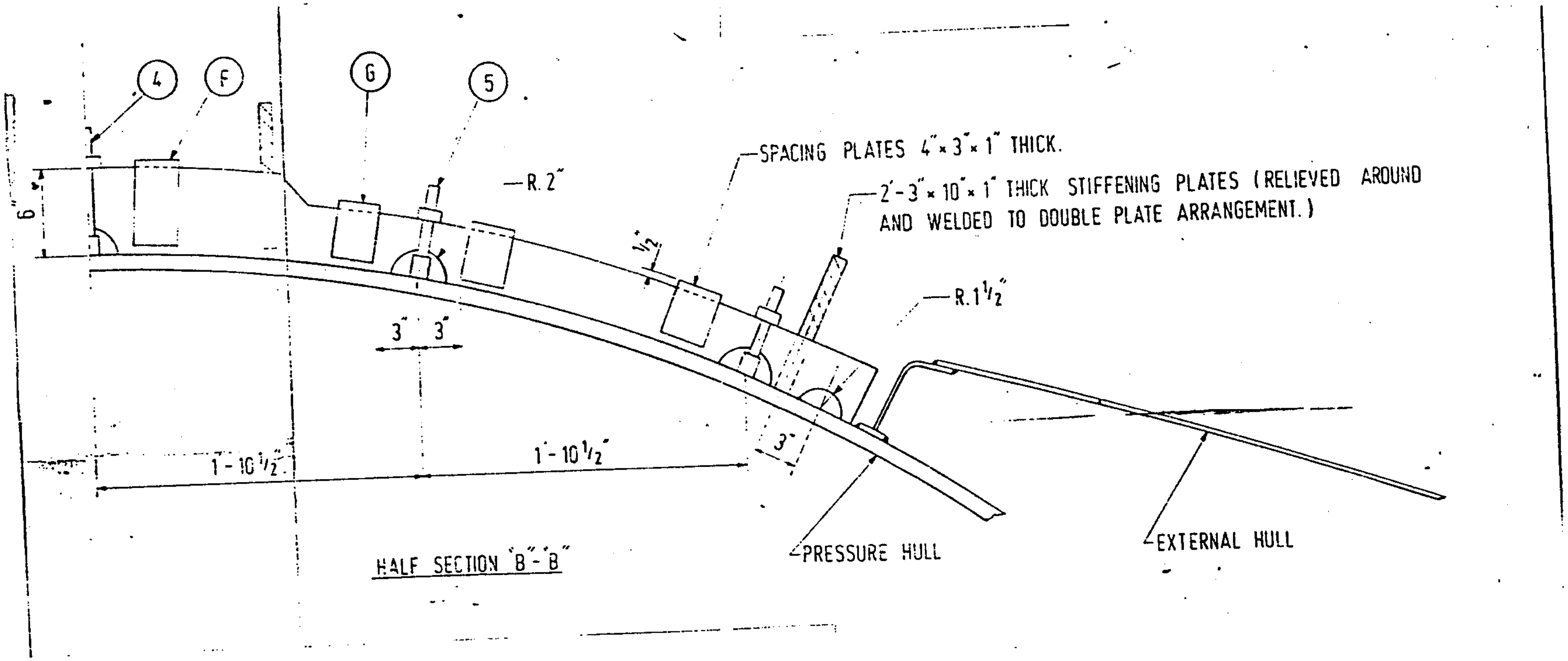


SKETCH 6 DETAILS OF MAIN FEMALE JIG

PLAN VIEW



SKETCH 7 DETAILS OF MAIN FEMALE JIG



(3) WHERE ANY PLATES OF THE JIG PASS OVER ANY PRESSURE PADS, SUITABLE CLEARANCE IS TO BE CUT OUT OF THE PLATE.

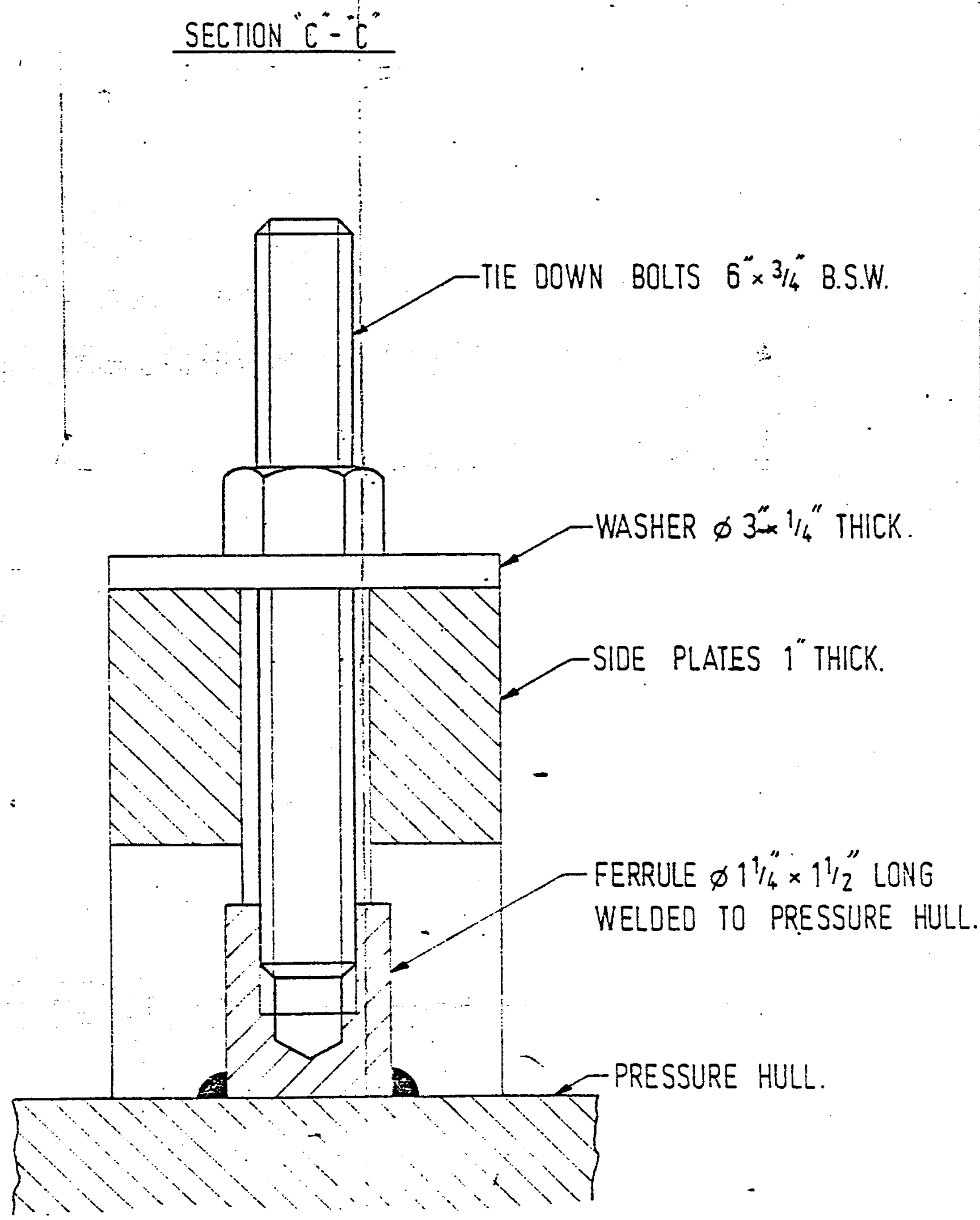
(4) ALL MATERIAL FOR JIG TO BE OUT OF MILD STEEL.

(5) ALL WELDING TO BE I.A.W. 706.

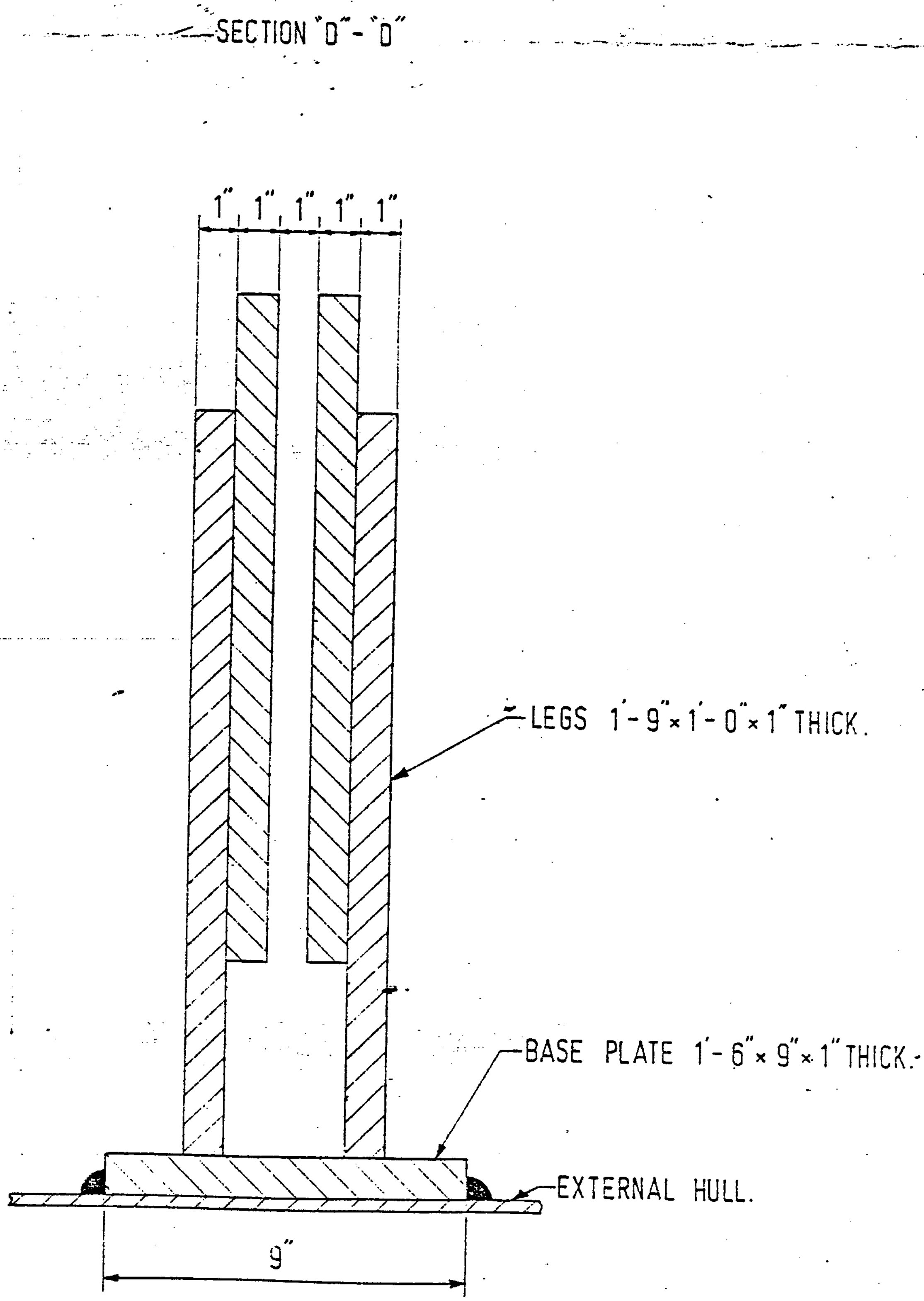
SKETCH 8 DETAILS OF MAIN FEMALE JIG

HALF SECTION SHOWING JIG FRAMING

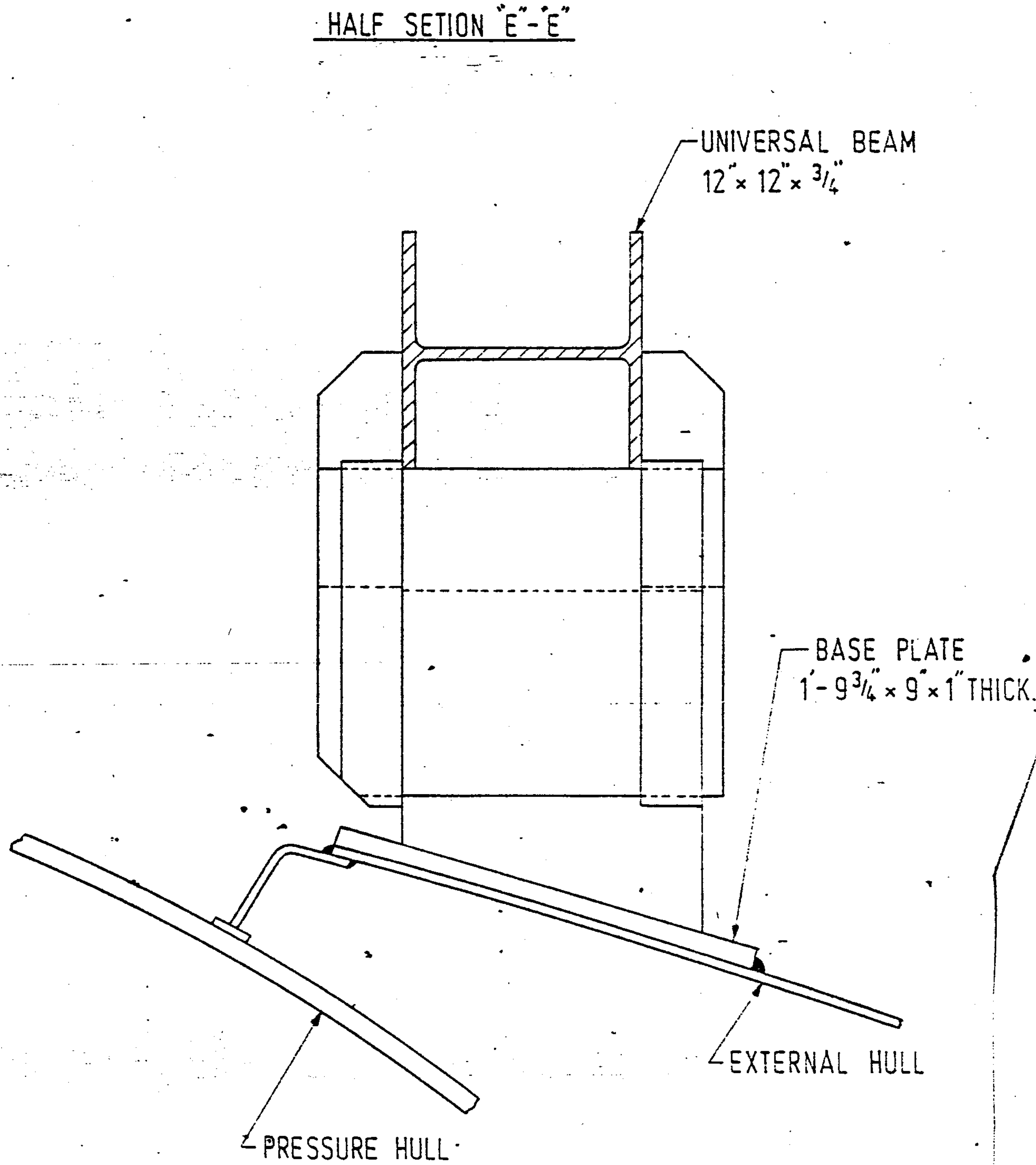
IN WAY OF END TRANSVERSE BUTT WELDS



SKETCH 9 DETAILS OF MAIN FEMALE JIG

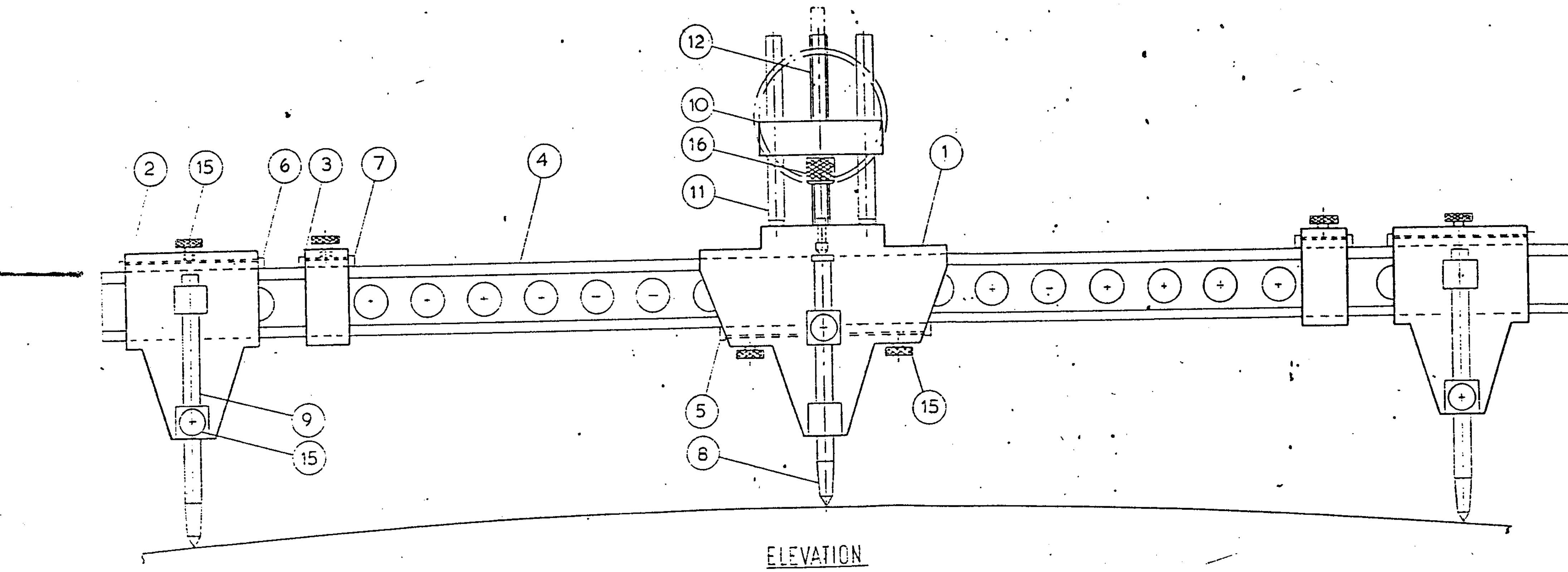


SKETCH 10 DETAILS OF MAIN FEMALE JIG

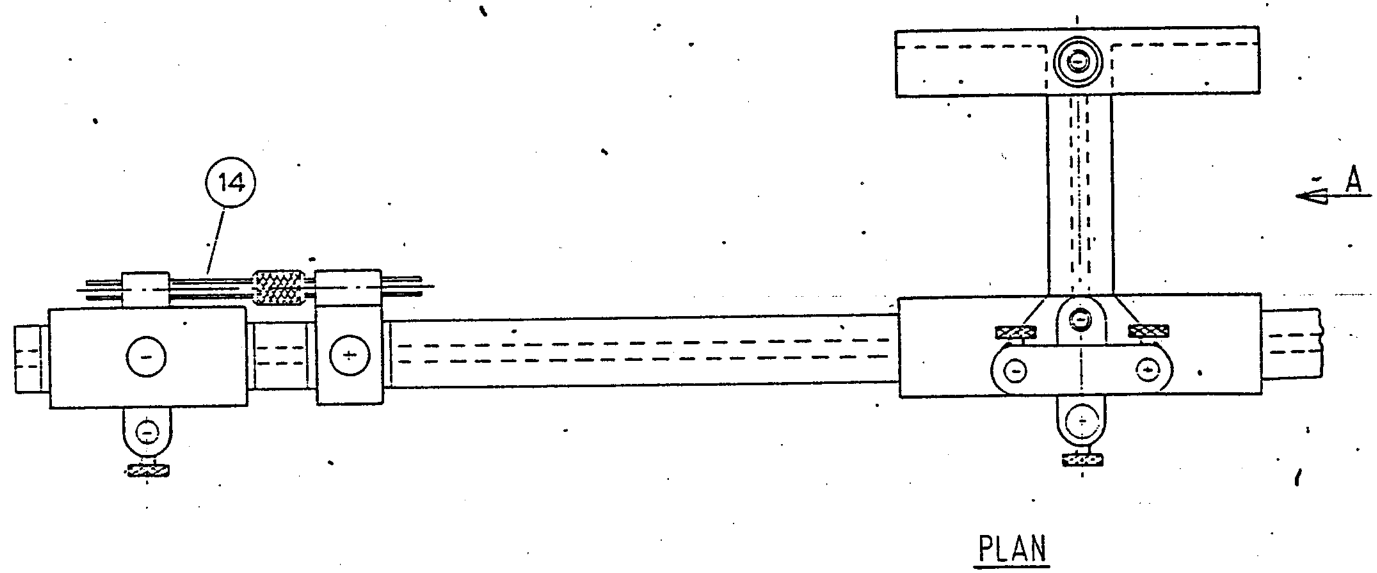


SKETCH 11 DETAILS OF MAIN FEMALE JIG

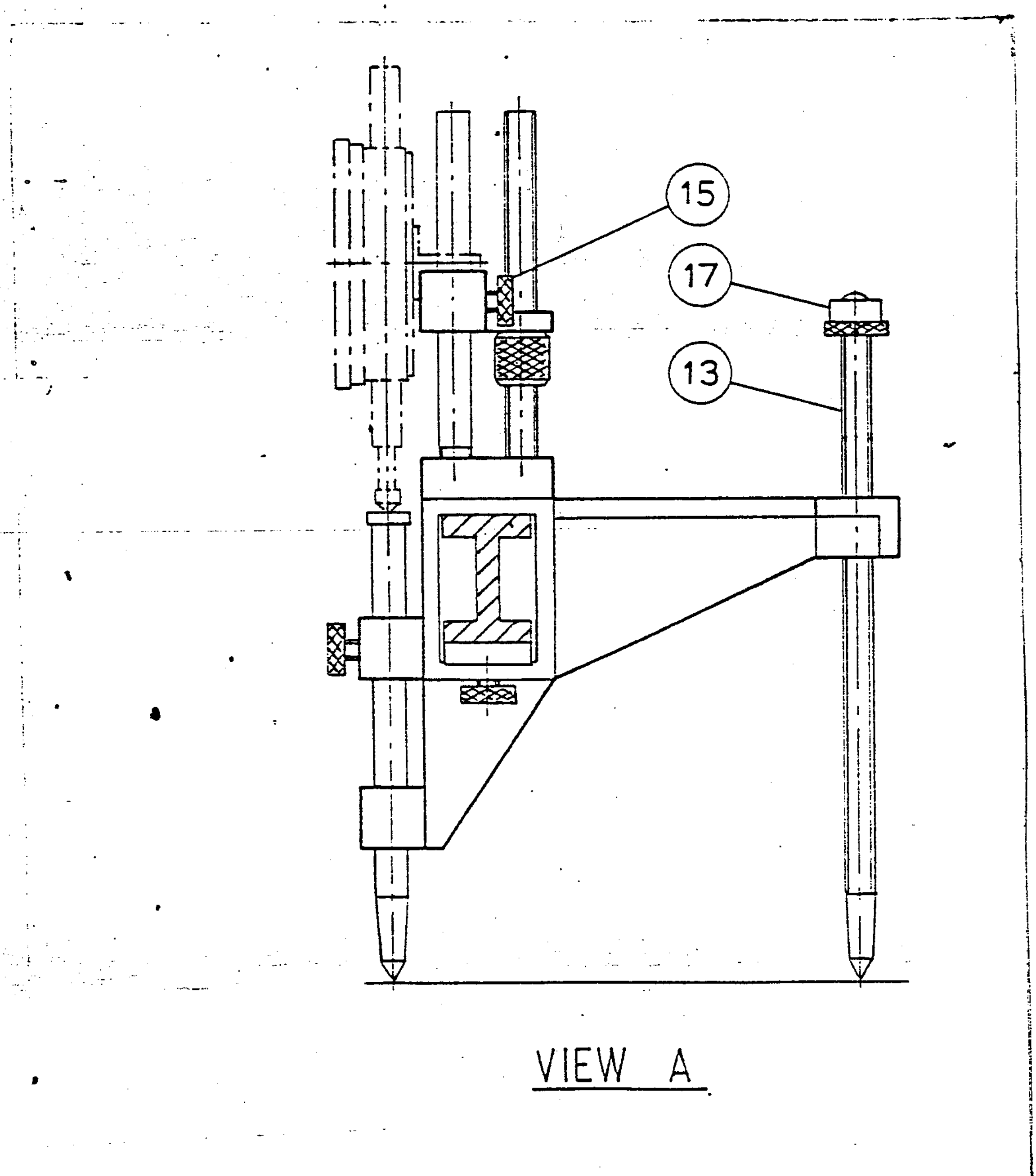
SUPPORT FOR JIG ON SURROUNDING HULL



SKETCH 12 DETAILS OF CHORD GAUGE



SKETCH 13 DETAILS OF CHORD GAUGE



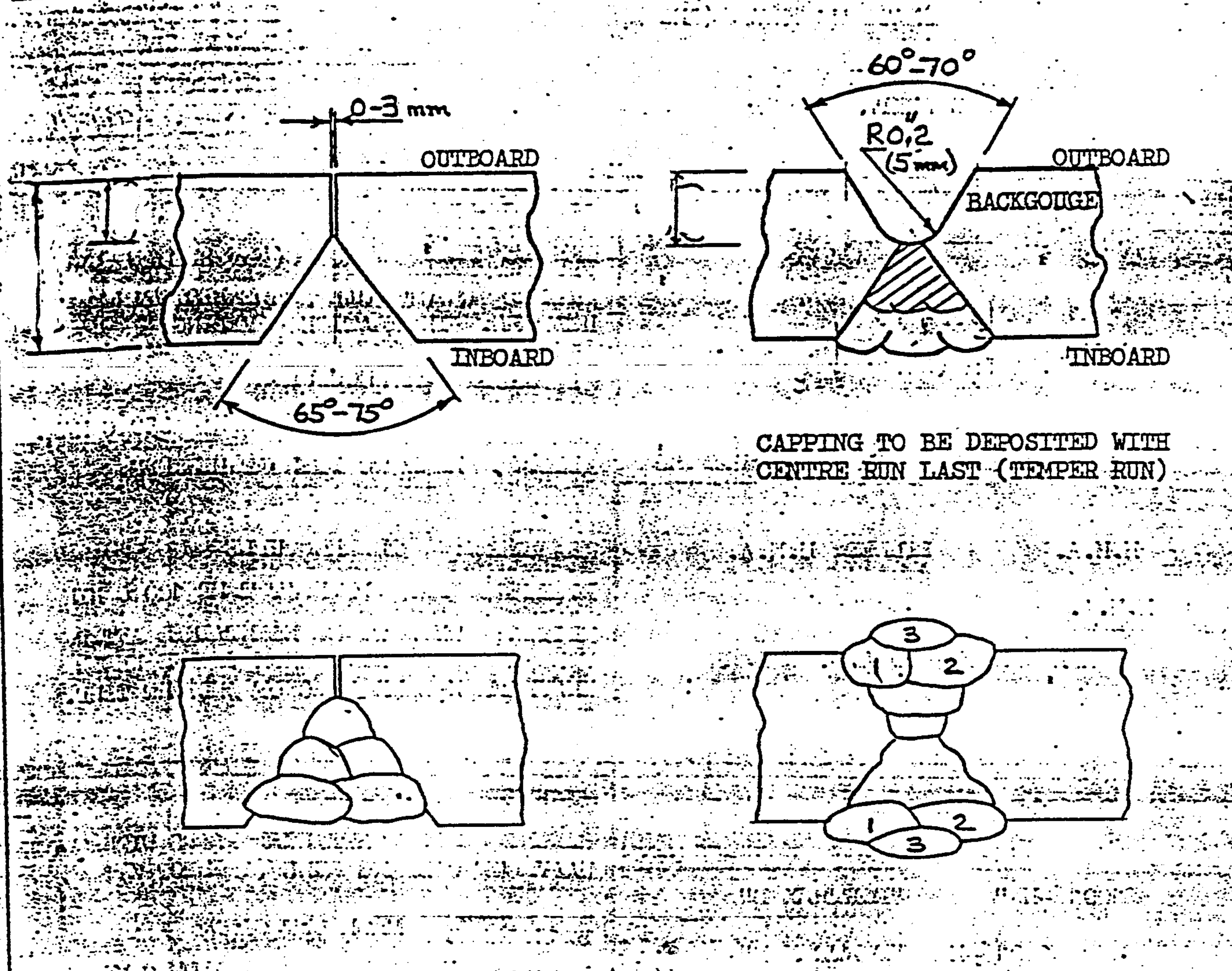
SKETCH 14 DETAILS OF CHORD GAUGE

JOINT DESIGN

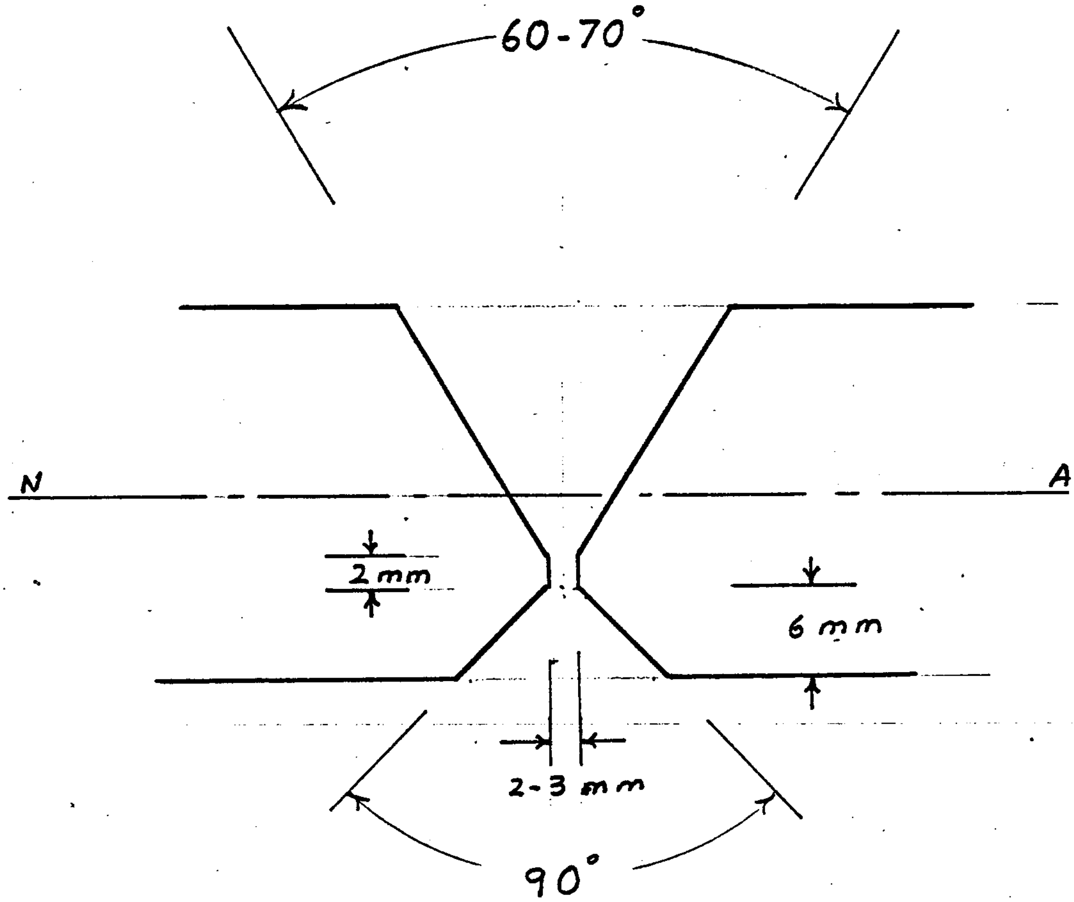
JOINT: SINGLE VEE BACKING STRIP: NONE

PREPARATION: PLANING/OR GAS TORCH FOLLOWED BY GRINDING MATERIAL: N/A

SKETCH (PROFILE, BEAD SEQUENCE, WELDING SEQUENCE)



SKETCH 15 DETAILS OF NORMAL WELD PREPARATION USED ON PRESSURE HULL PLATE



SKETCH 16 DETAILS OF WELD PREPARATION FOR USE OF CERAMIC BACKING STRIP. THE CERAMIC TILE WHICH IS MOUNTED ON AN ADHESIVE BACKING STRIP IS FITTED INTO THE BOTTOM 90 BEVEL AND THE ADHESIVE STRIP IS ADHERED TO THE SURFACE OF THE PLATE HOLDING THE TILE IN THE CORRECT POSITION

APPENDIX A

EXTRACT FORM THE `STATEMENT OF WORK FOR THE REPAIR/ RENEWAL OF THE ENGINE ROOM CLOSURE PLATE - HMAS OTWAY

CHAPTER 5 CICULARITY MEASUREMENTS PRIOR TO REMOVAL OF PRESSURE HULL PLATE

5.0 Circularity Measurements Prior to Removal of Pressure Hull Plate

Purpose: To take measurements around the hull in way of the relevant frames by the use of a circularity gauge (chord gauge), to enable the circularity of the hull to be computed, to ensure insert plates are replaced within the required circularity standard.

Location of Circularity Readings

5.1 Circularity Readings are to be taken at the following frames within a band 6 inches either side of the frame.

Readings at frames 90,89,87,85,83,80 and 79.

The exact location of the readings within the band for each frame will depend on results of a ship check. All circularity readings at a frame must be taken at a constant distance from the frame.

Circularity Gauge.

5.2 A circularity gauge, chord gauge, is to be fabricated in accordance with Ref F, and a chord gauge setting plate in accordance with Ref K. is to be fabricated.

Prerequisites

5.3 Blocks of docking cradle may need to be resited in way of frame(s) for circularity check.

5.4 Staging to be erected around the pressure hull at the relevant frame(s)is to be positioned to the satisfaction of the Metrology Department Officers who will be taking circularity measurements.

5.5 Access holes in external tanks and ballast boxes to be cut in accordance with Reference J. Casing, pipes and fittings to be removed in way of the relevant frame(s) to permit access of the circularity gauge.

5.6 Ballast is to be removed out of the keel ballast boxes in way of 5 & 6 Main Ballast tanks & No4CF tank and from the wings of these tanks.

5.7 Pressure hull plating in way of the frames specified in paragraph 5.1 is to be cleaned back to bare metal by chemical or mechanical means for a band extending 9 inches fwd and aft of each frame.

5.8 In case of inclement weather, suitable protection is to be rigged in way of the frames being checked.

5.9 Adequate lighting to be provided.

5.10 The position of the forward edge of the heel of the relevant frame(s) is to be identified by NDE staff using ultrasonics.

5.11 When the position of the frames has been identified, it is to be marked around the hull using waterproof yellow crayon.

5.12 Dimensional inspection room to be made available for the setting up of the circularity gauge before and after use.

5.13 Ladders to be suitably positioned within easy reach of frames being measured so that teams can climb or descend around the hull width with the calibrated gauge.

5.14 Circularity checks are to be carried out during silent hours.

5.15 No burning or welding is to be carried out in the vicinity within the 24 hours prior to carrying out circularity checks.

Precautions:

5.16 Care must be taken when cleaning the pressure hull plating back to bare metal to avoid damaging the plating.

5.17 Openings, fittings etc to be protected during removal of pressure hull coating.

5.18 Staging is to be kept clean and clear of all paint and rubbish.

5.19 The bare surfaces of the hull are to be protected until DNSD have accepted results.

5.20 No holes are to be cut in the pressure hull until DNSD have indicated acceptability and SNA (PNO staff) is satisfied that all pre-requisite action has been satisfactorily completed.

5.21 The results of all circularity readings are not for general distribution or discussion and are to be classified "confidential".

Procedure in the Dimensional Inspection Room.

5.22 The design moulded measurements of the frame(s) to be checked are taken from the table of offsets.

5.23 The design chordal height information is obtained from Ref K

5.24 Use the chord gauge setting plate to set the end pointers of the circularity guage to the chord length for 48 readings.

5.25 Centre the chordal height pointer and using the block gauge related to the design offset radius for the section and the number of readings, zero the dial on the circularity gauge and secure by clamping (this procedure is most important and should be double checked before proceeding to ship).

Procedure at ship for each circularity location.

5.26 Measure at top of hull to establish TDC of vessel. Check wi a dummy trammel (batten with three pointers) around the hull over the 48 positions for any obstructions or indentations. If necessary move the start point to port or starboard, aft or fwd within 6 inch band either side of the frame(s), to establish clearance around the hull form. The start point is to be marked on hull. The start point distance away from the Top Dead Centre and the distance away from each frame are to be measured and recorded on the record sheet.

5.27 A line parallel to each frame is to be marked on the pressure hull using yellow crayon at each clearance distance determined in paragraph 5.24.

5.28 Place one end pointer of circularity gauge on position 1 determined in paragraph 5.24 and lower the other end pointer to the hull. Read off clock gauge reading at mid point (position 2) mark off hull at clock gauge (position 2) and end pointer (position 3). See sketch page 9. The chord height = gauge block thickness plus clock gauge dial reading.

5.29 Lift beam carefully away, move half a chord length and position end pointer on position 2. Read off clock gauge reading at position 3 and mark position 4. (See sector detail - 2nd position on page 9). Continue in this way until 48 readings are obtained, taking care at all times not to alter the pointer positions or clock gauge when handling circularity gauge around staging etc. The offset pointer on the circularity gauge can be used to keep the gauge normal to the hull.

5.30 The gauge may be used in way of inserts of hull plating of increased thickness (not hull pads) in the normal way but the position of these insert plates etc must be recorded on the standard form.

5.31 On completion of the 48th reading, the girth error is to be less than or equal to ±3/8 of an inch. Should the girth error be outside this tolerance - the measuring of the hull will have to be repeated. Before remeasuring, the circularity gauge must be checked in the Dimensional Inspection room to establish that the pointers have not moved, then the distance between them is to be reduced or increased so that the girth error falls within the tolerance span.

5.32 The circularity gauge when adjusted should then be taken back to ship and the check repeated.

WARNING

5.33 It is vital that 48 connected readings are obtained and the girth error is less than ± 3/8 of an inch. Failure to obtain the 48 readings and good closure will completely abort the circularity check and the readings will only give local bumps in the hull.

Reporting and Processing Procedure

5.34 Having recorded readings at ship, add the constant block gauge readings, as shown by the following example:-

Chordal height recorded at ship	= 0.5223
Add the constant block gauge reading	= 1.25
Final result is	= 1.7723

This applies to all 48 readings

5.35 The results, position where readings are started; state of hull; position of inserts or plating of increased thickness; and girth error at completion of readings are to be recorded on sheet.

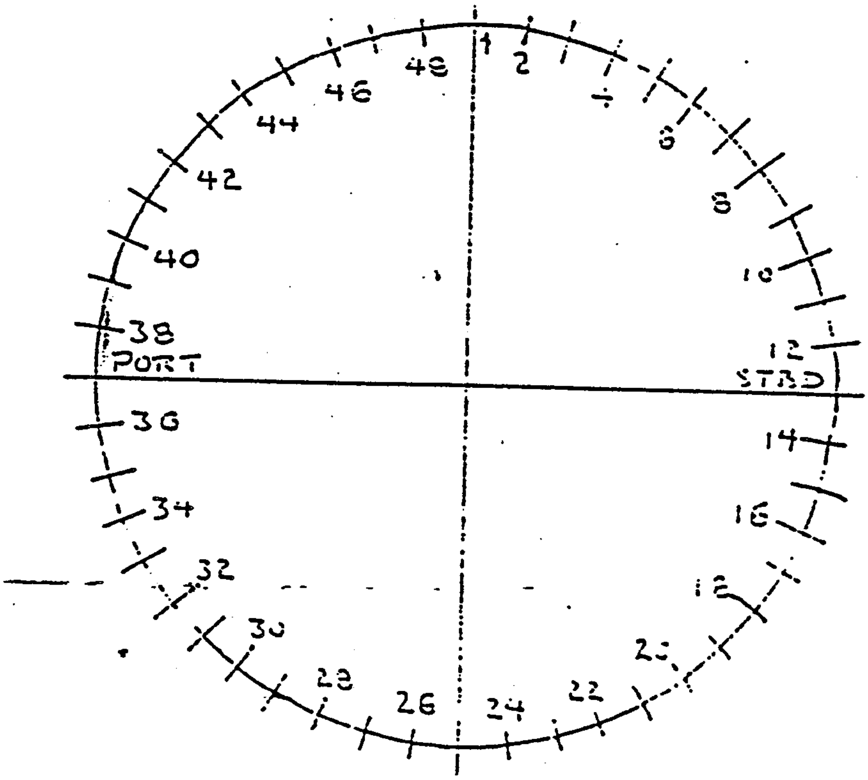
5.36 Immediately on completion of the circularity record sheets they are to be handed to SNA (PNO) who will forward them to DNSD for processing.

5.37 The results are to be processed in accordance with procedure detailed in Annex C, and analysed by DNSD (SPDM) to check that contours do not deviate from the mean circles than by the amounts specified for class. DNSD will plot results in standard format as shown in page 10.

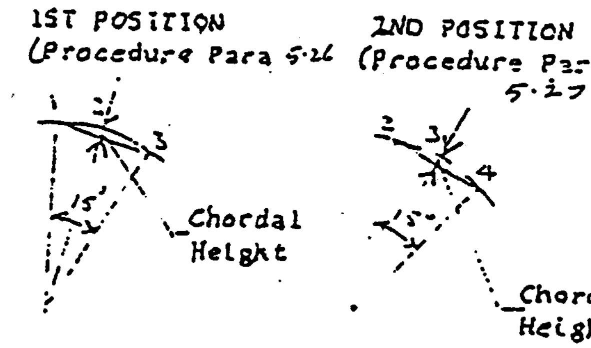
5.38 On completion DNSD SPDM, or his delegated representative will immediately inform the Dockyard via SNA (PNO) if further measurements are necessary or if they are acceptable.

5.39 The dockyard will retain re-measurement facility until DNSD have accepted results. Notification will be given to the Dockyard within 3 days of receipt of circularity records.

5.40 All records are to be held until DNSD notification has been received that results have been accepted.



Sector Detail



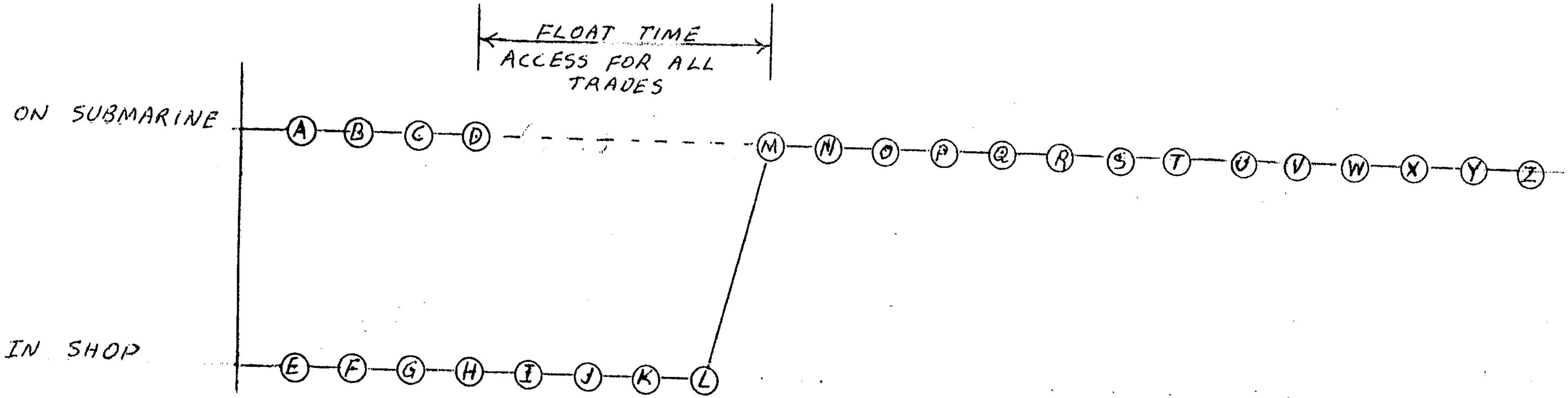
NOTES:

1. The 48 Sectors to be pitched off from Sector No 1 and the girth error at completion of sector 48 to be less than $\pm \frac{3}{8}$"

2. The readings are taken around the normal outside of shell. all inserts outside of this line to be indicated on the sector diagram.

APPENDIX B

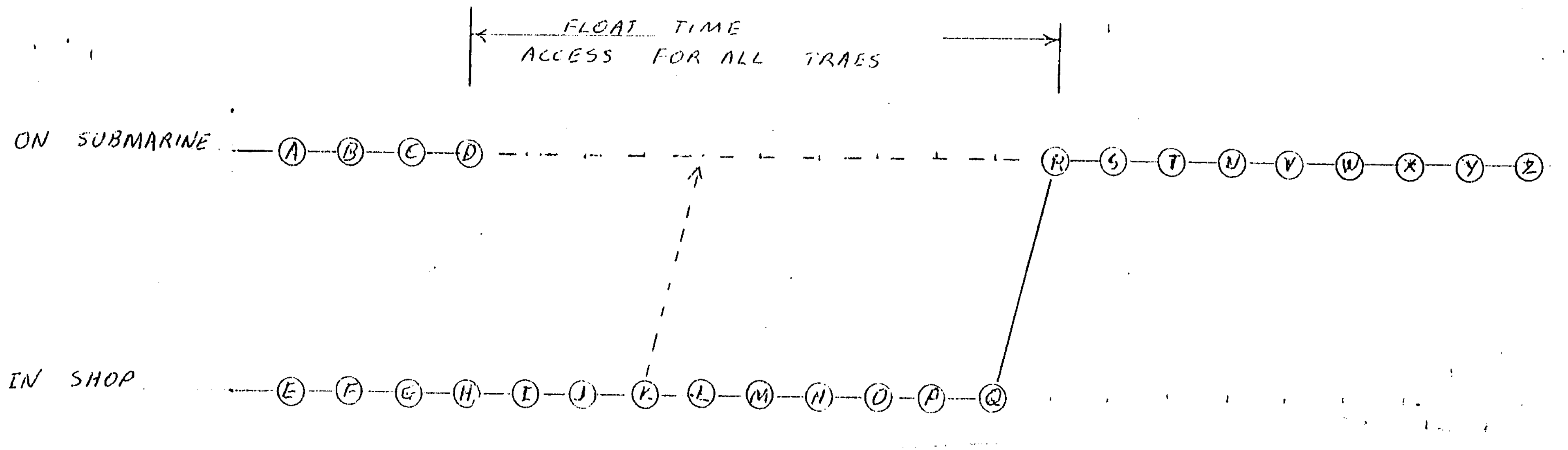
SCHEMATIC OF SINGLE STREAM METHOD OF PRODUCTION



A	MARK OUT CUT LINE ON SUB
B	REPAIR DAMAGE TO FRAMES
C	PREPARE PLATE EDGES
D	BUILD UP FRAMES
E	MARK OUT NEW PLATE
F	PREPARE EDGES TRANSVERSE BUTTS
G	INSTALL IN JIG
H	WELD PLATES TOGETHER-LONG FLAT PLATE
I	NDE WELDS
J	REMOVE FROM JIG AND ROLL PLATES
K	INSTALL ROLLED PLATES IN JIG
L	NDE PLATE EDGES LONG SEAMS
M	FIT PLATE TO SUBMARINE
N	PREPARE PLATE EDGES
O	NDE WELD PREP
P	PREHEAT PLATE
Q	WELD END BUTTS AND LONG SEAMS
R	NDE WELDS
S	WELD PLATE TO FRAMES
T	NDE FRAME WELDS
U	WELD CAPPING RUNS TO 3 TRANSVERSE BUTTS
V	NDE CAPPING RUNS
W	INSTALL 26 INSERT PADS
X	PREPARE INSERT PAD WELDS FO NDE
Y	NDE INSERT PADS
Z	REPLACE INSERTS IN PRESSURE HULL FRAMES

APPENDIX C

SCHEMATIC OF TWO STREAM METHOD OF FABRICATION



A MARK OUT CUT LINES ON SUB AND REMOVE OLD PLATE
B REPAIR ANY DAMAGE TO FRAMES
C PREPARE PLATE EDGES ON SUB
D BUILD UP FRAMES WHERE NECESSARY

E MARK OUT AND CUT NEW PLATES
F PREPARE PLATE EDGES AND NDE
G INSTALL PLATES IN JIG 1
H WELD PLATES TOGETHER FORM LONG FLAT PLATE
I NDE WELDS
J REMOVE FROM JIG AND ROLL PLATE
K INSTALL PLATES IN MAIN JIG
L PREHEAT PLATE IN WAT OF INSERTS AND CAPPING RUNS
M WELD CAPPING RUNS TO TRANSVERSE BUTTS
N NDE WELDS
O CUT HOLES PREPARE EDGES AND INSTALL ALL INSERT PADS
P PREPARE WELDS FOR NDE
Q NDE ALL INSERT PAD WELDS

R FIT PLATE TO SUBMARINE
S PREPARE PLATE EDGES OF END BUTTS AND LONG SEA
T NDE WELD PREP
U PREHEAT PLATE IN WAY OF INSTALLATION WELDS
V WELD PLATE TO HULL
W NDE WELDS
X WELD PLATE TO FRAMES
Y NDE FRAME WELDS
Z REPLACE INSERTS IN FRAMES

APPENDIX D

DETAILS OF WELDING PROCEDURE PREPARED BY THE WELDING ENGINEER OF COCKATOO DOCKYARD PTY LTD FOR CONSOLIDATION OF ENGINE ROOM CLOSURE PLATE HMAS OTWAY

P.N.O.

COCKATOO DOCKYARD PTY LTD

WELDING PROCEDURE SPECIFICATION

CLIENT/DESCRIPTION CROWN PLATE INSERT
PLATE TO PLATE (INSERT)

SPECIFICATIONS NES 706; NES 769;
D G SHIPS 10000B; D G SHIPS 234B.

W.P.S. No. S96

P.Q.R. No.

APPROVAL	SIGNATURE	DATE
WELD.ENG.	[signature]	07/11/86.
CLIENT	[signature]	19/12/86

BASE MATERIAL

TYPE: QT 28 TO: QT 28

GROUP No: 1 TO: 1

THICKNESS:

OTHER:

PROCESS

ROOT: M.M.A. FILLER: M.M.A.

CAP: M.M.A.

MACHINE: LINCOLN TM 400 A.C. WELDER

OTHER:

FILLER MATERIAL/CONSUMABLES

ELECTRODE:	TYPE	GROUP No/TRADE NAME
ROOT:	E10016-M	"FORTREX B"
FILLER/CAP:	E10016-M	"FORTREX B"

OTHER: BAKE AT 400°C FOR 2 TO 3 hrs. AFTER HOLD AT 150°C. ON JOB TO BE KEPT IN QUIVERS AT 150°C.

FLUX (S.A.W. ONLY)

TYPE: N/A

SIZE: N/A

GASES

SHIELDING: NONE

FLOW RATE: N/A

BACKING: NONE

FLOW RATE: N/A

OTHER: N/A

WELDING POSITION

POSITION OVERHEAD (INBOARD) FLAT (OUTBOARD)

PROGRESSION: BACKSTEP WELDING

HEAT TREATMENT

PREHEAT TEMP: 100°C (4hr BEFORE WELDING)

METHOD: ELECTRICAL STRIP RESISTANCE HEATERS. INSULATION COVERING.

MEASURING: THERMOCOUPLE

INTERPASS TEMP: 100°C MIN - 250°C MAX.

METHOD: KEEP TO PREHEAT MINIMUM.

MEASURING: THERMOCOUPLE

POSTHEAT TEMP: PREHEAT TEMP 100°C MIN

METHOD: THIS TO BE MAINTAINED AFTER WELDING FOR 4 HR. THEN COOLED UNDER INSULATION TILL 30°C OF AMBIENT TEMP.

TECHNIC

STRING/WEAVE: STRINGER BEADS WITH SLIGHT WEAVE OF CAPPING RUNS (2xELECT Ø)

BACK GOUGE: FROM OUTBOARD

METHOD: ARC AIR GOUGE FOLLOWED BY GRINDING

ELECTRODE STICKOUT: N/A

TORCH TYPE: N/A

WIRE FEED ANGLE: N/A
(LEAD OR TRAIL)

TORCH POSITION:

GAS CUP SIZE: N/A

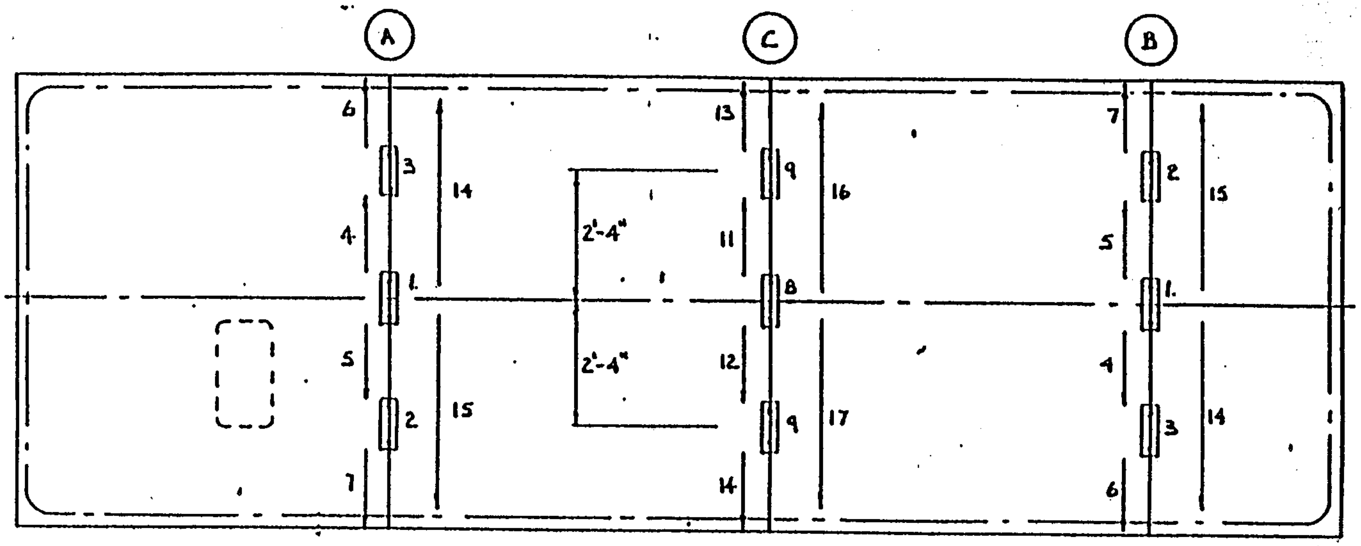
INTERRUN CLEANING: STAINLESS STEEL WIRE BRUSH AND CHIPPING HAMMER AND/OR GRINDING

DISTORTION CONTROL: SEQUENCE WELDING SEE ATTACHED SHEET.

OTHER: WELD INBOARD FIRST AND GOUGE OUTBOARD. SEE ATTACHED SHEETS.

SEQUENCE FOR WELDING PLATE SEGMENTS

INBOARD FACE



FOR INSERT SEQUENCE SEE PAGE No 5

WELD PREP SIDE - FLAT WELDING

1. ALIGN PLATES IN JIGS (DRAWING No OSS 788).

1.1 WELD SEAMS A & B 1 TO 3 BLOCK WELDS 12" TO 1/16"-1/8" BELOW SURFACE.

1.2 COMPLETE WELDS 4 TO 7, WORKING FROM CENTRE OUT, TO 1/16"-1/8" BELOW SURFACE.

1.3 TURN JIGS AND COMPLETE WELDS AS SHOWN ON PAGE 4

2. JOIN JIGS TOGETHER ALIGNING SEAM C.

2.1 WELD SEAM C, 8 TO 9, BLOCK WELDS TO 1/16"-1/8" BELOW SURFACE.

2.2 COMPLETE SEAM C 11 TO 14 WORKING FROM CENTRE OUT TO 1/16"-1/8" BELOW SURFACE.

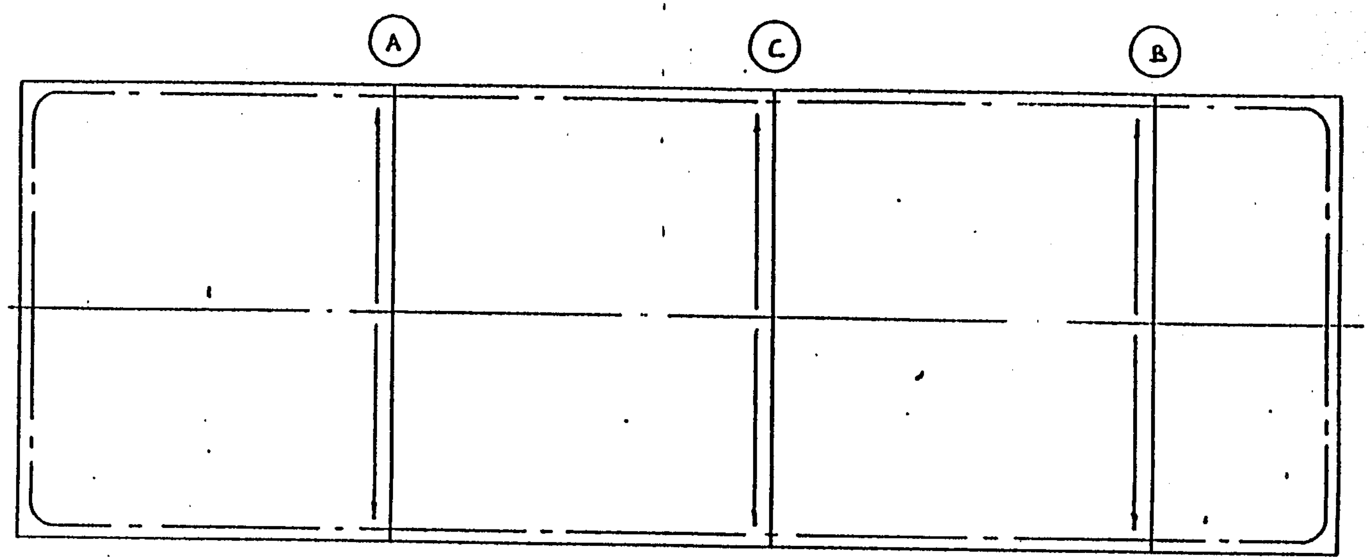
2.3 TURN JIG AND COMPLETE WELDS AS SHOWN ON PAGE 4

3. AFTER ROLLING AND POSITIONING IN JIG, WELD CAPPING COMPLETE, WORKING FROM CENTRE OUT. SEAMS A & B FIRST 14 TO 15 THEN SEAM C 16 TO 17.

NOTE: BACKSTEP WELDING.

SEQUENCE FOR WELDING PLATE SEGMENTS

OUTBOARD FACE



BACKGOUGE SIDE - FLAT WELDING

1. BACKGOUGE SEAMS A & B TO SOUND METAL (7-8 mm) CENTRE OUT.

1.1 WELD SEAMS A & B TO 1/16"-1/8" FROM SURFACE, FROM CENTRE OUT.

2. BACKGOUGE SEAM C TO SOUND METAL (7-8 mm) CENTRE OUT.

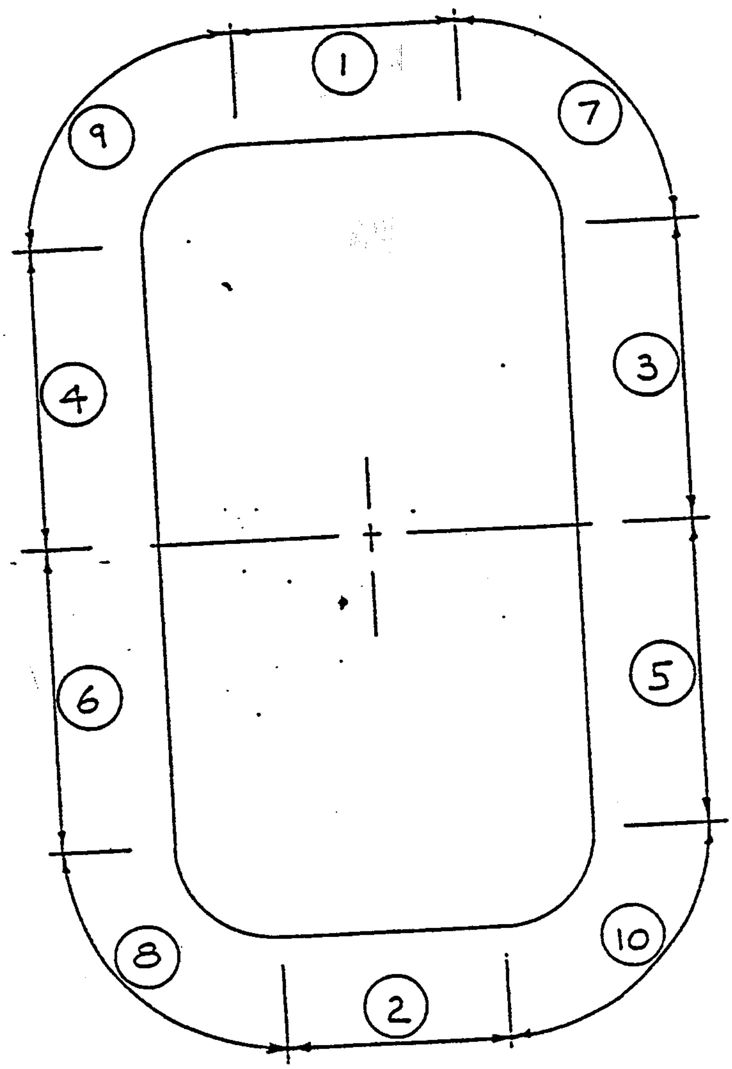
2.1 WELD SEAM C TO 1/16"-1/8" FROM SURFACE FROM CENTRE OUT.

NOTE: BACKSTEP WELDING.

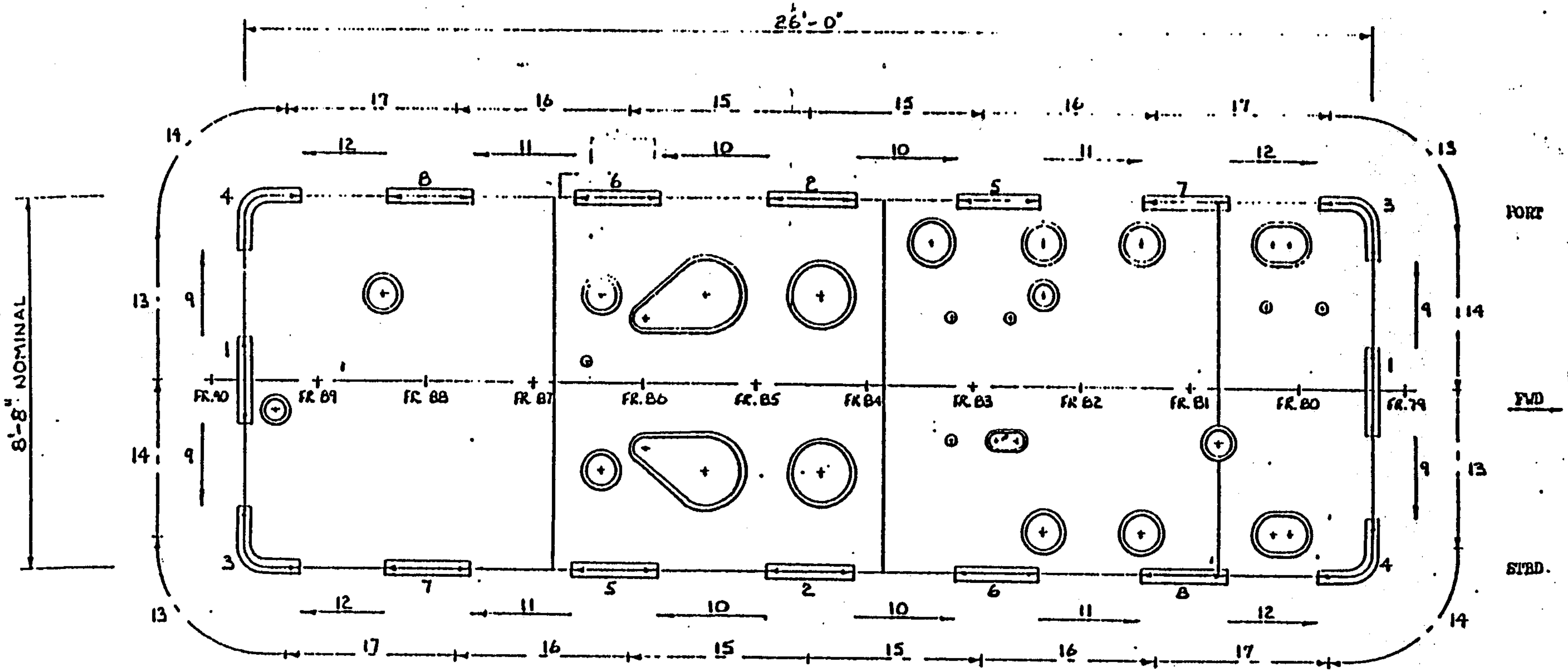
INSERT INTO CROWN PLATE

QT 28 TO QT 28

WELDING SEQUENCE



BACKSTEP WELDING



CROWN PLATE INSERT
WELDING SEQUENCE

INBOARD WELDING

1. TWO (2) WELDERS SIMULTANEOUSLY WELDING BLOCK WELDS.

2. BLOCK WELDS 2'-0" INDICATED BY [1-8]

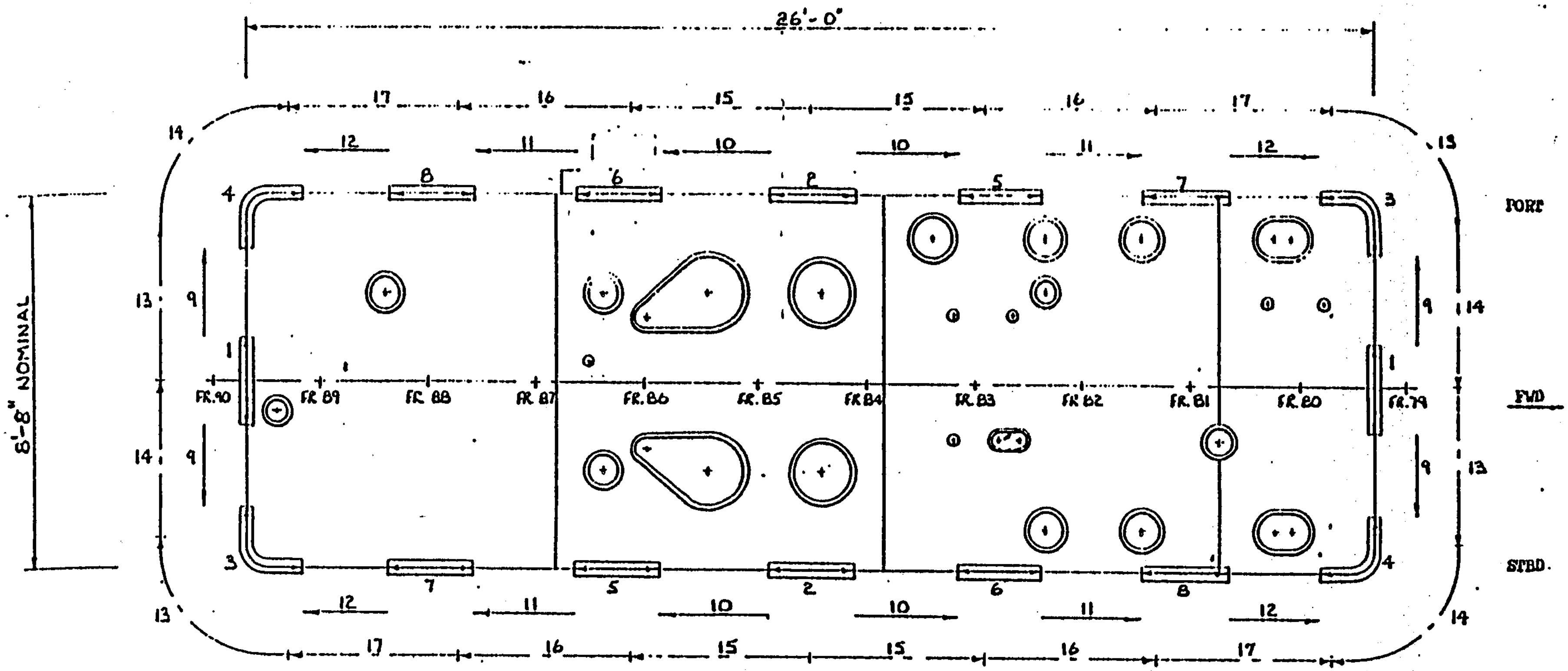
3. BACKSTEP METHOD OF ALL WELDING TO BE EMPLOYED.

4. BLOCK WELDS BUILT UP UNTIL 1/16"-1/8" BELOW THE SURFACE OF THE PLATE.

5. AFTER INITIAL BLOCK WELDS COMPLETE. FOUR (4) WELDERS SIMULTANEOUSLY WELDING AS INDICATED 9-12 BUILT UP AS IN NOTE 4.

6. COMPLETE WELDS WITH FOUR (4) WELDERS (IE., CAPPING) AS INDICATED 13-17. WELDERS WORKING AWAY FROM EACH OTHER.

NOTE: WELDING & CHIPPING ARE NOT TO BE CARRIED OUT SIMULTANEOUSLY.

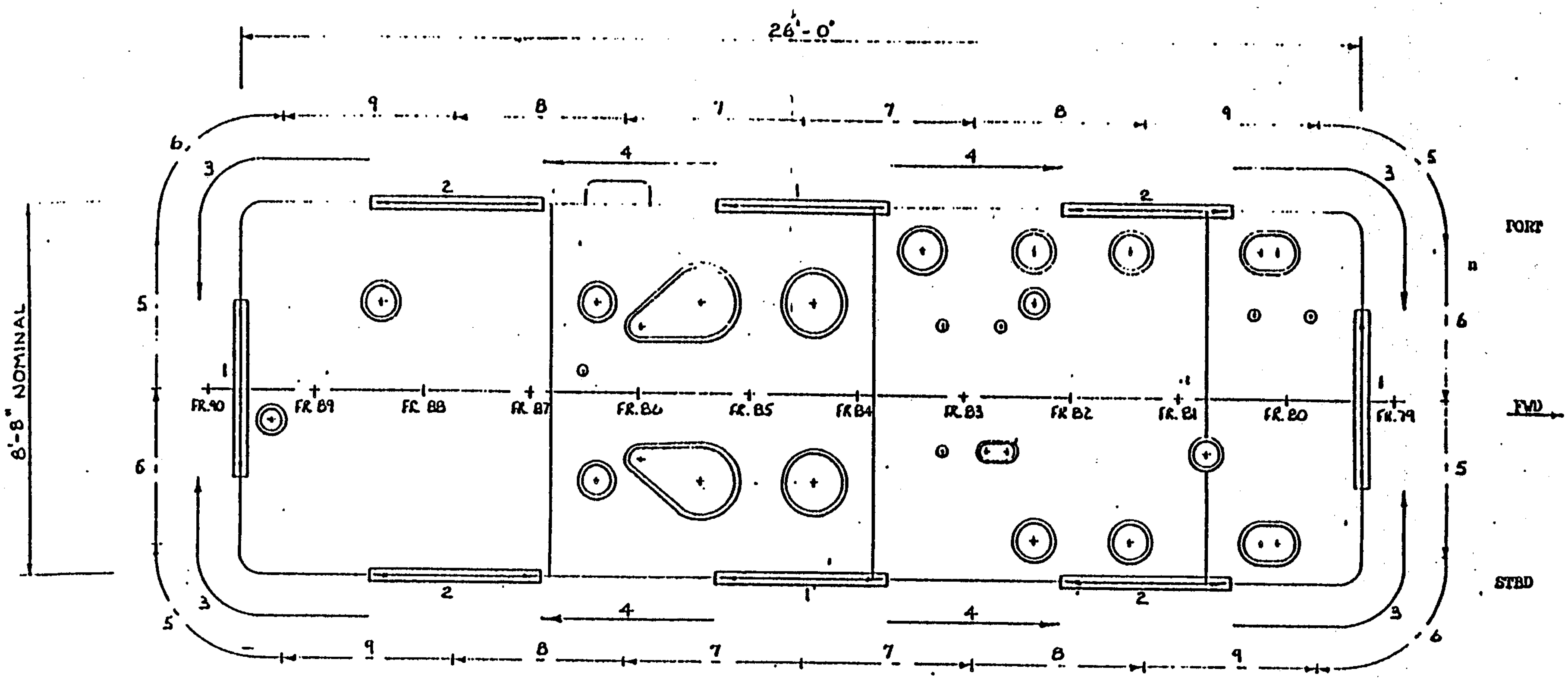


CROWN PLATE INSERT
WELDING SEQUENCE

INBOARD WELDING

1. TWO (2) WELDERS SIMULTANEOUSLY WELDING BLOCK WELDS.
2. BLOCK WELDS 2'-0" INDICATED BY [1-8]
3. BACKSTEP METHOD OF ALL WELDING TO BE EMPLOYED.
4. BLOCK WELDS BUILT UP UNTIL 1/16"-1/8" BELOW THE SURFACE OF THE PLATE.
5. AFTER INITIAL BLOCK WELDS COMPLETE. FOUR (4) WELDERS SIMULTANEOUSLY WELDING AS INDICATED 9-12 BUILT UP AS IN-NOTE 4.
6. COMPLETE WELDS WITH FOUR (4) WELDERS (IE., CAPPING) AS INDICATED 13-17. WELDERS WORKING AWAY FROM EACH OTHER.

NOTE: WELDING & CHIPPING ARE NOT TO BE CARRIED OUT SIMULTANEOUSLY.



CROWN PLATE INSERT
WELDING SEQUENCE

OUTBOARD WELDING

1. FOUR (4) WELDERS SIMULTANEOUSLY WELDING BLOCK WELDS

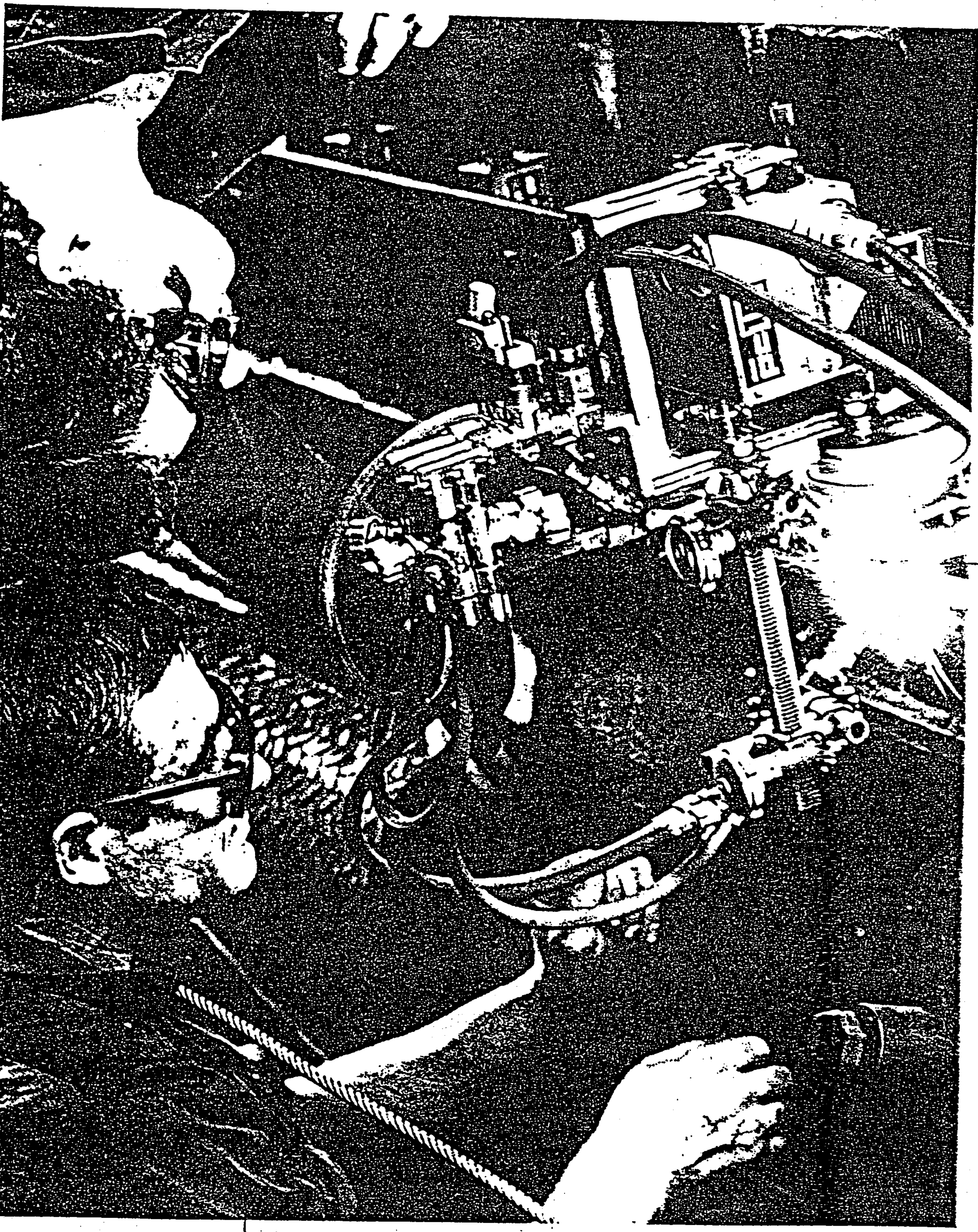
2. BLOCKWELDS 4'-0" INDICATED BY [1-2]

3. BACKSTEP METHOD OF ALL WELDING TO BE EMPLOYED.

4. BLOCKWELD SECTIONS TO BE GOUGED, GROUND AND WELDED TO 1/16"-1/8" BELOW SURFACE OF PLATE.

5. AFTER BLOCKWELDING, THE REMAINING WELD CAN BE GOUGED & GROUND FOR WELDING AS INDICATED —3-4—. WELD TO 1/16'-1/8" BELOW SURFACE OF PLATE.

6. CAPPING RUNS INDICATED BY ——5-9—— USING FOUR (4) WELDERS.



APPENDIX E

DETAILS OF PREHEATING EQUIPMENT PURCHASED SPECIFICALLY FOR THE RENEWAL OF THE CLOSURE PLATE ON HMAS OTWAY

PURCHASE ORDER ** 09735 ** PAGE

Cockatoo Dockyard Pty Limited

Incorporated in NSW:
A Comsteel Vickers Company

Cockatoo Island, Sydney
New South Wales 2000
Telephone: (02) 818 9201
Telex: AA21833 CODOC

COOPERHEAT OF AUSTRALIA PTY LTD
4 KELRAY PLACE
ASQUITH NSW 2078

DATE 18NOV86
DATE EXPECTED
ATTENTION: MR. E. LLOYD
PHONE: 476 4677

FOR CODOCK USE ONLY: JOB 3136
SPECIFICATION: HEATING EQUIPMENT FOR HULL WELDING
ORDERED BY WL/B.CLARK DELIVER TO ELECTRICAL SHOP INSP PR
REQN 965751 **DISTN:** PUR GS NS GOC GM SJ/2 QC/2 PNO SMS SFO PR
ACES DE EL

PLEASE SUPPLY IN ACCORDANCE WITH CONDITIONS SHOWN OVERLEAF

LINE	QUANTITY	DESCRIPTION	PRICE	ITEM
1	1 EA	MACHINE - PRE HEATING AS FOLLOWS:- 132 KVA, 415V, 50HZ, 3 phase, air cooled, double wound power transformer (primary supply 160 Amps per phase) provides low tension 3 phase output 65V pre-heat service, C/W 9 circuits, solid state switching, 2 auxillary 100V sockets, primary circuit breaker with shunt trips. Inlet/outlet thermocouple sockets feed via 1 Temperature Controller and Energy Regulator per circuit (excluding primary cables) 5 elements per circuit c/w built in 12 point Temperature Recorder. PRICE: .00 DUTY FREE (Includes all costs for direct flight air freight from U.K. to Cooperheat of Aust. Asquith Works).		
2	45 EA	ELEMENTS - PRE HEATING, 65 VOLT FLEXIBLE COMPLETE WITH CONNECTOR - TYPE CP24		

.../2

CONFIRMATION

E.E.Morris, Public Officer, per..........
I certify that we are holders of N.S.W. Sales Tax Certificate No.2-119-132

....
For the Financial Controller

Deliver to Cockatoo Dockyard Receiving Depot between Victoria Road and Balmain Power Station, Rozelle. The normal receiving hours are 7.25 a.m. to 12 noon and 12.30 p.m. to 3.55 p.m. but it is closed 1 day per month. Please check before attempting delivery.

Cockatoo Dockyard Pty Limited
Incorporated in NSW: A Comsteel Vickers Company

Cockatoo Island, Sydney
New South Wales 2000
Telephone: (02) 818 9201
Telex: AA21833 CODOC

LINE	QUANTITY	DESCRIPTION	PRICE	ITEM
3	1	SET CABLING - COMPRISING OF:-		

a) 18 only .. 30 M Heating Cable
280 Amp C/W Plug and Socket
Reference: 30002

Price ....

b) 18 only .. 5 way Splitter Cables
Reference: 32002

Price ....

c) 9 only .. 30M Compensating Cable Unshielded
C/W Plug and Socket
Reference: 34000

Price ....

TOTAL...............

LINE	QUANTITY	DESCRIPTION	PRICE	ITEM
4	1 EA	THERMOCOUPLE ATTACHMENT UNIT - VARIABLE REFERENCE - 41751		8066E
5	2 EA	TOP HATS - 3 WAY SOLID STATE HEATING REFERENCE: 15003 PRICE :		8066E
6	200 M	THERMOCOUPLE WIRE REFERENCE: 43000 PRICE :		8066E
7	9 EA	THERMOCOUPLE PLUGS REFERENCE: 516-111		8066E

.../3

E.E.Morris, Public Officer, per..........................

I certify that we are holders of N.S.W. Sales Tax Certificate No. 2-119-132

....
For the Financial Controller

~~L.M. JONES, Public Officer, per~~

~~I certify that we are holders of N.S.W. Sales Tax Certificate No. 2-119-132~~ ~~For the Commercial Director~~

Deliver to Cockatoo Dockyard Receiving Depot between Victoria Road and Balmain Power Station, Rozelle. The normal receiving hours are 7.25 a.m. to 12 noon and 12.30 p.m. to 3.55 p.m. but it is closed 1 day per month. Please check before attempting delivery.

PURCHASE ORDER ** 12568 ** PAGE 1

Cockatoo Dockyard Pty Limited

Incorporated in NSW
A Comsteel Vickers Company

Cockatoo Island, Sydney
New South Wales 2000
Telephone: (02) 818 9201
Telex: AA21833 CODOCK

COOPERHEAT OF AUSTRALIA PTY. LTD.
4 KELRAY PLACE
ASQUITH NSW 2078

DATE 27MAY87
DATE EXPECTED 28MAY87
ATTENTION: PETER ROBINSON
PHONE: 476 4677

FOR CODOCK USE ONLY: JOB 3136 OTWAY MAIN REFIT
SPECIFICATION: ELEMENTS FOR CROWN PLATE
ORDERED BY B.LARKIN/N.RIPPARD DELIVER TO ELECTRICAL SHOP INSP PR
REQN 956129 DISTN: PUR GS NS GOC GM SU/2 ACES QC/2 SMS SFO PNO EL DE

PLEASE SUPPLY IN ACCORDANCE WITH CONDITIONS SHOWN OVERLEAF

LINE	QUANTITY	DESCRIPTION	PRICE	ITEM
1	25 EA	ELEMENTS - CERAMIC STRIP CP 15		

DELIVERY:- F.I.S. to Rozelle Depot by 28/5/87.

All in accordance with telephone quotation from Peter Robinson.

To be to the satisfaction of Cockatoo Dockyard Pty Ltd
Production on receipt.

TOTAL VALUE ____________

ORDER
CONFIRMATION

PLEASE NOTE
ALL INVOICES ARE TO BE
DIRECTED TO THE SECRETARY,
COCKATOO DOCKYARD
PTY. LIMITED,
COCKATOO ISLAND, SYD [illegible]

E.E.Morris, Public Officer, per.............................
I certify that we are holders of N.S.W. Sales Tax Certificate No.2-119-132

For the Financial Controller

Deliver to Cockatoo Dockyard Receiving Depot between Victoria Road and Balmain Power Station, Rozelle. The normal receiving hours are 7.25 a.m. to 12 noon and 12.30 p.m. to 3.55 p.m. but it is closed 1 day per month. Please check before attempting delivery.

PURCHASE ORDER ** 11855 **

Cockatoo Dockyard Pty Limited
Incorporated in NSW
A Comsteel Vickers Company

Cockatoo Island, Sydney
New South Wales 2000
Telephone: (02) 818 9201
Telex: AA21833 CODOCK

COOPERHEAT OF AUSTRALIA PTY. LTD.
4 KELRAY PLACE
ASQUITH NSW 2078

DATE 27MAR87
DATE EXPECTED 30MAR87
ATTENTION: MR PETER ROBINSON
PHONE: 476 4677

FOR CODOCK USE ONLY: JOB 3136 OTWAY MAIN REFIT
SPECIFICATION:
ORDERED BY NRLS DELIVER TO ELECTRICAL SHOP INSP PR
REQN 956105 DISTN: PUR GS NS GOC GM SU/2 QC/2 PNO DE SMS SFO PR ACES EL

PLEASE SUPPLY IN ACCORDANCE WITH CONDITIONS SHOWN OVERLEAF

LINE	QUANTITY	DESCRIPTION	PRICE	ITEM
1	50 EA	CONNECTOR - PLUG, CAT. NO. 508-509 PRICE : [illegible] EACH		8066E
2	50 EA	CONNECTOR - SOCKET, CAT. NO. 508-010 PRICE : [illegible] EACH		8066E
3	100 M	CABLE - 16 MM, CAT. NO. 35-000 PRICE : [illegible] PER METRE		8066E
4	20 EA	PAPER - ROLL, RECORDER, CAT. NO. 542-017 PRICE : $[illegible] EACH		8066E
5	1 EA	RECORDER - INK, CARTRIDGE CAT. NO. 542-066 PRICE : [illegible]		8066E

PLEASE NOTE
ALL [illegible]

DELIVERY:- To Rozelle Depot by 30/3/87, at a charge to be advised.

All in accordance with telephone quotation from Peter Robinson on 26/3/87.

To be to the satisfaction of Cockatoo Dockyard Pty Ltd Production on receipt.

ORDER CONFIRMATION

TOTAL VALUE $1578.00
PLUS DELIVERY CHARGE

E.E.Morris, Public Officer, per..............................
I certify that we are holders of N.S.W. Sales Tax Certificate No.2-119-132

....
For the Financial Controller

L.M. JONES, Public Officer, per
I certify that we are holders of N.S.W. Sales Tax Certificate No.2-119-132

for the Commercial Director

Deliver to Cockatoo Dockyard Receiving Depot between Victoria Road and Balmain Power Station, Rozelle. The normal receiving hours are 7.25 a.m. to 12 noon and 12.30 p.m. to 3.55 p.m. but it is closed 1 day per month. Please check before attempting delivery.

PURCHASE ORDER

** 12270 **   PAGE 1

Cockatoo Dockyard Pty Limited

Incorporated in NSW
A Comsteel Vickers Company

Cockatoo Island, Sydney
New South Wales 2000
Telephone: (02) 818 9201
Telex: AA21833 CODOCK

COOPERHEAT OF AUSTRALIA PTY. LTD.
4 KELRAY PLACE
ASQUITH NSW 2078

DATE 08MAY87
DATE EXPECTED 13MAY87
ATTENTION: MR P ROBINSON
PHONE: 476-4677

FOR CODOCK USE ONLY: JOB 3136 OTWAY MAIN REFIT
SPECIFICATION: PARTS FOR COOPERHEAT UNIT "CROWN PLATE"
ORDERED BY B.LARKIN/N.RIPPARD DELIVER TO ELECTRICAL SHOP NO.2 INSP PR
REQN 956123 DISTN: PUR GS NS GOC GM SU/2 DE ACES QC/2 SMS SFO PNO EL

PLEASE SUPPLY IN ACCORDANCE WITH CONDITIONS SHOWN OVERLEAF

LINE	QUANTITY	DESCRIPTION	PRICE	ITEM
1	100 M	CABLE - TRIANGLE, 16 MM2	[illegible]	8066E
2	100 M	CABLE - COMPENSATING STOCK NO. 504-062	[illegible]	8066E
3	50 EA	SOCKET - 135 AMP STOCK NO. 508-010 PRICE : [illegible] EACH	[illegible]	8066E
4	50 EA	PLUG - 135 AMP STOCK NO. 508-009 PRICE : [illegible] EACH	[illegible]	8066E
5	20 EA	SOCKET - 180 AMP STOCK NO. 508-007 PRICE : [illegible] EACH	[illegible]	8066E
6	20 EA	PLUG - 180 AMP STOCK NO. 508-006 PRICE : [illegible] EACH	[illegible]	8066E
7	5 EA	CARRIER FUSE SOCKET (FOR 110 VOLT CONTROL CIRCUITS) PRICE : [illegible] EACH	[illegible]	8066E
8	1 EA	BATTERY - FOR THERMOCOUPLE ATTACHMENT UNIT STOCK NO. 558-008	[illegible]	3066E

ORDER CONFIRMATION

PLEASE NOTE
ALL INVOICES [illegible] BE DIRECTED TO: [illegible] (COCKATOO DOCKYARD) PTY. LIMITED, COCKATOO ISLAND, [illegible] 2000

DELIVERY:- F.I.S. to Rozelle Depot by 13/5/87.

All in accordance with telephone quotation from Peter Robinson on 6/5/87.

To be to the satisfaction of Cockatoo Dockyard Pty Ltd Production on receipt.

TOTAL VALUE $1526.09

E.E.Morris, Public Officer, per..........
I certify that we are holders of N.S.W. Sales Tax Certificate No, 2-119-132

.... For the Financial Controller

Deliver to Cockatoo Dockyard Receiving Depot between Victoria Road and Balmain Power Station, Rozelle. The normal receiving hours are 7.25 a.m. to 12 noon and 12.30 p.m. to 3.55 p.m. but it is closed 1 day per month. Please check before attempting delivery.