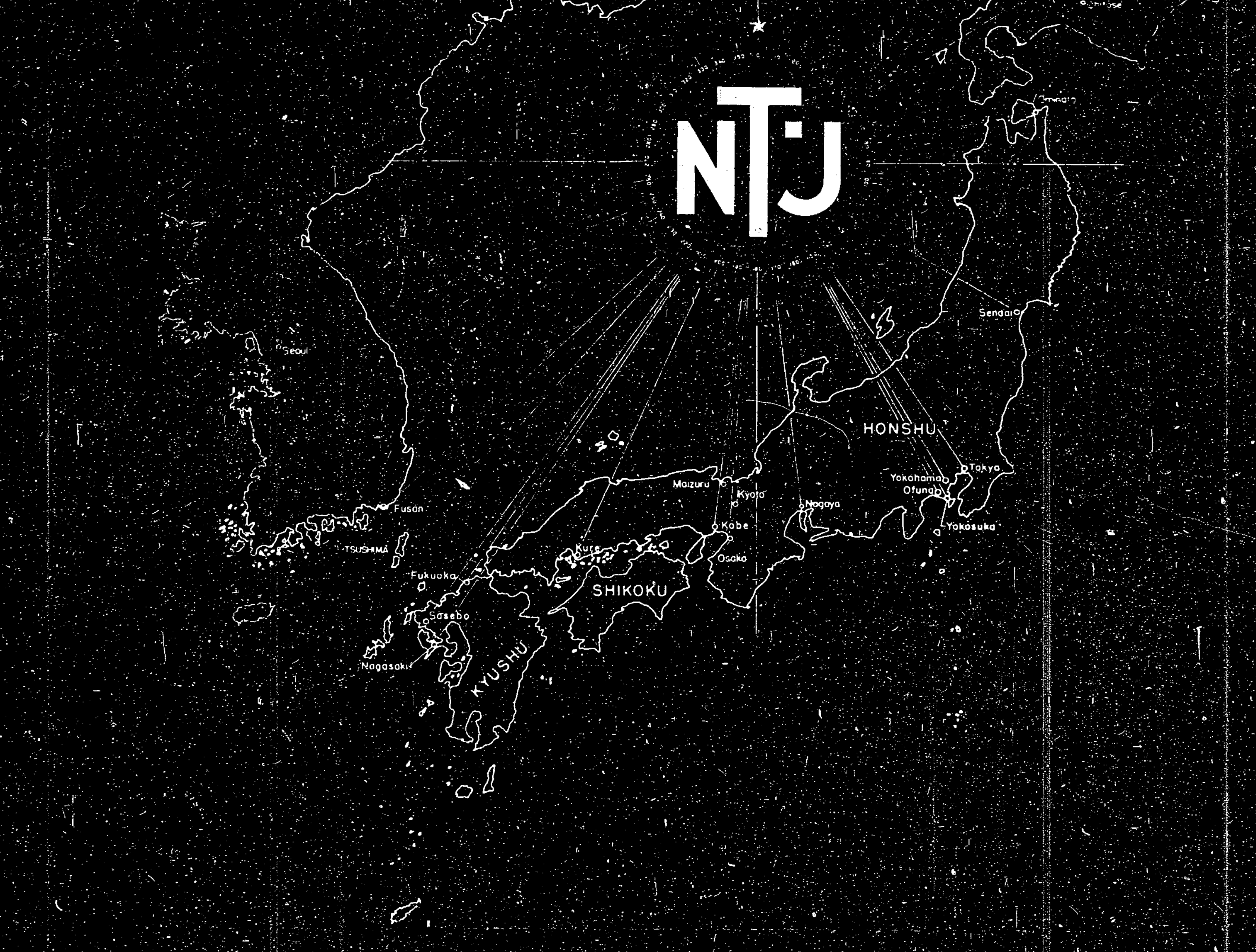

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INDEX NO. S-81(N)

SHIP AND RELATED TARGETS

WELDING IN JAPANESE NAVAL CONSTRUCTION

U.S. NAVAL TECHNICAL MISSION TO JAPAN

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U. S. NAVAL TECHNICAL MISSION TO JAPAN
CARE OF FLEET POST OFFICE
SAN FRANCISCO, CALIFORNIA

25 January 1946

RESTRICTED

From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Welding in Japanese Naval Construction.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report dealing with Target S-81(N) of Fascicle S-1 of reference (a), is submitted herewith.

2. The investigation of the target and the preparation of the report were accomplished by Construction Lieut. J. A. H. Paffett, RN, and U.S. Navy Civilian Technician T. J. Griffin, assisted by Lieut. R. Cunninghame, RNVR, who acted as interpreter and translator.

C. G. Grimes

C. G. GRIMES
Captain, USN

RESTRICTED S-81(N)

WELDING IN JAPANESE NAVAL CONSTRUCTION

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945

FASCICLE S-1, TARGET S-81(N)

JANUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

SHIPS AND RELATED TARGETS

WELDING IN JAPANESE NAVAL CONSTRUCTION

This report describes the use of welding in Japanese naval construction. The Japanese showed little appreciation of the real advantages to be gained by the use of welding; their lines of research, none of which were original, were aimed at increasing output rather than at improving the quality of the product. Their equipment and workmanship were poor. In fact the Japanese were years behind the U.S. and Great Britain in the development of welding.

It is considered that the report is principally negative in that it shows how little of value there is to be learned from Japanese welding.

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LIST OF ENCLOSURES

LIST OF ILLUSTRATIONS

REFERENCES

Japanese Personnel Interviewed:

Constructor Captain Kenji YADA, IJN, Extensive Dockyard experience.

Constructor Captain NAKAMURA, IJN, Submarine Designer, Navy Technical Dept., Navy Ministry.

Mr. Kageo TISUJI, Welding Engineer, KURE Navy Yard. Long experience in welding.

Professor AKASAKI, Former Constructor Captain, IJN, Author of several papers on fire-cracker welding method.

Mr. Tamaichi UMEYAMA, Welding Supervisor, YOKOSUKA Navy Yard.

INTRODUCTION

Part I of the report gives a brief history of the development of Japanese welding from 1932 onward and shows that the Japanese never proceeded beyond considering welding as a supplement to riveting.

Part II outlines Japanese welding design, practice and policy, which were based upon the assumption of the superiority of the riveted joint.

Part III describes the principal lines of welding research, the most notable of which dealt with large electrodes up to 3/4 inch in diameter.

Part IV describes Japanese welding plants, electrodes and X-ray equipment, and illustrates the general inferiority of Japanese equipment.

Part V deals with the organization and training of dockyard welders and the standard of workmanship, which was generally poor.

THE REPORT

PART I - HISTORICAL

The small minelayer YAEYAMA, built in 1932, was the first ship in which welding was employed extensively. Little modification was made in the conventional riveted design of construction. The shell was partly welded, using lap connections, and two frames in every three were welded to the shell, the third being riveted. It was hoped that this arrangement would minimize distortion, and it appears to have been fairly effective.

Following the success of YAEYAMA, introduction of extensive welding into ship construction was first contemplated in 1934, when comparative tests on welded and riveted structures were carried out at KURE. This work is described in NavTechJap Document No. ND50-1116. The conclusion reached was that the welded butt joint was superior to the riveted lap except under conditions of impactive loading.

About the same time considerable experimental work on the welding of mild steel and Ducol steel (Japanese equivalent of U.S. high tensile steel) was carried out at YOKOSUKA Navy Yard (NavTechJap Document No. ND50-1126). As a result, it was decided that the welding of ducol steel was not advisable for strength purposes, but that the all-welded mild steel ship was a practical proposition. A little later the various navy yards and principal private yards produced a series of pamphlets describing their welding practice and their plans for the extension of welding. From these documents, it is evident that great things were expected of welding.

The first all-welded ship to be built was the 10,000 ton submarine depot ship TAIGEI, completed in 1935. The outer bottom was completely welded using butt connections, and the frames were welded to the shell. Very severe distortion was encountered during construction. Frame lines in places departed as much as 80cm from designed positions and both the bow and the stern lifted about 20cm from the blocks. Both the bow and the stern portions were cut completely adrift from the central portion of the hull, lowered into their correct relative positions, and secured to the hull again by heavy riveted butt straps.

In this ship, fabricated shaft brackets were fitted, but they were later replaced by castings because trouble was anticipated, though not actually experienced. The estimated saving in hull weight in TAIGEI due to the use of welding was 15 percent.

Following this experience with TAIGEI, Japanese welding practice was modified, and the cruiser MOGAMI was built with an all-welded shell in which, however, riveted butt straps were used to connect "blocks" of welded structure. Distortion was thus partly overcome, but the welding was not considered a complete success as serious cracks developed in shell welds during trials.

Following the TAIGEI and MOGAMI setbacks, the Japanese appear to have given up hope of constructing a successful all-welded ship. Welding came to be valued as a convenient and rapid method of fabrication rather than as a means of saving weight and increasing the strength of ships. As described in this report under the sub-heading "Design", in later cruisers and larger ships, welding was used only for the ends of the ship and minor internal structure.

During the war, construction of large ships was stopped, and all efforts were concentrated upon the rapid building of small ships and submarines. These were designed for quick and easy assembly using the "block" system, by which prefabricated welded blocks of up to 30 tons weight were joined together at the slip by riveting. As holes for riveting were drilled in place, this method allowed considerable latitude for poor workmanship.

Late in the war the Japanese appeared to have recovered their faith in welding, and submarines of the Ha-101, Ha-201 and I-201 classes were built with all-welded pressure hulls. Earlier classes, e.g. I-361, had been built with a mixture of welded and riveted pressure hull seams.

PART II - DESIGN: WELDING SEQUENCES AND PROCEDURES

DESIGN

1. General - The Japanese Navy did not develop welded design as extensively as the U.S. Navy. Riveting was retained as the principal method of construction, and the welding actually undertaken, in most instances, was restricted to the fabricating of other than the strength members of vessels. Apparently the Japanese realized that welding was a means whereby lighter vessels, increased production, and a saving in materials could be achieved, but they were unable to take full advantage of the process due to the low level of skill and experience posessed by personnel of the building yards. In the main, therefore, the development of welded design in the Japanese Navy, was along the lines of increased efficiency in the construction of riveted ships. The assumptions upon which this development was founded, the principles and policy governing the extent of welded design, and the controlling specifications, are outlined in the following paragraphs.

2. Assumptions Governing Design - Japanese naval construction was founded, apparently, upon the following assumptions:

a. That the welded connection was inferior in strength to the riveted connection.

b. That serious distortion and misalignment were unavoidable in the welded structure, except where a large percentage of the joints were riveted.

c. That a certain number of riveted joints were necessary in order to expedite the work of the shipfitter.

3. Principles Governing Design - Developed in accordance with the foregoing assumptions, the principles governing design may be stated briefly as follows:

a. Longitudinal strength members, particularly in large vessels, should be of riveted design.

b. In general, transverse deep web frames, floors, and bulkheads could be fabricated by welding, but should be designed for riveted connections to longitudinals, innerskins, shell and decks.

c. In large combatant vessels, approximately four-fifths of the shell plating amidships should be of riveted design.

d. Welded sections should be limited to a size which, depending upon crane facilities, would be suitable for welding ashore on platens or slabs.

e. The design of the welded sections, assemblies or panels, should be such that all connections on the ways would be riveted.

f. Intermittent welding should be used where possible.

4. Exceptions to Standard Design Principles - In endeavoring to speed construction and save materials during the war, the Japanese modified their standard design principles to the following extent:

a. The cutting in and welding of riveting strips, to transverse bulkheads and floors on the ways, was approved.

b. The welding together of subassemblies or panels on the ways, to form larger sections weighing up to 100 tons, was approved for constructing patrol vessels, minecraft and auxiliaries.

5. General Design Policy - A general design policy, governing the extent of welding as averaged for classes of vessels, is given in the following sub-paragraphs. For simplicity, the various classes of vessels have been divided into four representative groups. In explanation of any divergence in design policy noted, the larger warship midships sections were generally fabricated from "Ducol", a high-tensile material regarded as unsuitable for structural welding.

a. Battleships, Large Carriers - In the construction of battleships and large carriers, welding was, in general, restricted to the fabrication of relatively unimportant structural members such as the flats, floors, transverse bulkheads and deck sections located in the fore and aft 1/20 lengths of the vessels. Fabrication of these items by welding was limited to work which could be performed on platens or slabs and usually consisted of welding the plating joints and the riveting strips around one-half of their peripheries. The welding of stiffeners or light beams to plating was optional; riveting could be used if desired. It is noteworty that the Japanese considered the floors and transverse bulkheads in the midship sections of these vessels too massive for welding and too susceptible to distortion and warpage. In addition to the foreging structural welding, numerous miscellaneous attachments throughout the length of the vessels, such as wireway hangers, insulation fasteners, and lightly loaded brackets, were welded. The ends and intersections of riveting strips or boundary angles were also welded for watertightness. One restriction was placed upon the welding of miscellaneous attachments to "Ducol"; it was specified that the length or run of weld should not exceed 300mm.

b. Cruisers, Destroyers, Light Carriers - In cruisers, destroyers, and light carriers, the transverse deep web frames, floors, transverse bulkheads and approximately 1/10 of the shell and decks, in the fore and aft ends of the vessels, were designed for welding. Design as usual was such that welding was restricted to the fabricating on platens or slabs of subassemblies weighing in the neighborhood of 30 tons, with the principal phases of welding consisting of welding the plating joints and of the attachment of riveting strips to one-half of the peripheries of bulkheads and floors. As a rule, only light beams or stiffeners were welded to the plating; the heavier frames or beams were riveted. The usual items were designed for welding on the ways such as composite collar plates, riveted to the cut member and then welded to the through member, miscellaneous light brackets, wireway hangers, insulation pins, and the ends or intersections of boundary angles or riveting strips.

c. Mine Craft, Patrol Craft, Auxiliaries - Mine Craft, patrol craft, and auxiliaries such as tankers, cargo ships, etc, were constructed entirely from welded subassemblies. The usual design methods prevailed; shell and deck panels, bulkheads and deep web frames and

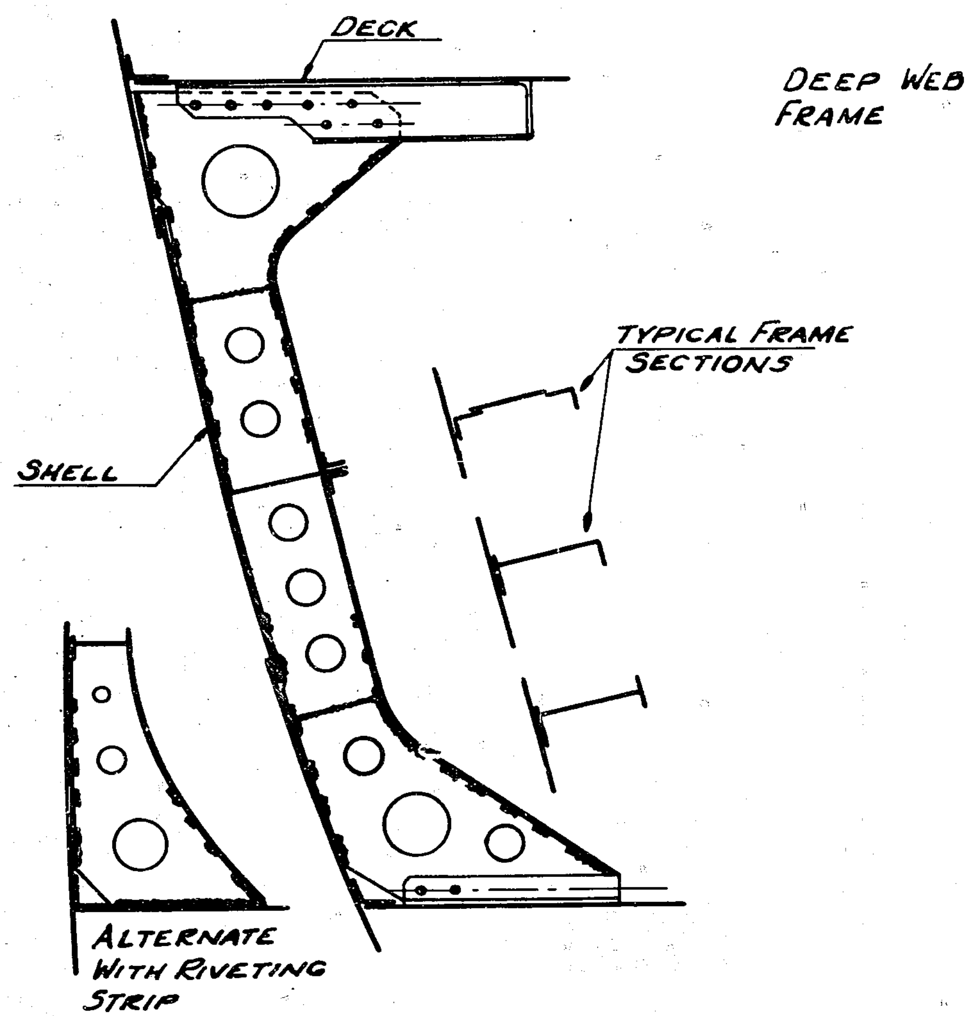

Figure 1

TYPICAL DEEP WEB FRAME, KAIBOKAN

Riveted at ends and intermittently welded to face plate and riveting strip.

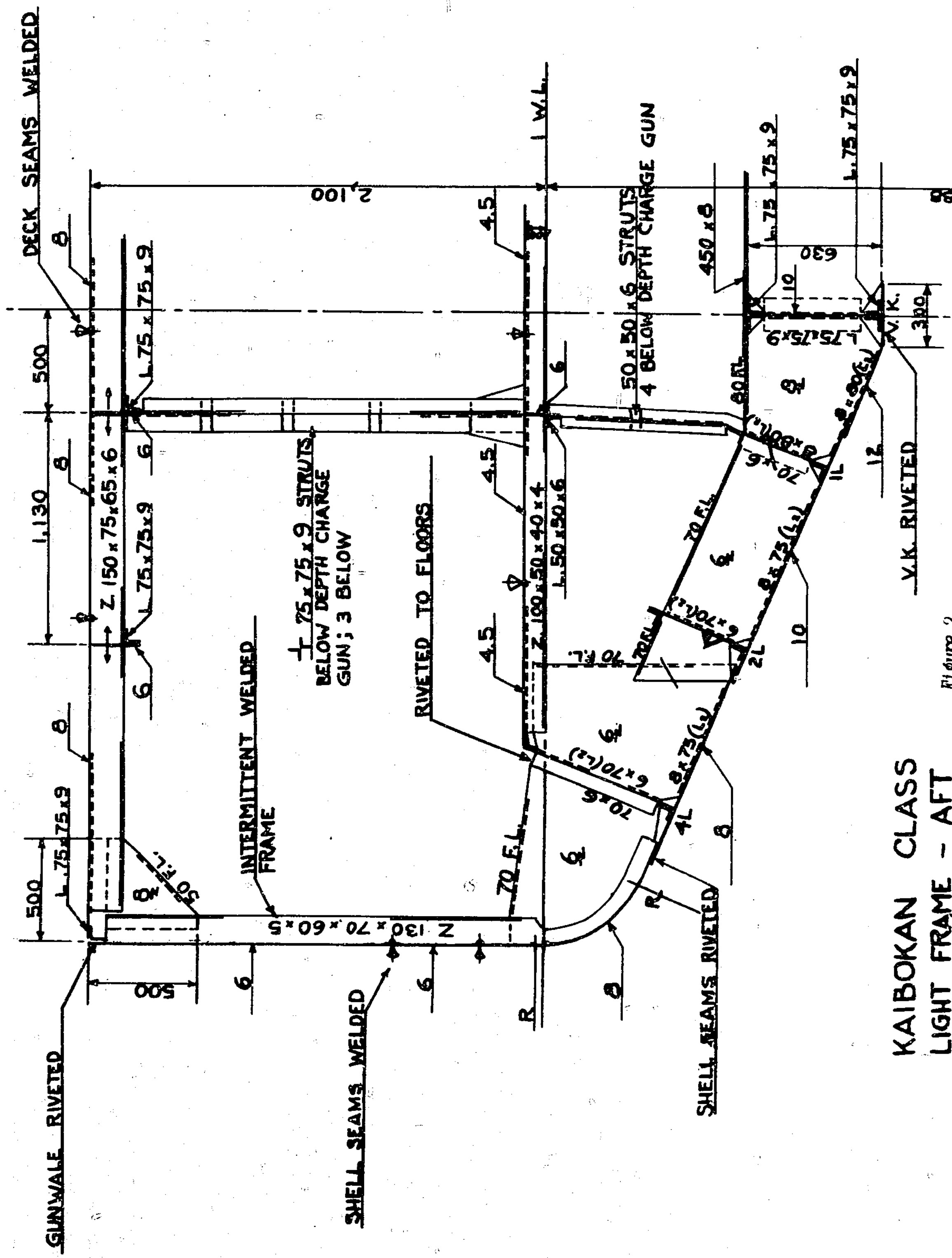

Figure 2

TYPICAL LIGHT FRAME, KAIBOKAN

Intermittently welded to shell and riveted to brackets, side shell shown as welded in seams and riveted to gunwale, bottom shell seams riveted.

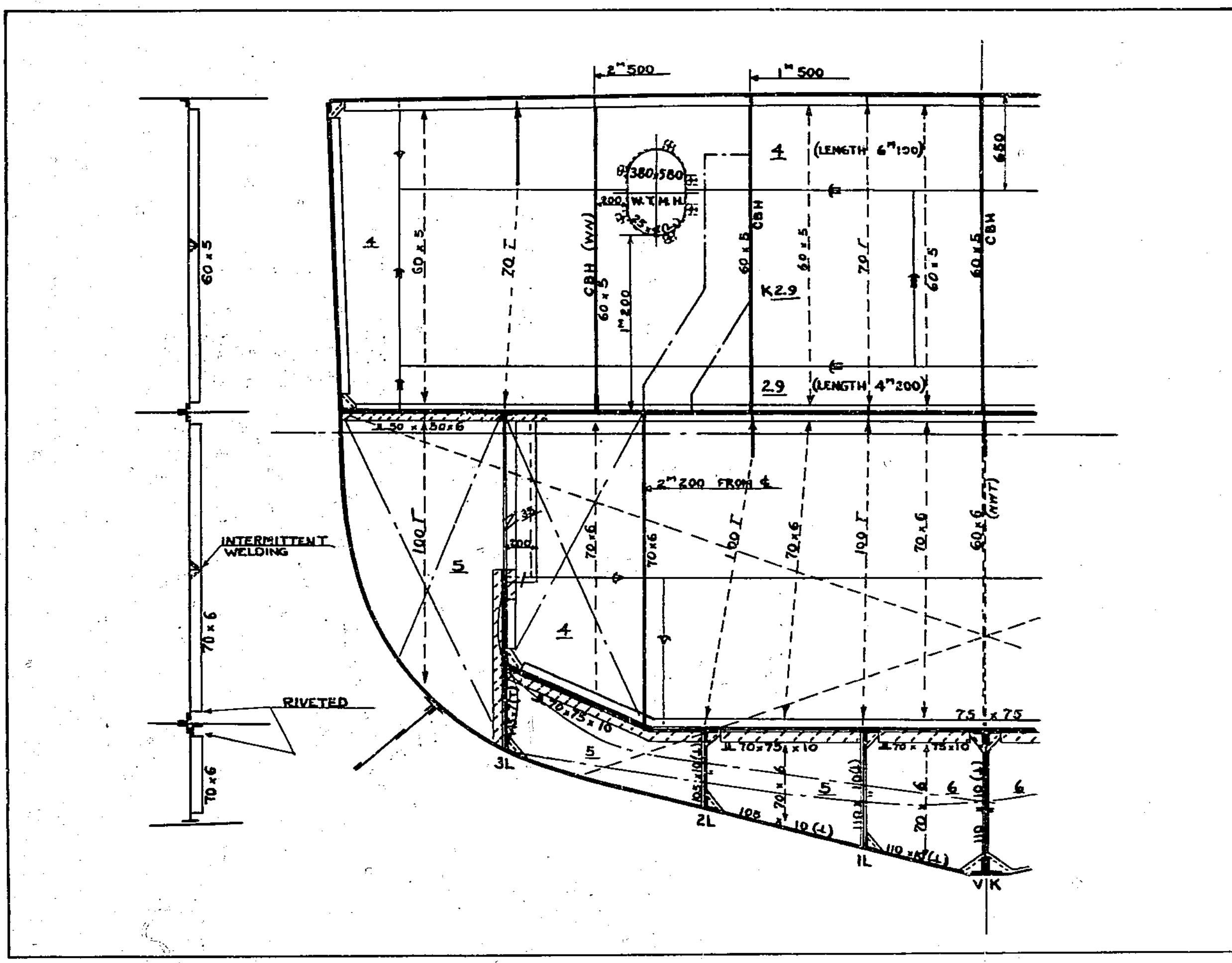

Figure 3

BULKHEAD, KAIBOKAN

Floors, longitudinals, transverse bulkheads.

girders were welded as units on platens or slabs and were connected on the ways by riveting. This practice entailed the use of the familiar welded riveting strip in combination with riveted boundary angle type connection of innerbottom longitudinals, longitudinal deep web frames and girders, and transverse and longitudinal bulkheads, shell innerskins and decks. Typical design and details of this method of construction may be found in Figures 1, 2 and 3.

d. Tabulation of Design Policy - Surface Vessels

ITEM	CONNECTION	BATTLESHIPS	CRUISERS DESTROYERS CARRIERS	MINE CRAFT PATROL CRAFT AUXILIARIES
Shell Plating	Butt and Seams	R	W 20% #	W #
Vertical Keel	To flat keel and rider plate	R	R	R
	To shell plating	R	R	R
	To brackets	R	R	R
Innerbottom-Longitudinals and Longitudinal Girders	Ends to abutting structure	R	R	R
	At butts	R	R	W 15% #
	To riveting strips and face plates	R	R	W 25% #
Deep Web	To plating	R	R	R
Floors and Deep Web Transverse Frames and Girders	Ends to abutting structure	R	R	R
	At butts	W 15% #	W #	W #
	To riveting strips and face plates	W 20% #	W #	W #
	To plating	R	R	R
Ordinary Longitudinals under 8 inch Web Section	Ends to abutting structure	R	R	R
	At butts	W 10% #	W 15% #	W 40% #
	To face plates	W 10% #	W 15% #	W 40% #
	To plating	W 10% #	W 15% #	W 40% #
Ordinary Transverse Framing below 8 inch Web Section	Ends to abutting structure	R	R	R
	At butts	W 10% #	W #	W #
	To face plates	W 10% #	W #	W #
	To plating	W 10% #	W 20% #	W #
Bilge Keels	Butts and seams to plating	R	R	R
Breast Hooks	Butts and seams	W #	W #	W #
	To plating	R	R	W #
Brackets to Longitudinals	To shell	R	R	R
	To longitudinals	R	R	W 25% #
Strength Decks	Butts and seams	W 10% #	W 20% #	W #
	Periphery	R	R	R
Bulkheads Transverse	Butts and seams	W 15% #	W #	W #
	Periphery	R	R	R
	To stiffeners	W 15% #	W 80% @	W #
	Stiffeners to face plates	W 15% #	W 80% @	W #
	Ends to decks and lone Bulkheads	R	R	R
	Tangency or tilting brackets	R	W 20% ¢	W

ITEM	CONNECTION	BATTLESHIPS	CRUISERS DESTROYERS CARRIERS	MINE CRAFT PATROL CRAFT AUXILIARIES
Platforms in Deckhouses and Bridges	Butts and seams	R	W 80% #	W #
	To side plating and coamings	R	R	R
Stanchions	Head and heel	R	R	W
Collar Plates	To cut member-in strength	R	R	R
	-non strength	W	W	W
	To through member	W	W	W
Deck Houses	Butts and seams	R	W 80% #	W #
	To stiffeners and beams	R	W #	W #
	To decks	R	R	R
Face Plates	Doors and lightening holes	W #	W #	W
Panel Stiffeners	At ends to abutting structure	W 10% #	W 20 #	W #
	To plating	W 10% #	W 20% #	W #
Waterstops	All	P	P	P
Piping	Butts	B	B	B
	To pierced member	B	B	B
Wireway Hangers	To mild steel and HTS (Ducol)	W 80%	W 90%	W
Insulation Pins	To mild steel and HTS (Ducol)	W	W	W
Deck Studs	To mild Steel and HTS (Ducol)	W	W	W

B - Bolted flanges-threaded, swaged or cast.
R - Riveted
P - Packed
W - Welded throughout
% - Total length welded from fore and aft ends of vessel.
# - Welded only in assembly-panels riveted on ways.
@ - Except in stern tacks subject to vibration.
¢ - Intercostal bulkheads-not in strength.

e. Submarines - In designing submarines the Japanese naval architect faced the usual difficulties. Only mild steel was considered weldable, and of even more critical importance, the yards were unable to hold the moulded form of large vessels within practicable limits. The above facts restricted the development of a completely welded design to vessels of small tonnage and led to the use of a composite riveted-welded design for the larger vessels. Establishment of a design standard for these later vessels is difficult, since the Japanese submarine designer was more welding minded, apparently, than the designer of surface vessels, and was currently increasing the use of welded construction. In addition, the welding application restrictions set forth in naval specifications, were, in the main, considered as not applicable to submarine construction allowing a great deal of latitude in design. For information purposes, however,

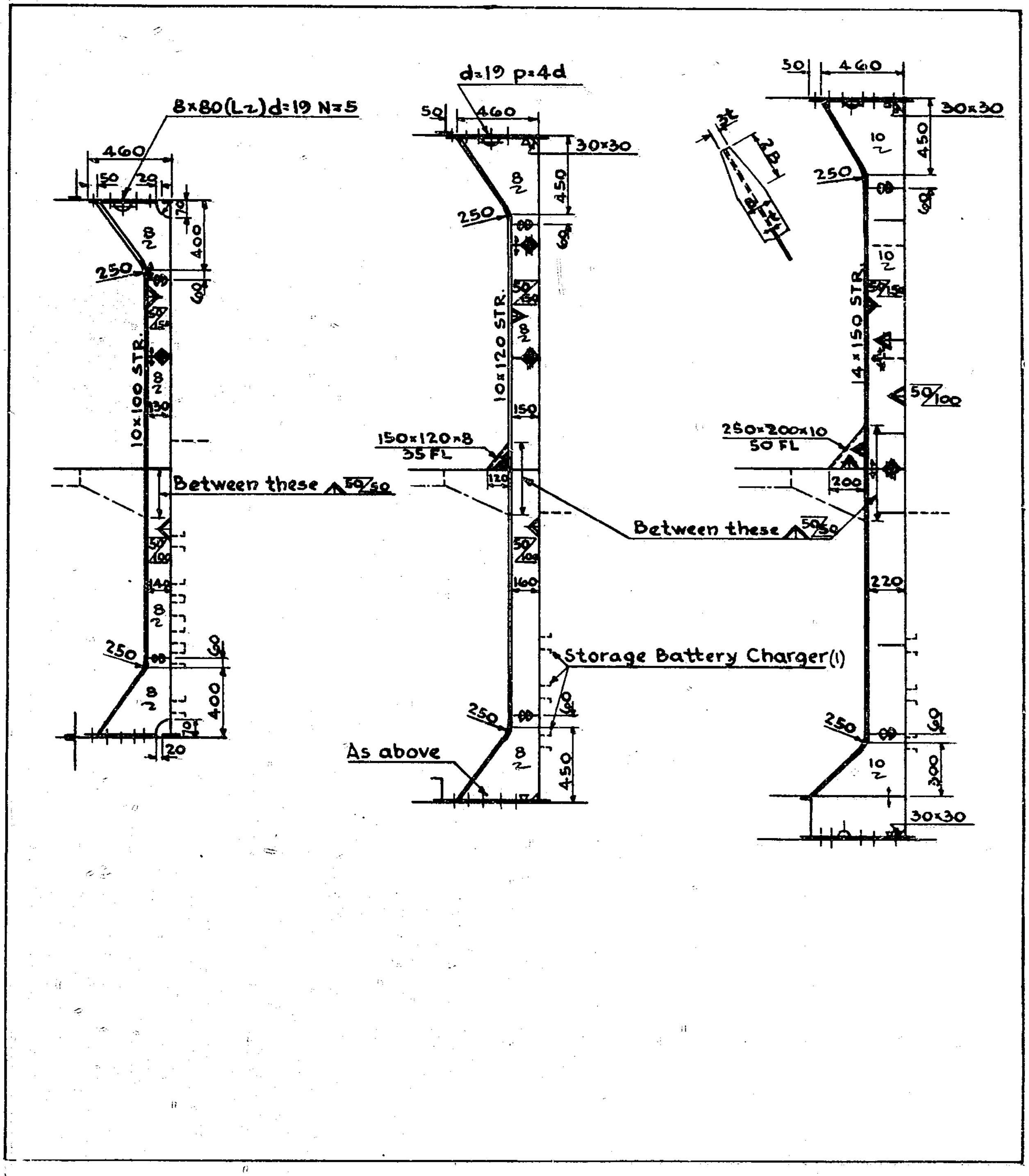

Figure 4

BULKHEAD STIFFENERS, KAIHOKAN

Welded to face plate and bulkhead plating - riveted to pressure hull.

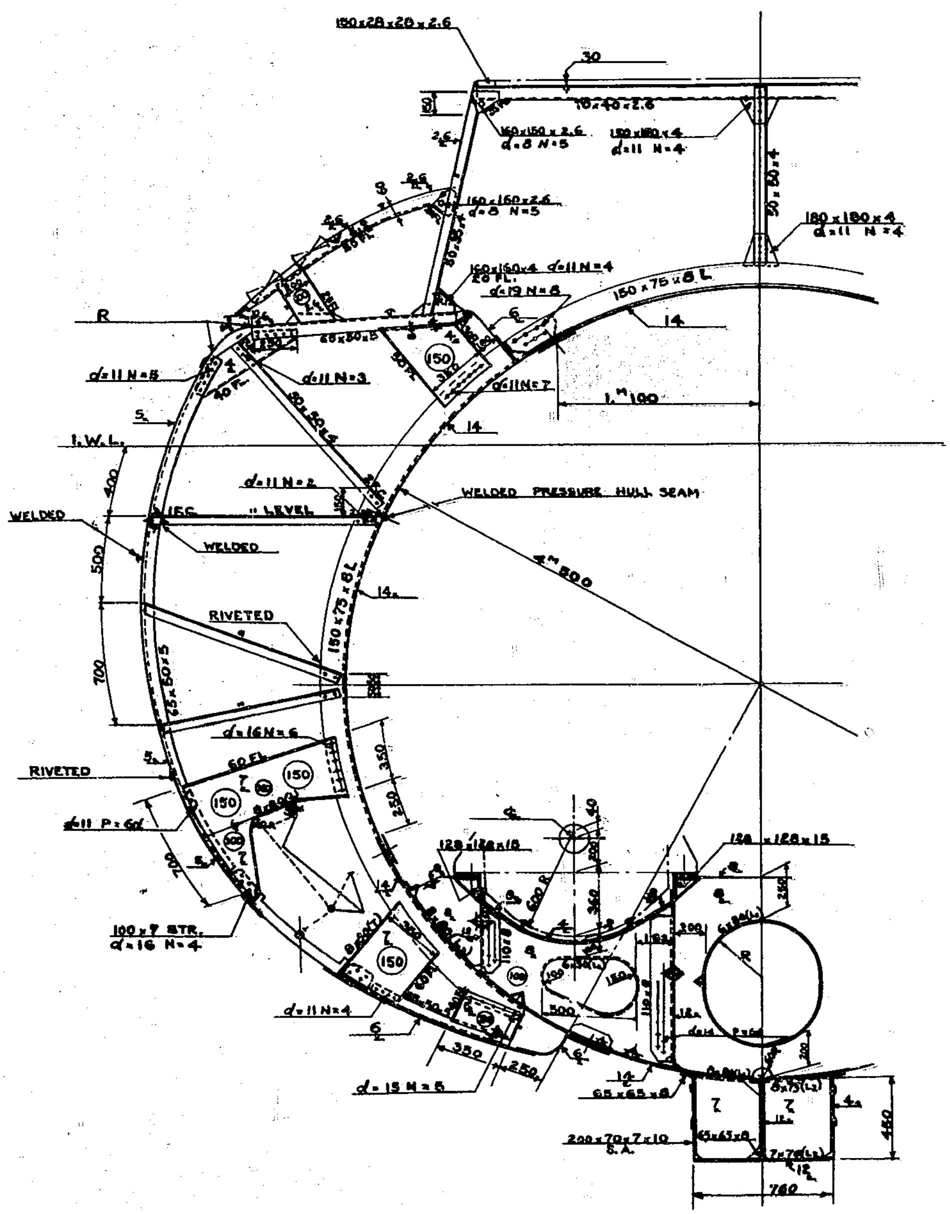

Figure 5
TRANVERSE FRAME, SUBMARINE

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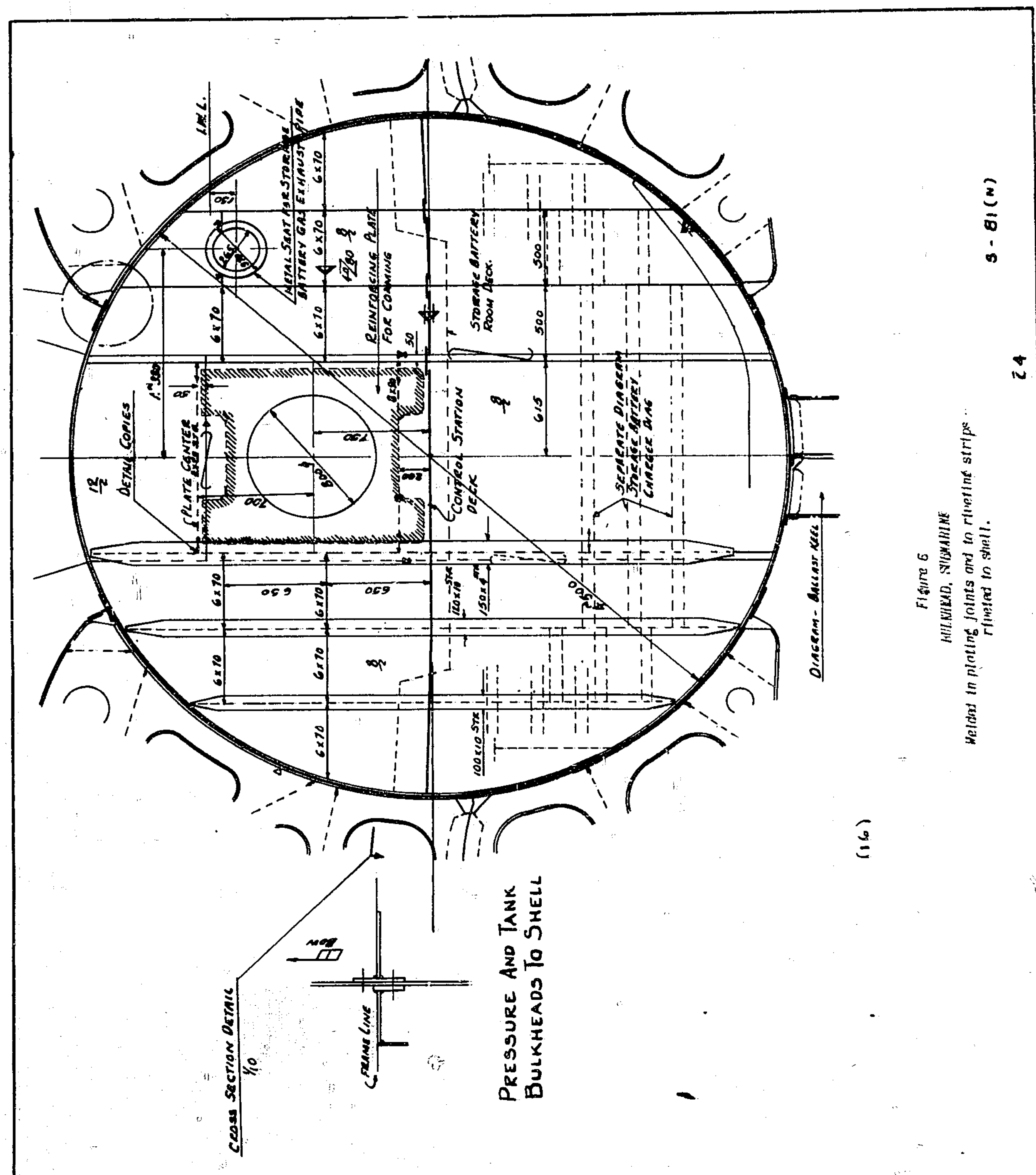


Figure 6
BULKHEAD, SUBMARINE
Welded in plating joints and to riveting strips riveted to shell.

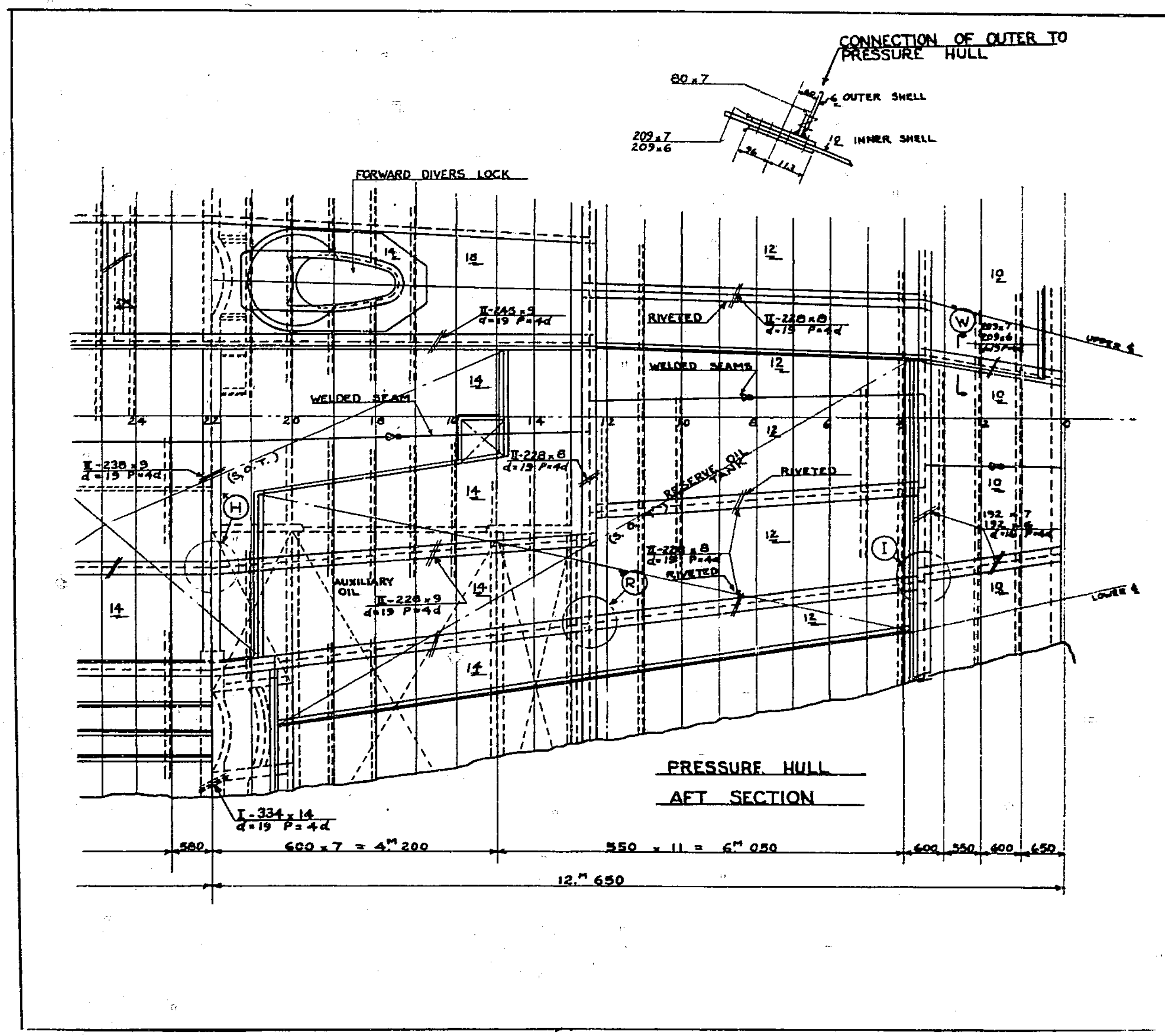


Figure 7

PRESSURE HULL PLATING, SUBMARINE

Showing welded shell panels.

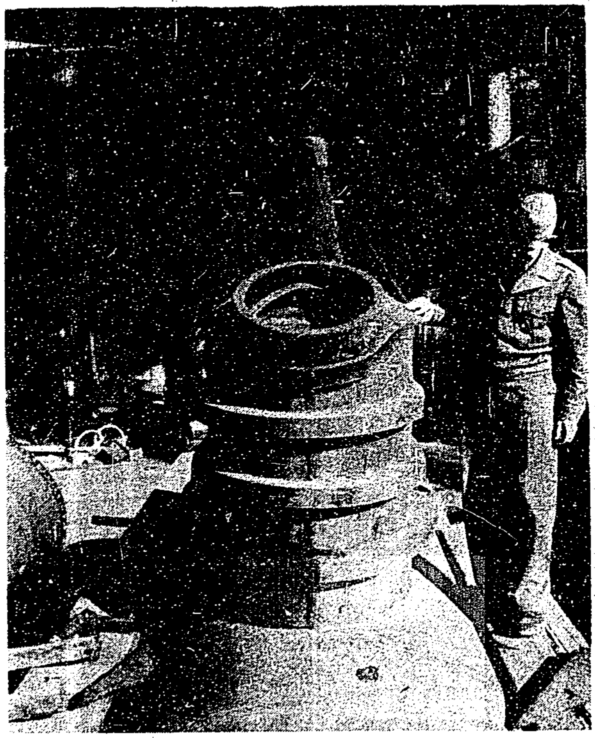


Figure 8
KORYU SUBMARINE CONNING TOWER
Note the intermittently welded stiffeners.

Figure 9
KORYU SUBMARINE INTERIOR, MIDSHIP SECTION
Note the intermittently welded frames and bulkhead stiffeners.

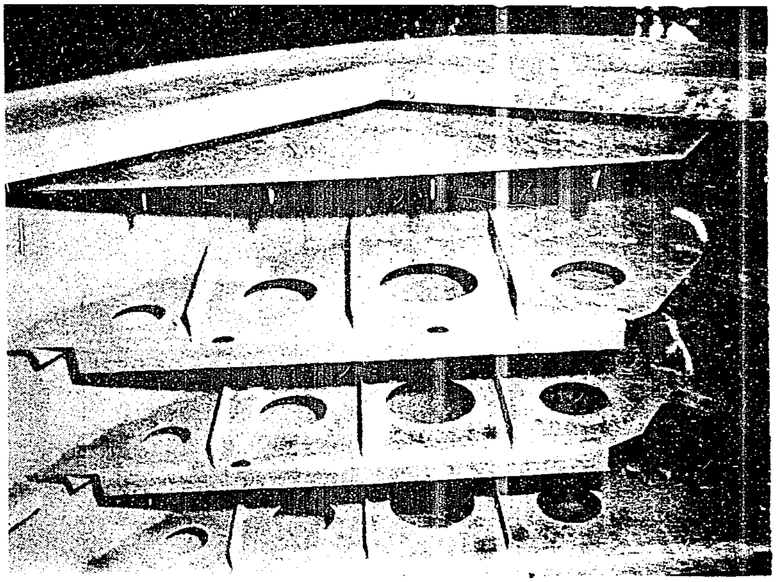


Figure 10
KORYU SUBMARINE INTERIOR, MIDSHIP SECTION
Note the intermittent welds connecting stiffeners to floors and floors to shell plating.

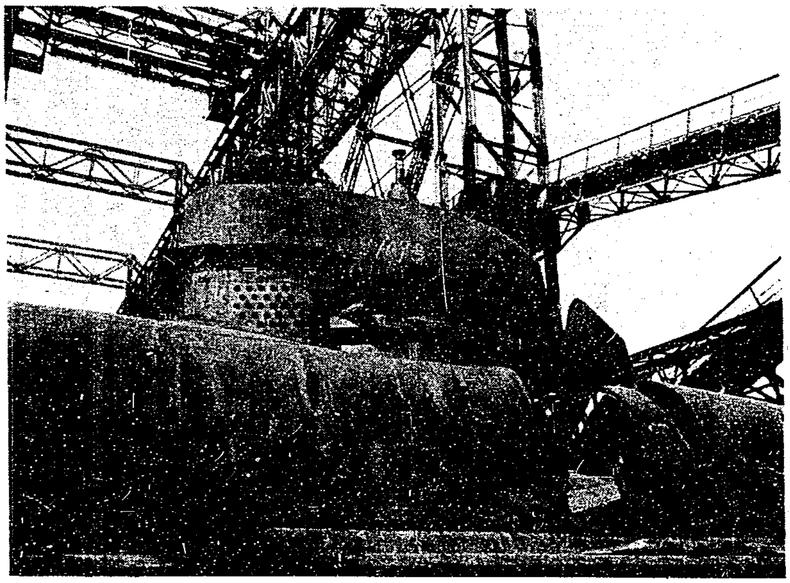


Figure 11
KORYU CONNING TOWER AND SUPERSTRUCTURE SHEATHING FIELD CONNECTIONS
Joints are of the square edge type without backing strips.

certain typical welding details, considered as indicative of standard design practices for large vessels, are shown in Figures 4, 5, 6, and 7. It will be noted that the inner hulls were of riveted design essentially, except where seams were welded to increase the size of panels; that the outer hulls were composed of welded panels riveted into the vessels' structures; that bulkheads were welded in plating joints and to stiffeners and riveting strips, but were riveted to the hulls; and that the frames were of a composite riveted welded type. The design of the all welded light tonnage vessels was conventional, in that joints or connections were of the standard flush butt and Tee type. For purposes of illustrating standard design practices, sections of the KORYU class submarine are shown in Figures 8, 9, 10 and 11. Specific design practices that differ from those common in the U.S. are shown such as the intermittent welding of frames, stiffeners and fairwaters to shells, bulkheads and conning towers, the use of welded liners in the connections of bulkheads to shells, and the use of incomplete penetration type welds, made without backing straps, to join superstructure and conning tower sheathing panels on the ways.

6. Design Specifications - Specifications governing joint design details, welding applications, and welding symbols, are set forth in booklets (see NavTechJap Documents No. ND50-1015.6 and ND50-1015.7). Promulgated by the Kure Navy Yard, these specifications were drafted at periodical conferences of welding supervisors, sponsored by the Navy Ministry.

a. Joint Designs - The joint designs specified are of the conventional type, but, by U.S. standards are lacking in detail. For butt joints, the included angles of bevel may be either 60° or 90° and maximum root openings may be equal to the diameter of the electrode used, a highly uncertain requirement when it is considered that Japanese electrodes range up to and above ½ inch in diameter. Tee joints are shown without chamfer and with the weld size arbitrarily fixed in accordance with a formula, whereby the leg length of the weld must equal the thickness of the thinner member joined. Corner joints and back strapped joints are not shown and were evidently left to the discretion of the architect and building yard. The efficiencies or strengths of the various welded connections are not given. In this connection, the Japanese practice was to assume that the average shipyard welded joint could not possibly have an efficiency greater than 70 to 75 percent and that only under laboratory conditions was it possible to achieve efficiencies approximating 90 to 95 percent of the strength of the base material.

b. Welding Application Requirements - The welding requirements set forth are basically application restrictions, placed upon the welding process in order to avoid previous construction difficulties. In brief, these requirements served as a standard for the architect and shipbuilder to follow in regard to design and construction methods and had little bearing upon the quality of welds. In general, these requirements prohibit welding in ship construction for applications such as:

(1) Main decks, innerskins, shell plating, and longitudinal strength members (except at the bow and stern).
(2) Welding on the ways.
(3) High tensile steel.
(4) Armor.

Where welding is permitted, intermittent welding is specified, except for water and oil-tight joints and for areas subject to vibration panting or gun blast. The increment and interval measurements required are as given in Table I. In the following applications, intermittent welding with ratio of length of weld increment to interval equal to ½ is specified:

(1) In the stern tanks and around the struts.
(2) Machinery foundations.
(3) To and around circular bulkheads and in areas adjacent to the turrets.

In other locations, the intermittent welding ratio 1/3 is specified generally, except for unimportant thin scantlings or bulkheads, where the ratio 1/4, 1/5, 1/6, is permitted.

c. Welding Symbols - The welding symbols specified are shown in Table II and are rudimentary as judged from the U.S. viewpoint. With these symbols, the information which may be secured or delivered on the working plans is limited to a broad definition of the type of weld to be used. Butt welds may be distinguished as chamferred or unchamferred and fillet welds as convex or flat. It is impossible, however, to indicate the depth of the groove, degree of bevel or chamfer, root face or root opening. Likewise a combination of welds such as a fillet superimposed on the groove weld of a chamferred Tee joint, may not be shown. Where the delivery of such information was necessary, the Japanese apparently preferred to detail the specific joints involved, without recourse to symbols.

Table I
INTERVAL MEASUREMENTS

Plate Thickness (cm)	Length of Weld (cm)	Interval Measurements¢				
		1/6	1/5	1/4	1/3	1/2
2.6	20	120			60	
3.0	20		100		60	
5.0	30			120	90	60
8.0	40				120	80
10.0	50				150	100

¢ Ratio of length of weld increment to interval

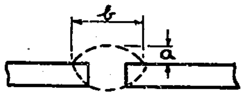
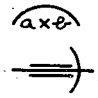
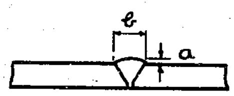
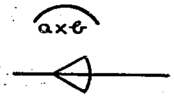
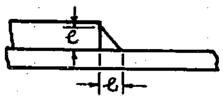
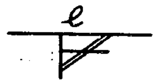
B. WELDING SEQUENCES AND PROCEDURES

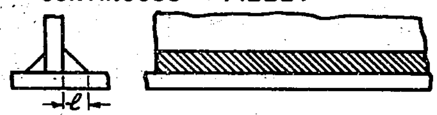
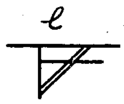
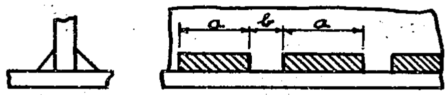
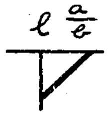
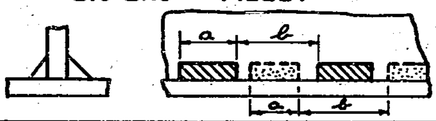
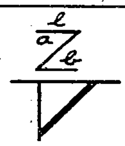
1. General - Japanese welding sequences and procedures date from the welding of MOGAMI in 1935 and were developed principally to minimize distortion. The standard rules and methods, followed in developing procedures and sequences, are outlined below.

2. Sequences - Japanese welding sequences were based upon the welding of comparatively small panels, clamped upon platens or slabs to minimize distortion. The basic rules, accepted generally throughout the building yards for both surface vessels and submarines, were similar in principle to those commonly used for welding subassemblies in the U.S., namely:

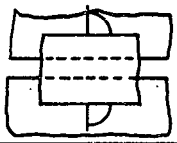
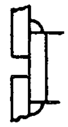
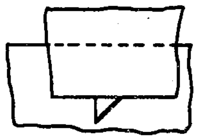
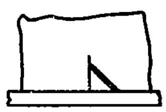
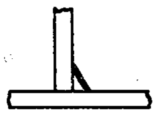
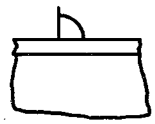
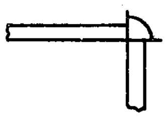
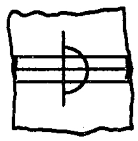
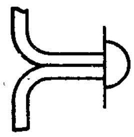
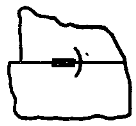
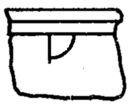
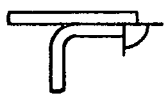
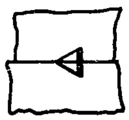
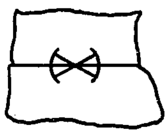
a. That butts should be welded before seams.

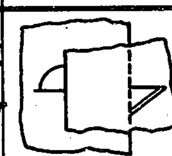
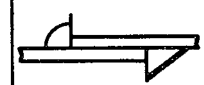
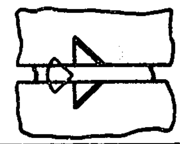
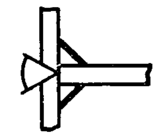
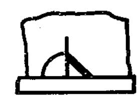
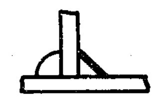
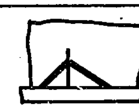
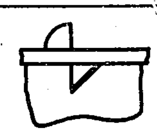
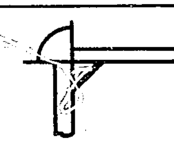
b. That the joints in framing or stiffeners should be welded after

INDICATION OF DIMENSIONS	
WELD	**SYMBOL**
	
	
	

INTERMITTENT WELDING	
WELD	**SYMBOL**
CONTINUOUS FILLET 	
INTERMITTENT FILLET 	
ZIG-ZAG FILLET 	

WELDING SYMBOLS

TYPE OF JOINT	TYPE OF WELDING	PLAN	SECTION
STRAPPED BUTT	CONVEX CORNER		
LAP JOINT	FLAT FILLET		
"T" JOINT	FLAT FILLET		
CORNER JOINT	CONVEX DEPOSIT		
EDGE JOINT	EDGE WELD		
BUTT JOINT	CONVEX "I" TYPE		
EDGE JOINT	CONVEX DEPOSIT		
BUTT JOINT	FLAT "V" TYPE		
BUTT JOINT	CONVEX "X" TYPE		

TYPE OF JOINT	TYPE OF WELDING	PLAN	SECTION
LAP JOINT	TOP CONVEX BOTTOM FLAT		
3-DIRECTION JOINT	SIDES-FLAT "V"-CONVEX		
"T" JOINT	CONVEX & FLAT		
"T" JOINT	BOTH SIDES FLAT		
CORNER JOINT	OUTSIDE-CONVEX INSIDE-FLAT		

the plating joints and prior to welding the framing to the plating.

c. That the welding of a given assembly should proceed radially and progressively out from a center point toward the free ends.

d. That the back-stepping technique of depositing weld increments should be followed where practicable.

3. Procedures - Prior to the war, a general welding procedure or welding schedule was not considered necessary by Japanese shipbuilders, since standard methods of erection were based upon riveting welded sub-assemblies together on the ways to form the vessels or sections thereof. During the war, this standard riveting procedure was modified in the following cases:

a. Cargo and small naval vessels were partially erected on the ways by welding. The procedure followed consisted of welding the usual 20 to 30 ton panel section upon the platens or slabs and of welding these panels together on the ways to form larger panels. The size or weight of the larger panels was restricted to 100 tons and below. The connections at butts and to plating of longitudinal strength members were riveted, as were the periphery connections of bulkheads, floors, and shell or deck panels. No special sequence outside of that given in paragraph B-2, was developed for the welding.

b. A general welding procedure was established for the construction of submarines of the all-welded type. The procedure used in constructing the KORYU class submarine may be regarded as typical of those established for other classes. For the KORYU class, a welding procedure was necessitated by the assembly line method of erection involved, in which the various parts, hull section, etc. progressed from work station to work station, on rollers and skids, until at final assembly the practically completed sections were joined to form the hull proper. The welding procedure employed during the course of erection, could be laid down as follows:

(1) Tack the shell plating, interior frames, floors, and bulkheads in place, after installing temporary ring stiffeners at the ends and at intervals throughout the shell sections.

(2) Weld the root or inside seal bead pass of the single Vee type welds in the shell plating.

(3) As the inside seams are seal welded and the sections are rotated, progressively weld the frames, floors and bulkheads to the shells.

(4) Weld the exterior seams.

(5) Remove only the temporary jigs or stiffeners in fitting the next shell section into line.

(6) Tack the two shell sections together; if necessary, install additional temporary ring stiffeners.

(7) Without rotating the structure and in the order given, weld the interior butts and seams, seal bead pass, and tie in the framing; weld the exterior butts and seams.

(8) Repeat (5), (6), and (7) above, for the next section fitted into line.

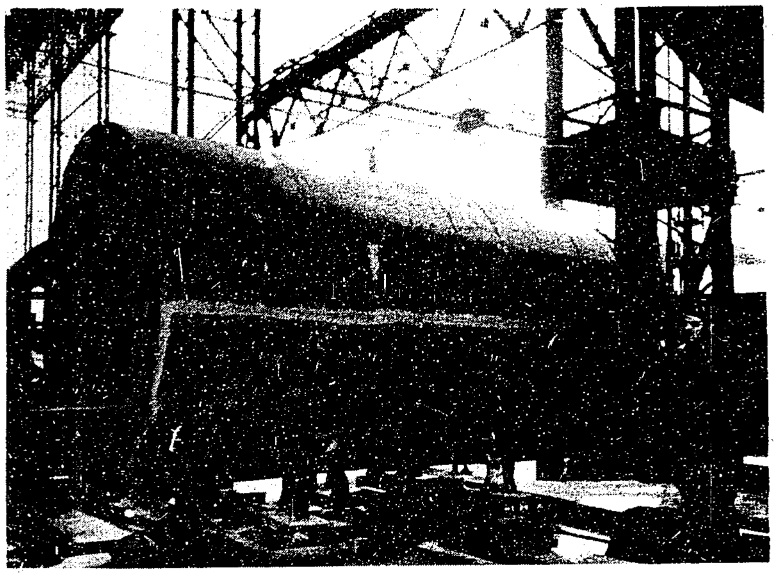


Figure 12
KORYU SUBMARINE, HULL SECTION
Showing seam weld - end ring stiffener and travel carriage rollers.

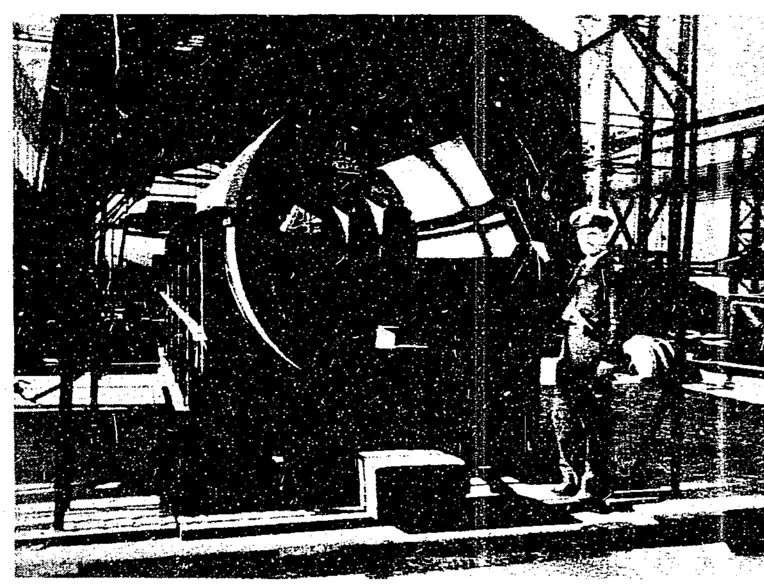


Figure 13
KORYU SUBMARINE, HULL SECTION
First operation showing temporary interior ring stiffeners and fitting platen.

Figure 14
KORYU SUBMARINE, HULL CENTER SECTION FINAL ASSEMBLY
Interior welds made; ready for back chipping.

Figure 15
KORYU SUBMARINE, ASSEMBLY LINE

Briefly analyzed, the welding procedure described in the foregoing was based in principle upon a method of minimizing distortion by means of temporary ring stiffeners and by installing sufficient of the interior frames and bulkheads to achieve rigidity of structure. Details of ring stiffeners and hull sections are shown in Figures 12, 13, 14, and 15.

PART III - WELDING RESEARCH

Research on electric welding was carried out independently at KURE and YOKOSUKA Navy Yards and at the Naval Technical Institute, Meguro, TOKYO. Liaison between the various research centers appears to have been weak, although experiment reports were circulated among the yards. Private shipyards did little research work on their own account. The Japanese government did not receive or ask for assistance from private sources in welding research. The various research projects are described below.

A. LARGE-DIAMETER ELECTRODES

Electrodes up to 8mm (5/16") in diameter came into general use at KURE Navy Yard in 1939 and were found successful, and in 1941 research into the use of even larger rods was commenced. The investigation was conducted by Captain YADA and Mr. TSUJI and is described by TSUJI with considerable verbosity in NavTechJap Document No. ND50-1121. The principal results were as follows:

1. Strength - Welds were made with rods 13, 16 and 19mm in diameter of various core compositions. The coating used throughout was the standard "M.K. 23", the composition of which is shown in the section "Electrodes". Mechanical tests were carried out on welded joints and all-weld-metal specimens. The results are shown in Tables III and IV. All values quoted are in each case the mean of three test results. It was deduced from the test results that welds made with large rods were equal to those made with small rods in tensile strength but were inferior in elongation. However, earlier research was quoted as showing that, even for small electrodes, welds in thick plates had a poor elongation in any case, and so it was claimed that the low elongation figures could be blamed upon the plate thickness rather than upon the large electrode diameter. An investigation into the effect of introducing up to 0.4% copper into the core metal gave inconclusive results.

2. Length-Diameter Relationship - Mr. TSUJI pointed out that the length of rod was limited only by ease of handling and resistance of the coating to heat and gave the following figures:

Diameter		6 - 7mm	8 - 10mm	13 - 16mm
Length -	Manual	600mm	800mm	1mm
	Automatic	1mm	1 - 2 m	1 - 2 m

3. Distortion - Linear contraction and angular distortion were as follows for a 60° V - butt joint in 22mm, M.S. plate.

Rod Diam (mm)	Linear Contraction (mm) (Gauge Length - 180mm)	Angular Distortion	
6	3.55	6°	High shrinkage attributed to "excessive melting of base metal".
8	3.08	5°	
13	1.90	4°	
16	2.85¢	3°	
19	2.40¢	3°	

Table III
VEE BUTT JOINTS

Core Wire	Diam. (mm)	Core Analysis							Test Results	
		C	Si	Mn	P	S	Cu	Ni	U.T.S. (kg/mm^2)	Elongation (%)
A Exper. Wire. t=22mm	13 16 19	.10 .10 .10	.06 .06 .06	.28 .28 .28	.005 .005 .005	.024 .024 .024		.05 .05 .05	54.9 54.4 55.9	17.0 25.8 16.9
B Rivet Bars. t=22mm	13 16 19	.17 .20 .27	.21 .03 .14	.33 .48 .60	.014 .028 .034	.016 .048 .039	.15 .22 .21		55.3 53.2 56.5	20.7 20.9 12.2
C Rivet Bars. t=22mm	13 16 19	.22 .13 .38	.16 .18 .17	.52 .50 .79	.030 .013 .057	.038 .035 .035	.22 .16 .24		55.3 53.2 56.5	20.7 20.9 12.2
D YAWATA Steel-works Exper. Wire. t=20mm	10 13 16	.05 .11 .12	.01 .015 .01	.27 .27 .28	.011 .015 .02	.037 .037 .041	.29 .26 .25		54.3 50.8 50.7	16.1 12.7 15.2

Note: (1) Gauge length used in measuring elongation % not quoted.

(2) 1 kg/mm^2 = 1.442 lb/in^2 = 0.635 English Ton/in^2.

Table IV
ALL-WELD-METAL TESTS

Core Wire	Specimen	Rod Diam (mm)	Yield (kg/mm^2)	U.T.S. (kg/mm^2)	Elongation¢ (%)	R.A. (%)	Brinell Hardness
C Rivet Bars	Right-Angles to Bead	13 16 19	36.7 35.9 37.4	47.2 46.2 48.5	26.0 19.4 17.1	42.2 42.9 39.1	132 129 133
	Parallel to Bead	13 16 19	31.8 32.0 34.3	43.9 45.9 47.8	18.9 25.9 17.1	35.8 37.7 31.7	122 127 134
D YAWATA Steel-Works Exper. Wire	Right-Angles to Bead	10 13 16	31.1 30.1 31.9	41.4 44.9 42.7	13.9 23.2 17.1	29.6 52.6 26.5	128 123 119
	Parallel to Bead	10 13 16	32.2 29.1 28.4	43.6 39.8 41.8	26.4 20.5 28.0	40.7 33.7 36.8	121 112 116

¢ Gauge-Length = 50mm

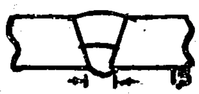
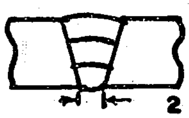
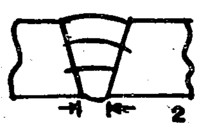
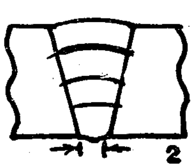
2. Length - Diameter Relationship - Mr. TSUJI pointed out that the long length of rod was limited only by ease of handling and resistance of the coating to heat and gave the following figures:

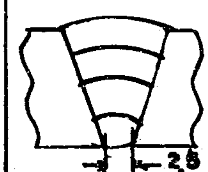
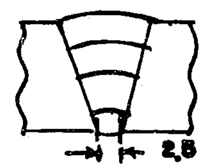
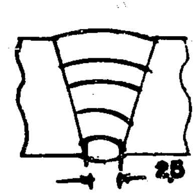
Diameter		6-7mm	8-19mm	13-16mm
Length -	Manual	600mm	800mm	1mm
	Automatic	1mm	1-2m	1-2m

3. Distortion- Linear contraction and angular distortion were as follows for a 60° V - butt joint in 22mm M.S. plate.

Rod Diam. (mm)	Linear Contraction (mm) (Gauge Length 180mm)	Angular Distortion
6	3.55	6°
8	3.08	5°
13	1.90	4°
16	2.85*	3°
19	2.40*	3°

DESIGNS, FOR ½-AUTOMATIC WELDING.

PLATE THICKNESS	JOINT	NO PASS	ROD DIA.	CURRENT AMPS,
8 MM.		1 2	5 8	190 300
10 MM.		1 2	5 8	190 320
12 MM.		1 2 3	5 5 8	190 200 340
14 MM.		1 2 3	5 8 8	190 385 385
18 MM.		1 2 3 4	6 6 8 11	240 240 300 490

P'TE	JOINT	NO PASS	ROD DIA	CURRENT AMPS.
20 MM.		1 2 3 4	5 8 18 13	200 300 640 640
25 MM.		1 2 3 4	6 8 13 19	240 365 640 870
30 MM.		1 2 3 4 5	6 8 13 13 19	240 365 640 640 870

NOTE.- IN FIRST RUN IN ALL CASES WELDING IS MANUAL

4. Rod Diameter and Current Related to Plate Thickness - Some proposed joint designs and recommended current values for various size plates are as shown in Table V.

5. Power and Rate of Fusion - Table VI shows experimentally observed values of deposition time per meter of rod, KVA and KVA per unit volume fused. Note that volumes quoted are volumes of electrodes consumed and not of metal actually deposited, no account having been taken of spatter. Note

*High shrinkage attributed to "excessive melting of base metal".

also that no account has been taken of power factor; the experiment report refers to KVA as "power".

Table VI
FUSION SPEEDS AND CURRENT CONSUMPTION

Rod Diam	Sect. Area (mm^2)	Current (amps)	Fusion Time 1m Rod (sec)	Volume Fused Per Sec (mm^3)	Current Density (amp/mm^2)	Arc Voltage	KVA	KVA (mm^3 10^{-3})
3.2	8.05	105 (20%over) 132	239 218	33.6 36.9	13.00 16.40	20	2.10 2.65	63 72
4	12.55	155 (20%over) 186	228 183	56.1 68.7	12.35 14.80	22	3.40 4.10	60 60
5	19.60	215 248	254 214	77.2 91.6	10.95 12.65	32	6.90 8.00	89 87
6	28.25	260 312	307 225	92.0 125.5	9.20 11.05	32	8.30 10.00	90 80
8	50.25	315 376	315 255	159.5 197.0	6.27 7.50	32	10.05 12.05	63 61
10	78.6	400	350	224.0	5.10	33	13.20	59
13	132.5	550	358	370.0	4.15	34	18.70	50
16	201.0	700	363	554.0	3.42	35	24.50	44

c. Power Supply - This was in all cases 50 cycle AC, 80 volt open circuit, provided by two standard shipyard transformers in parallel. A large 1500 ampere transformer produced by HITACHI had been found satisfactory, but production difficulties prevented its general use.

7. Automatic Welding Methods - These were considered to have many theoretical advantages, notably uniformity of output and ability to handle rods too large to use manually. Every effort was made to extend the use of the YADA semi-automatic machine (described in a later section). It was admitted, however, that the space occupied by the machine and the time taken in setting it up ruled out the semi-automatic process for most shipyard work, and in fact the machine was only found suitable for heavy downhand butt joints. (An electrode 2 meters x 25mm was actually employed for this work, but no test results were available). Comparative tests on similar manual and automatic welds showed the manual weld to be only very slightly inferior in mechanical properties and appearance.

8. Difficulties Encountered

a. It was found that the heavy currents, used with large rods, tended to cause overheating of an area of plate in the neighborhood of the arc, causing a local deterioration in the mechanical properties. With this problem in mind, further research was proposed (1) on flat electrodes and (2) on the twin rod multiphase system, but no progress had been made at the end of the war.

b. Physical limitations - Electrodes over one meter long were found impractical for manual use. Even then it was found necessary to use the touch - technique.

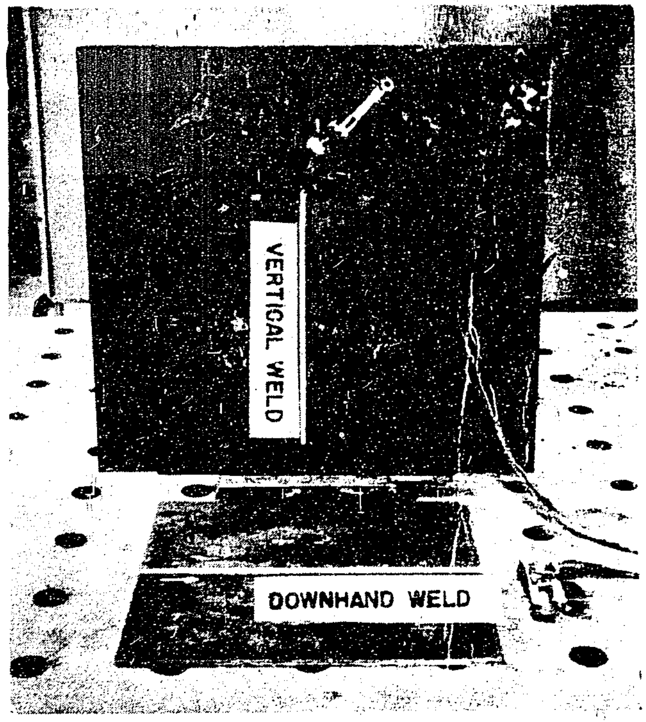


Figure 16
"FIRECRACKER METHOD" - METHOD OF HOLDING ELECTRODES

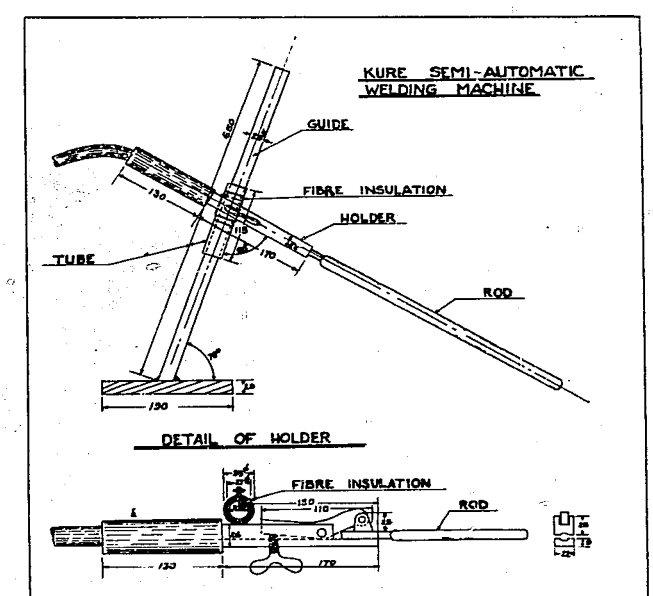


Figure 17
DIAGRAM, SEMI-AUTOMATIC WELDING MACHINE

c. Rods up to 8mm were found suitable for fillet welds, but rods above 8mm were thought to be suitable only for downhand V - butt welds. It was not considered feasible to "position" fillet welds for downhand work.

d. Specialized training was found essential for welders using large electrodes. A party of suitably trained men at KURE produced very good results.

9. There appears to have been no metallurgical investigation into big - electrode welding.

10. Conclusions - The low impact values notwithstanding, it was considered that the advantages of speed and efficiency fully justified the widest possible extension of big rod welding for work of all kinds.

B. THE FIRECRACKER SYSTEM

This system, developed by Professor AKASAKI at the Naval Technical Institute, Meguro, TOKYO, is described in NavTechJap Documents Nos. ND50-1110.1 to 1110.3. The system is not original and may be described as follows. A coated electrode is gripped at one end by a chuck and held so that it lies flat in the groove. The chuck is attached to a permanent or electro-magnet by which it is secured to the plating being welded. A small electro-magnetic holder is shown in Figure 16. Electrode and groove are covered with powder flux, and the arc started. The arc burns automatically until the whole of the electrode is consumed. To ensure against premature extinction of the arc, it was found that the coating should not exceed 0.2 x diameter of rod in thickness. Rods, ranging in size from ordinary 5mm shipyard electrodes up to specially made rods 20mm x 5 meters long, it is claimed, have been used with success, though little information on work done with large sizes is available. Long rods have to be held down into the groove by weights or pieces of adhesive tape.

The function of the powder flux is to enable high currents to be used, hence speeding up deposition. The flux also secures a smoother bead. Various substances have been tried as a flux, including lime, glass powder, coarse and fine sand and "Unionmelt" powder. Unionmelt has been found best, followed by sand, coarse and fine grain sizes being equally effective. Speeds of deposit of up to five times the normal manual welding speeds are claimed. Current values are given by the relation current in amperes = 40 x diameter in mm for DC or 50 to 55 x diameter in mm for AC. It is claimed that the process can be used vertically or overhead, but in these cases the powder flux has to be dispensed with, and welding speeds are decreased by one-third. The edge preparation is a 45° bevel, giving a 90° groove with 1mm gap and 2mm "standing leg" or "root face". The advantages claimed for the method are speed, soundness of weld, reduction of the personal factor, fine grain structure, good mechanical properties, and ability to weld inside pipes. The disadvantages, pointed out by representatives of shipyards which tried the system, are the necessity of a very high standard of edge-preparation and set-up, the tendency of the deposit to fall more heavily on one side of the groove than on the other, and the habit of the arc of extinguishing itself in the middle of a run.

The firecracker process was never used on production.

C. SEMI-AUTOMATIC WELDING MACHINE

This machine was developed by Captain YADA and Mr. TSUJI at KURE Navy Yard and is described in NavTechJap Document No. ND50-1119. It resembles generally the "MUREX" deck welder, and the operation may be described as follows: An electrode is gripped in a holder which slides down an inclined guide in such a way that the rod is fed into the groove at a constant angle of inclination. The

Figure 18
PHOTOGRAPHS, SEMI-AUTOMATIC WELDING MACHINE

electrode tip rests actually in contact with the groove walls. Machines were made in two sizes. The smaller type was designed for use with electrodes 1 meter long and is illustrated in Figure 17. The large type was designed for electrodes 2 meters long and 25mm in diameter with a current of 1500 amperes. Figure 18 illustrates this machine in action.

It is admitted that welds made by the semi-automatic machine have a poor elongation and coarse grain-structure.

The process was used for welding seams of submarine pressure hulls and butts and seams of bulkheads.

D. AUTOMATIC WELDING PROCESSES

The "unionmelt" automatic welding process was tried at KURE and YOKOSUKA, but in neither case was any success obtained. The process was never employed on production.

An automatic machine using bare 5mm wire was manufactured by Shibaura Electric Co. The rate of feed of wire in this machine was regulated by the potential across the arc which, acting through a relay, speeded up or slowed down the feed motor as required. This machine was tested at MEGURO, using both "unionmelt" flux and unprotected arc, but results were unsatisfactory. The machine was never employed on shipyard production work although MITSUBISHI used it for fabricating large diameter pipes.

E. TWIN ROD MULTI-PHASE WELDING

Some experiments were conducted at KURE in 1943 in which twin electrodes, secured side by side, were used. The supply was 2 - phase AC, the electrodes being connected to the ends of the transformer secondary and the work to the center - tap. It was claimed that this method gave a very smooth deposit. It was never employed on production. The experiments and test results are described in NavTechJap Document No. ND50-1120.

F. NON-FERROUS WELDING

Non-ferrous electric welding was never employed on production work. Some bronze electrodes were produced by a small Hiroshima firm and submitted to the Meguro laboratory but were not considered worth testing.

Oxy-acetylene welding was employed for small brass and aluminum fittings.

G. WELDING OF ARMOR

1. Armor to Armor - The welding of armor to armor was never employed and seems never to have been contemplated.

"Ducol" plating was sometimes welded where fitted for protective purposes, and where strength was not important. Some work done at YOKOSUKA in 1934 on the welding of "Ducol" is described in NavTechJap Document No. ND50-1126.

2. M.S. and H.T. Plate to Armor - Some experimental work done on welding structural plate to N.C. armor was done in 1934 and is described in NavTechJap Document No. ND50-1113. In later ships, welding was employed to a small extent for attaching unimportant structure to N.C. armor. Welding to cemented armor was never attempted.

Austenitic electrodes were never used for welding armor. However, a nickel-chrome austenitic rod was used at the Naval Air Arsenal, YOKOSUKA for experimental work on the welding of alloy steels.

H. UNDERWATER WELDING AND CUTTING

1. Underwater welding was used on emergency repair work for jobs such as the blanking of holes. The process was not considered a complete success as the deposit was brittle and irregular. Ordinary dockyard-made electrodes were used with a binding of insulating tape. The current supply was DC, and the diver experienced no trouble from shocks.

2. An underwater oxy - hydrogen cutting torch, copied from a Russian model, was tried at YOKOSUKA but was abandoned because no method could be found for relighting it underwater if once extinguished.

3. Underwater cutting, using tubular steel electrodes carrying a stream of oxygen, was used for emergency repair work. It was admitted that the cut was rough and electrode consumption heavy but the method was preferred on account of its simplicity.

I. FLAME GOUGING

An oxy - acetylene flame gouging torch was developed at KURE by Mr. TSUJI. The torch is described in NavTechJap Document No. ND50-1122. The nozzle was developed from a German Model. The center orifice is 4.5mm in diameter and emits the cutting oxygen. The heating orifice is concentric with the cutting orifice and is 8.5mm in diameter and 0.5mm wide. The torch employs low pressure acetylene from carbide generators. Oxygen cutting pressure is 7.5 kg/cm^2.

The flame gouge came into use at KURE in early 1945 and was employed in taking out the back run in butt welds and in removing cracked welds and welds shown to be defective by radiographic examination. The other yards had not proceeded beyond the trial stage at the end of the war.

PART IV - WELDING EQUIPMENT

A. SHIPYARD WELDING PLANT

1. Current Supply - Eighty volt AC is used almost universally for ship yard work both in the navy yards and in private firms. Each welder is provided with an individual transformer, input to which is generally 200 - 240 volt single - phase AC. The transformers are of the air-cooled type, some being provided with small fans. Current settings are obtained by opening and closing a gap in the magnetic circuit for fine adjustment and tapping the secondary for coarse adjustment. The standard transformer has a capacity of 260 amperes, though larger sizes of similar construction giving up to 400 amperes are found in the yards. The transformers are mounted in large steel boxes on wheels, are crude in construction, and vibrate loudly when operated. Typical transformers are illustrated in Figures 19 and 20. That shown in Figure 19 is fitted with a fan. A few very large air-cooled transformers with a capacity of 1775 amperes and built by Hitachi Co. were used on large - electrode development work at MEGURO and YOKOSUKA.

A very small amount of constant potential DC welding apparatus was used, in most cases for shop work. A few portable DC single operator sets with a capacity of 300 amperes also were used.

2. Electrode holders are generally copies of American types. A typical speciman is shown in Figure 20.

3. Headshields are of light fiber construction, fitted with glasses 4" x 2½". Both single green glasses and ruby-blue combinations are found.

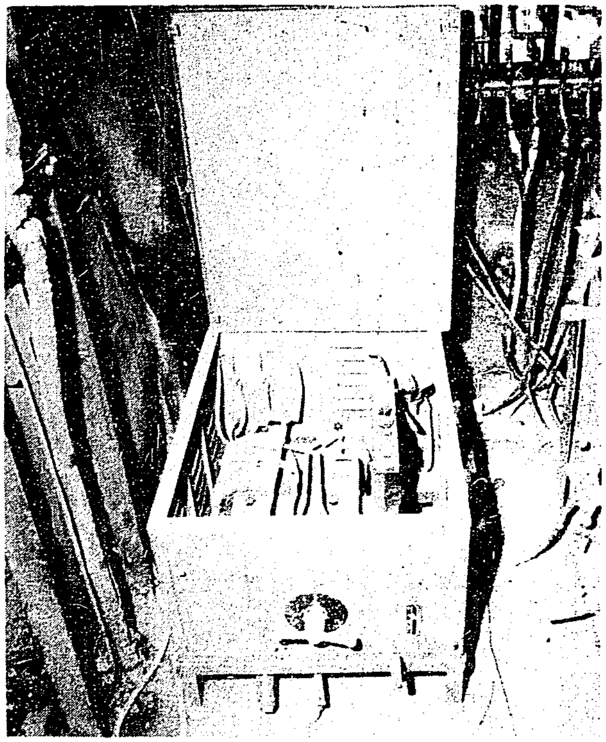


Figure 19
TRANSFORMER

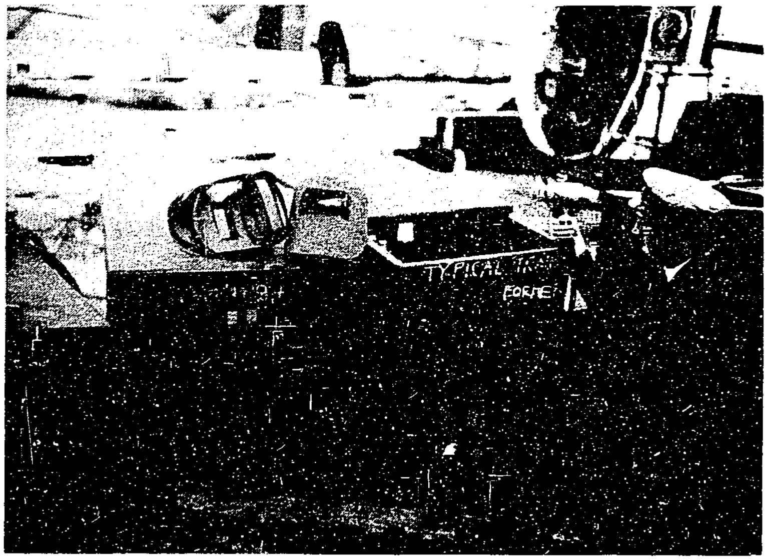


Figure 20
WELDING TRANSFORMER AND ACCESSORIES

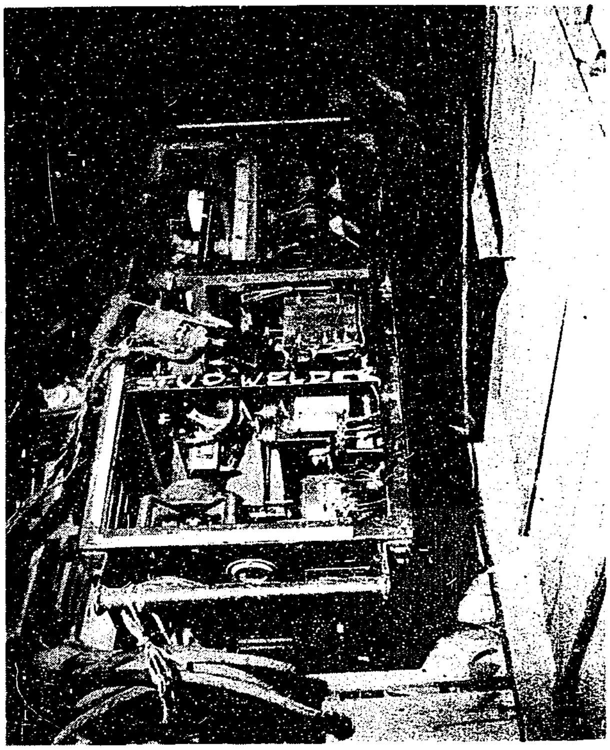


Figure 21
STUD WELDER

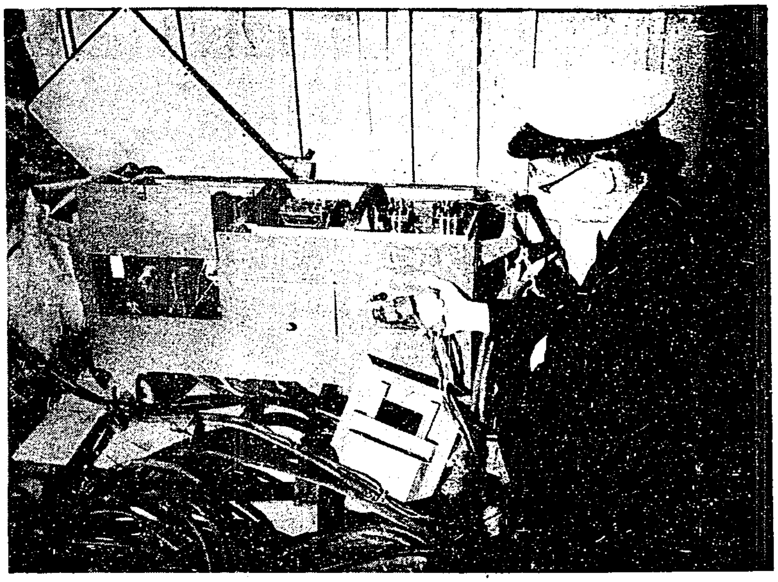


Figure 22
STUD WELDER

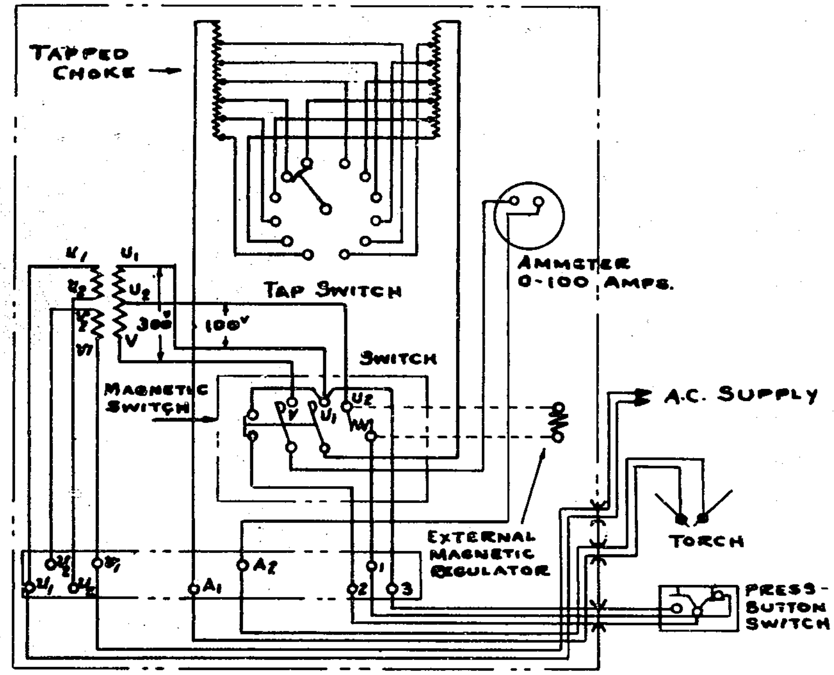


Figure 23
CIRCUIT DIAGRAM, ATOMIC HYDROGEN SET

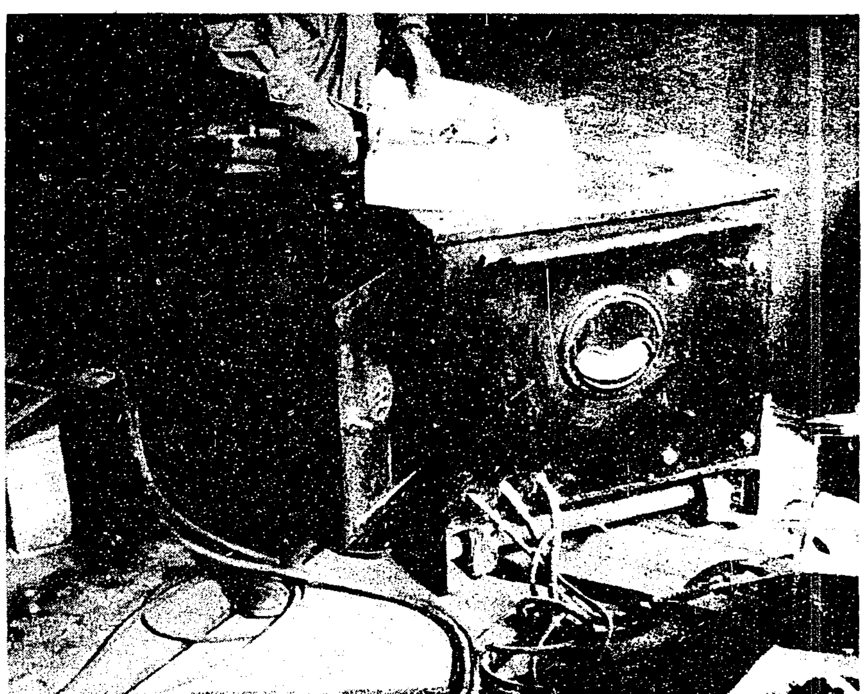


Figure 24
ATOMIC HYDROGEN SET

Hand screens are used for shop work. Typical headshields are shown in Figure 20.

4. Stud - welders resembling the "CYC-ARC" machine were used for securing small brass studs to steel structure. The transformer unit and gun of a set found at YOKOSUKA are shown in Figures 21 and 22.

B. ATOMIC HYDROGEN PROCESS

This process was not used in shipyard work. Atomic hydrogen sets manufactured by the Shibaura Electric Co. were employed, however, at the Naval Air Arsenal, YOKOSUKA, for tipping tools and for welding the blades of gas turbines using an austenitic filler-rod. The sets consist of an aircooled transformer supplying up to 100 amperes AC, and a tapped choke for regulating current. The torches are clumsy and crude in construction. The circuit diagram of the set is shown in Figure 23. The torch and transformer are shown in Figure 24.

C. BURNING PLANT

The only fuel gas used was acetylene. Dissolved acetylene in cylinders was very seldom employed during the war owing to its high cost. Plate shops are fitted with large carbide gas generators and gas holders, the gas being distributed as required by pipes. Small portable generators are provided for work at ships. Burning torches, reducing valves and gauges are of conventional type and are mostly manufactured by Imperial Oxygen Co. Flame gouging torches were in use at KURE and are described in the section on Research.

Oxy - acetylene plate-edge preparation machines, consisting of one or two cutting torches mounted on an electrically driven carriage running on a track, are found at most yards. They have no novel features. A machine intended to give a U-shaped edge-preparation was produced by MITSUBISHI, at Nagasaki. It consisted of a carriage carrying a flame-gouge and was not successful.

D. ELECTRODES

The various navy yards and private shipyards manufactured their own electrodes. There were no large-scale private electrode manufacturing firms in Japan, though various small firms existed. Specifications giving required mechanical properties of weld deposit were laid down by the Japanese Navy Ministry. Although the standard was reduced during the war, the various yards could not meet these specifications, and apparently made very little effort to do so in the later stages of the war. The latest set of specification (November, 1942) is shown in NavTechJap Document No. ND50-1117 and summarized in Table VII.

The core wire was manufactured by private wire-drawing firms. The composition mechanical properties were checked at the works by the Navy Ministry inspector. The wire was supplied to the yards in coils as shown in Figure 25. Each of the various shipyards mixed and applied its own coating compositions. Details of coating and mechanical test results of two typical rods made at the Kure yard are shown in NavTechJap Documents Nos. ND50-1111 and 1112. The core and coating compositions of the "M.K.23" general purpose all-position mild-steel electrode manufactured at the Kure yard are as shown below:

CORE ANALYSIS

C	.06 - .08%
Si	.03%
Mn	.35 - .45%
S	.03%
P	.03%
Cu	.10%

Figure 25
ELECTRODE WIRE

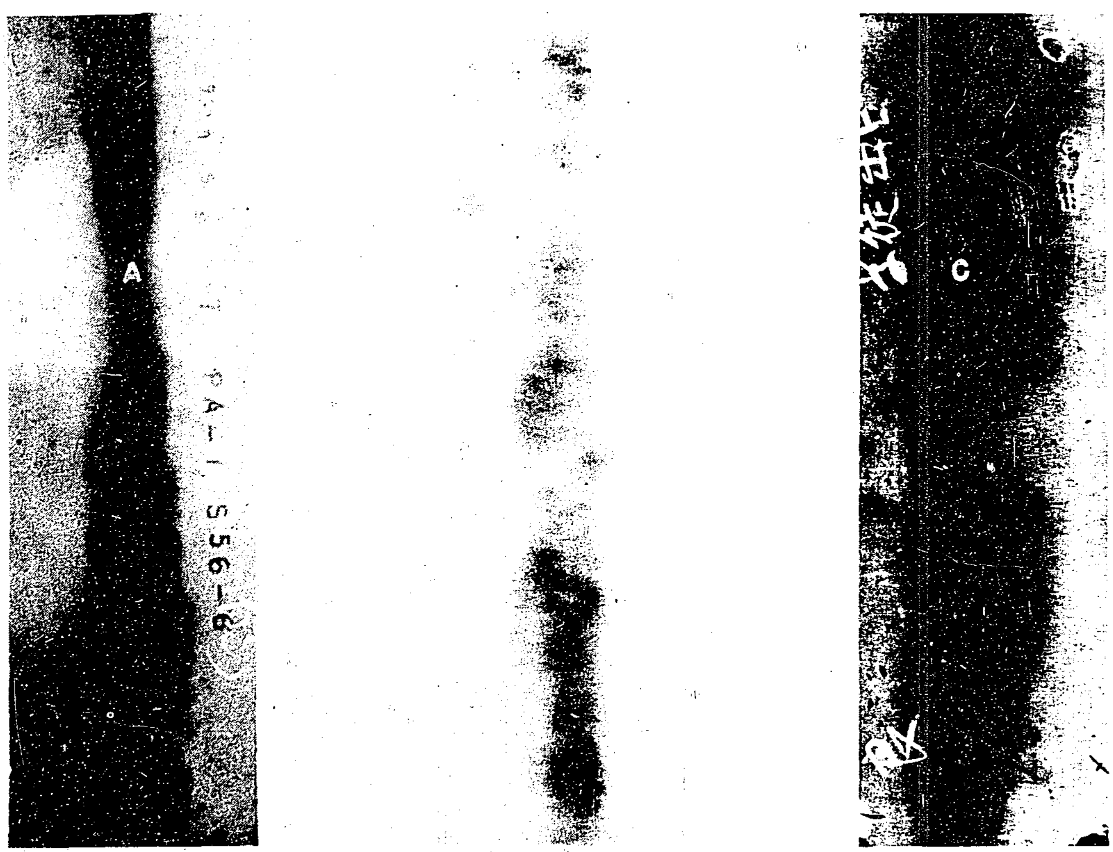


Figure 26
SUBMARINE WELDS, A, B AND C
"Typical radiographs of welds in submarine pressure hulls".

TESTS
All-Weld-Metal

Yield Point .... 43.2 kg/mm^2
U. T. S. .... 51.8 kg/mm^2
Elongation .... 32.5 %
Reduction of Area .... 49.8 %

TABLE VII
TEMPORARY NAVAL SPECIFICATION FOR COATED ELECTRODES
FOR M.S. SHIP CONSTRUCTION

(All results are the mean of three specimens.)

Test		M.S. Plate V-Butt Weld	All-Weld-Metal
Tensile	Min. U. T. S. Min. Elongation	45 kg/mm^2 18 %	41 kg/mm^2 28 %
Charpy Impact		25 KgM	30 KgM
Fatigue	Stress limit for 4×10^6 cycles min.	17 kg/mm^2	
Bend Test	800° - 900° C 180° Bend	No surface imperfections	
Forging Test	At 800 - 900° C Specimen is hammered to thickness of 2mm	No surface imperfections	
Minimum Specific Gravity			7.8

Some specimen "MK 23" and "MK 1" electrodes seized at KURE have been shipped to the United States (NavTechJap Equipment Nos. JE22-2029 and JE22-2030).

Detailed information on standards and welding specifications are contained in NavTechJap Report, "Japanese Welding Standards," Index No. X-36(N).

The extrusion process was used for coating the standard shipyard rods (400 x 3.5mm and 400 x 5mm) while the large rods (1 meter x 13mm and larger) used for the semi-automatic process were coated by dipping. Wound rods were never used. The electrodes made in the navy yards were intended for all-position use, although the YOKOSUKA yard did at one time produce a special rod for overhead work, it was not used extensively. The general policy was to manufacture one type of rod for use in all positions, thus simplifying production and distribution of rods. It was also felt that the labor employed was not of high enough standard to be relied upon to correctly decide between different types of rods, if available. Some electrodes from each batch manufactured were subjected to tests at the manufacturing yard as follows: (1) Simple bend test on a butt weld, (2) two plates were joined by a fillet which was fractured by forcing the plates together.

If a 180° bend was obtained without fracture in (1), and the fracture in (2) was clean, and in addition the weld bead had a good appearance, the batch was passed for main structural welds. If the batch was rejected, it was relegated to unimportant work. Electrodes from each of the navy yards and private yards were tested from time to time at the Naval Technical Institute, MEGURO, and at the Naval Architecture Research Laboratory, KURE, but these tests were spasmodic and no action appears to have been taken as a result of them.

TABLE VIII
COMPOSITION OF COATING OF THE "M.K. 23"
GENERAL-PURPOSE ALL-POSITION MILD-STEEL ELECTRODE MANUFACTURED AT KURE
(This coating was used in Large-Electrode Research work, Q.V.)

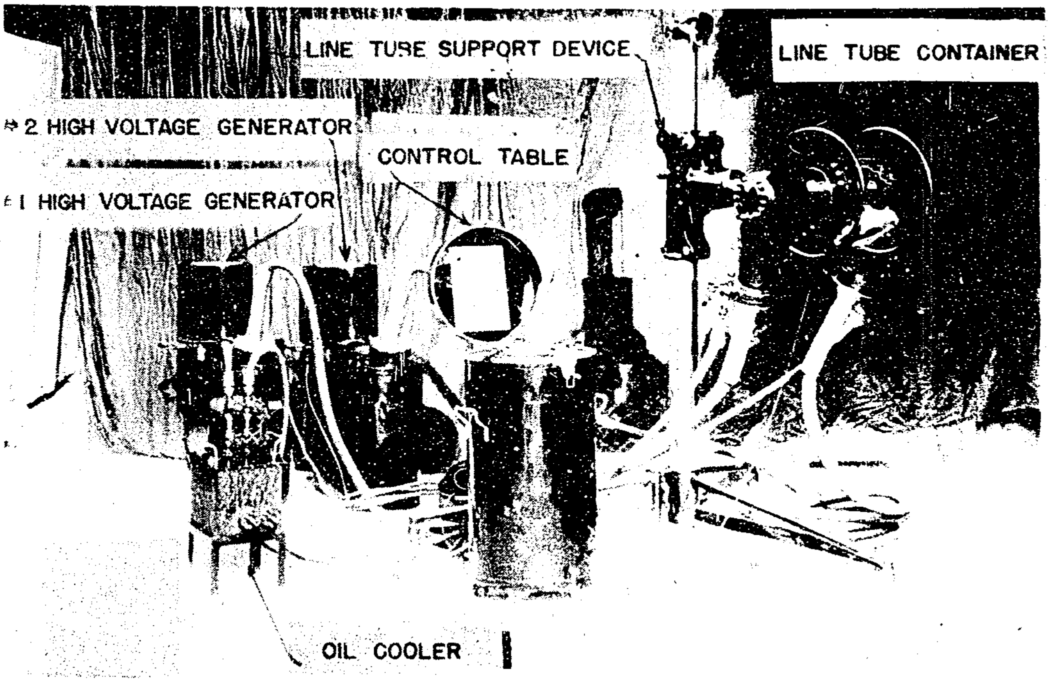
Substance	Analysis	Amount (kg)
Ilmenite	TiO_2-48 FeO-42-45 CaO-2 SiO_2-2 Al_2O_3-2 MgO-3 MnO-2 Cu-.05	30
Soapstone	Magnesium Silicate MgO-64 SiO_2-36	20
Sand	SiO_2-99	10
Blue Asbestos	SiO_2-40-45 Al_2O_3 17-19 Fe_2O_3 8-10 CaO 7-9 MgO 16-199	10
Ferro-Manganese	Mn-74 C 5-7 Cu-.05 Si-2.5 P-.3 S .01 Fe Remainder	15
Manganese Dioxide	MnO_2-74-78 SiO_2-.2 MgO-.33 Al_2O_3-.7 Fe_2O_3-.6	6
Gum Arabic	>88% Dextrine	4
Sodium Silicate Solution	Na_2O-17 SiO_2-344 NaCl-2.6	26 for Extrusion 43 for dipping

E. RADIOGRAPHY

Trials of X-ray apparatus were made in all the navy yards but only in the Kure yard was radiography employed on production work where regular radiography examination of submarine pressure-hull welds commenced in March 1945. Two similar sets were used, one of which is illustrated in Figure 27 and 28. NavTechJap Document No. ND50-1128.1 gives a detailed description of the sets, principal particulars of which are as follows:

Maximum Tube Voltage.................... 200 KV
Maximum Tube Current .... 4 ma
Power Consumption .... 2.6 kw
Maximum Steel Penetration .... 70 mm
Total Weight of Set .... 650 kg
Weight Including Carriage .... 930 kg
Sensitivity .... Film indicates 2% of plate thickness
Tube Cooled by Circulating Oil
(The sets have now been handed over to the Railway Research Establishment, TOKYO.)

An elaborate book of rules was produced laying down percentages of welds to be examined and procedure for reporting on examinations. (NavTechJap Document No. ND50-1128.2). From this document, it is evident that it was intended systematically to X-ray important structure in surface ships. However, up to



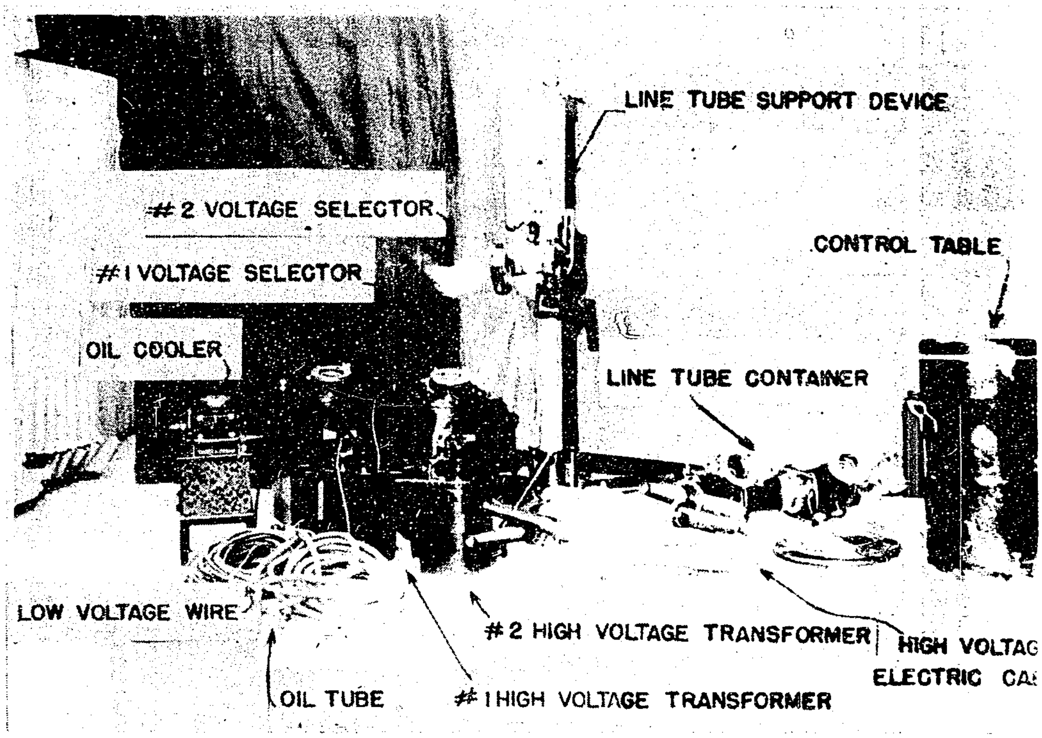


Figure 27
X-RAY APPARATUS

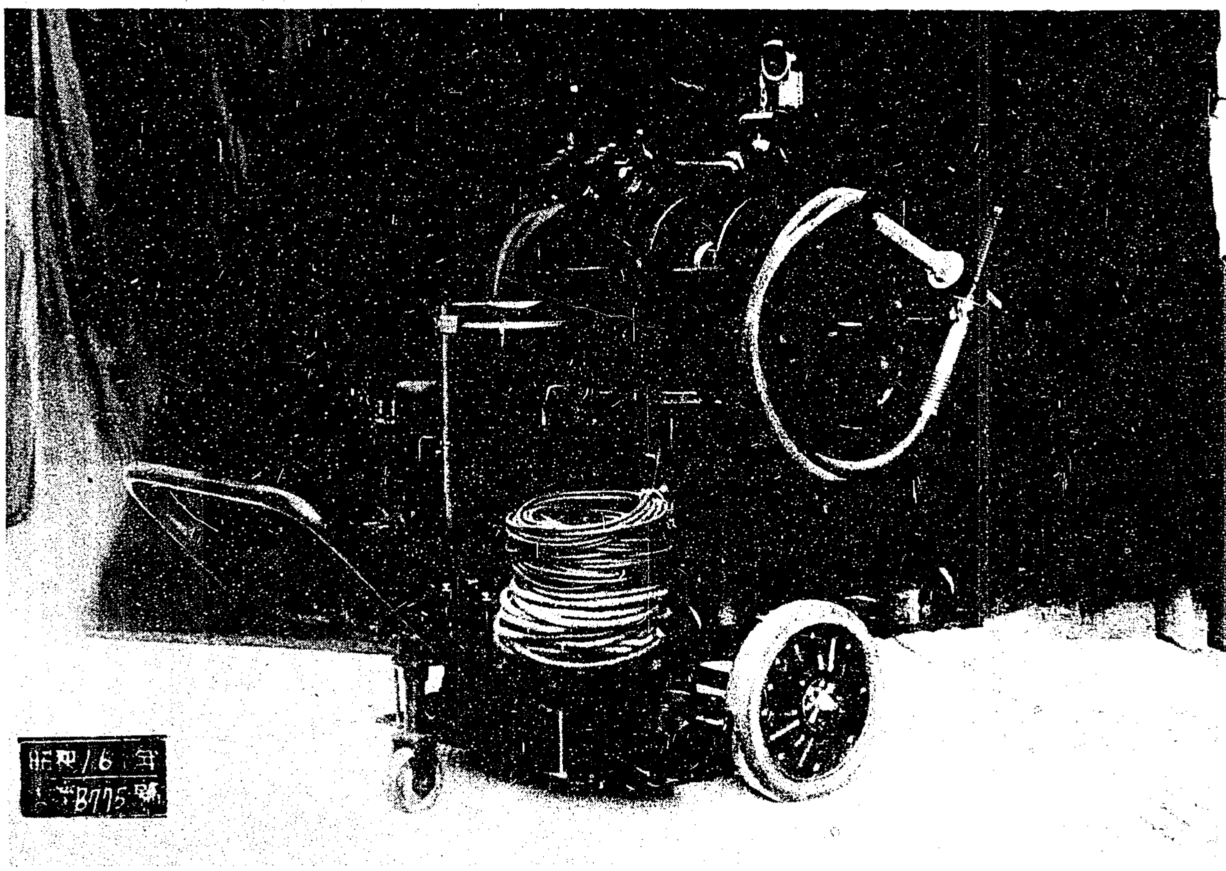


Figure 28
X-RAY APPARATUS

the end of the war, the only work done was on submarine pressure hulls where the welds examined amounted to about 10% of the whole. Special attention was paid to Tee junctions. Three typical radiographs of pressure hull welds are shown in Figure 26.

The actual welds to be radiographed were selected by the dockyard inspection department. Welds were not ground flush before examination. Defective welds, when found, were removed by chipping or flame gouging and rewelded, the replacement weld being peened when cold. Attempts had been made to X-ray fillet welds, but the results were poor.

NavTechJap Document No. ND50-1129 shows the extent to which radiography was employed in German ship construction, indicating that there was some German guidance in the development of Japanese radiography.

PART V - PERSONNEL

A. LABOR

Welders were in general "raw" labor, that is they had had no training in any other trade before being entered as welders. Female welders were employed during the war on shop work only and were considered satisfactory.

B. TRAINING

In the navy yard, welder trainees were given a two months' course in a training center, where they received instruction in downhand, vertical, and overhead welding from full-time instructors. Instruction in the theory of welding was not considered worth-while. At the end of the course, the trainees were sent to production work without undergoing any kind of test. On the job they were visited from time to time by instructors from the training center. A welder was considered to be fully competent only after three years from commencement of training.

C. PAYMENT

Piecework systems of payment were not employed as it was considered that, to be fair, a piece work system would have to be inoperably complicated. Financial incentive was however applied by means of a bonus system, under which a consistently good welder was awarded a weekly bonus at the discretion of his supervising officer.

D. SUPERVISION

In the navy yards a standard of one supervising officer to every ten welders was aimed at but in actual practice never attained. In the YOKOSUKA yard, for instance, there were only six supervisors in charge of five hundred welders and burners. It was admitted that the standard of workmanship suffered through inadequate supervision. The dockyard welding engineer was in charge of instruction and experimental work but had no authority over welders on production. He was, however, expected to maintain a watch on standards of welding and to initiate action to correct bad practice. A foreman of welders was in charge of production workers, who were organized in parties closely integrated with the platers parties.

Welders were purely welding operatives and were not expected to assist in setup and fairing of plating preparatory to welding.

E. WORKMANSHIP

All welding observed in the yards visited was uniformly bad, showing in nearly all cases irregular contour, undercutting, craters at ends of runs, inadequate

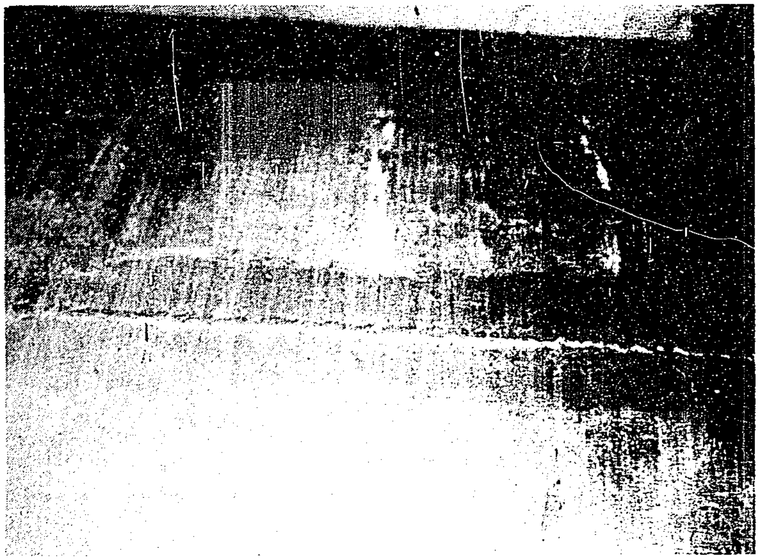


Figure 29
TYPICAL WELD

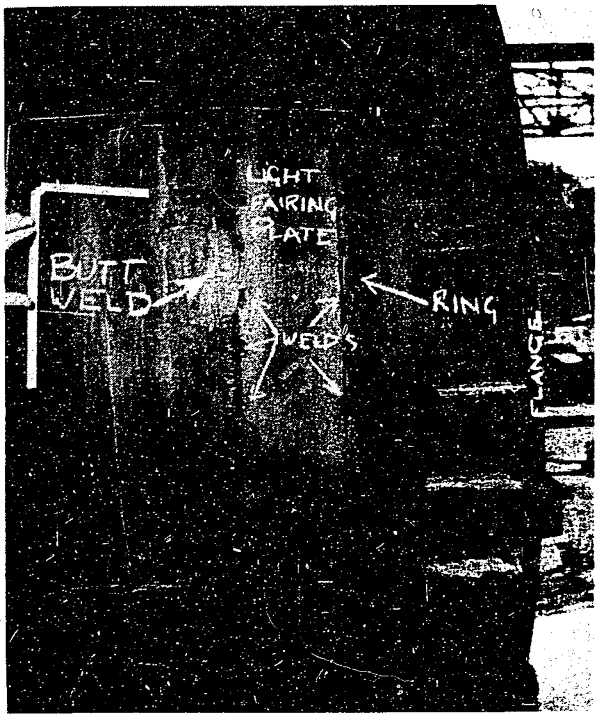


Figure 30
TYPICAL WELD

removal of slag, and general sloppiness. Tack welds were extensively used in set-up and were unnecessarily large and frequent. Edge-hooks and wedges were seldom used for lining up edges. Edge preparation was poor and very little effort seemed to have been made to line up the grooves correctly or to obtain the specified root-gap.

A typical downhand butt-weld is illustrated in Figure 29, which shows a pressure hull seam in a "KORYU" five-man submarine. A vertical butt weld in pressure hull and spot welds attaching light fairing plate are shown in Figure 30.

F. HEALTH

Occasional cases of "Flash" or "Arc - Eye" occurred, especially among trainees. These were not considered serious. NavTechJap Document No. ND50-1123.1 deals with the effects of welding on the human body and gives several prescriptions for eye-lotions for use in case of flash, but remarks that prevention is better than cure.

Cases of electric shock were frequent and "many" fatalities were admitted, though actual figures are not available. The open-circuit voltage of all AC apparatus was limited to 80 volts by agreement with the welders' association.

The danger from poison gases was appreciated, and respirators were provided for men working in confined spaces.

ENCLOSURE (A)

LISTS OF JAPANESE DOCUMENTS FORWARDED TO THE BUREAU OF SHIPS

NavTechJap No.	ATIS No.	Contents
ND50-1110.1 .2 .3 .4	4201	Description of Professor AKASAKI's Firecracker Method of Welding.
ND50-1111	4202	Practical application of Welding to Naval Surface Vessels.
ND50-1112.1 .2 .3	4204	Research on M.S. Coated Electrodes M.K.1 and M.K.23 - KURE, 1941.
ND50-1113.1 .2 .3	4203	Description of Experimental Work in Welding M.S. and H.T. Plate to Armor.
ND50-1114	4205	Welding Symbols and Types of Connection.
ND50-1116	4207	Comparative Experiments Welding and Riveting - KURE, 1930.
ND50-1117	4208	Temporary Specification for M.S. Coated Electrodes, 1942.
ND50-1119	4209	Description of Semi-Automatic Welding m/c.
ND50-1120	4210	Description of Experiments in Multiphase Welding Methods.
ND50-1121	4211	Research on Large Diameter Electrodes.
ND50-1122	4212	Description of Flame-Gouging Torch.
ND50-1123.1 .2 .3	4365	Influence of Welding on the Human Body. Extent of Welding in Hull Construction. Residual Stress and Distortion. } KURE, 1941
ND50-1124.1 .2 .3 .4 .5 .6	3641	Proceedings of Japanese Technical Bodies-Papers dealing with welding, published 1935-6.
ND50-1125.1 .2 .3 .4 .5 .6 .7 .8 .9 .10	3642	Series of pamphlets compiled by various ship building yards in 1935. Each entitled "Welded Construction Methods - Present Practice and Future Plans".

ENCLOSURE (A), continued

NavTechJap No.	ATIS No.	Contents	
ND50-1126.1	3640	Defects in Welding.	
.2		Welding Davits.	
.3		M.S. Electrodes.	
.4		Tests on "Purox" rods.	
.5		M.S. Electrcdes.	Series of pamphlets
.6		M.S. Electrodes.	compiled in YOKOSUKA
		D.S. Electrodes.	Navy Yard 1934.
.8		D.S. Electrodes.	
.9		Avoidance of Defects.	
.10		Tests of Welds in D.S. Plate.	
.11		Electrodes.	
ND50-1127.1	3643	Research on Electrodes for D.S. -KURE, 1933.	
.2		Strength of Welds H.T. to M.S. Plate - KURE, 1934.	
.3		Welding of D.S. Plate - KURE, 1934.	
.4		Welding Methods Research - KURE, 1938.	
ND50-1128.1	4215	Description of X-ray Apparatus.	
		Specimen Radiographs of Submarine Hulls.	
.2		Rules for Inspection of Welding on Hull Construction.	
ND50-1129		X-ray Tests of German Ships.	