SR-12

PROGRESS REPORT

on

CLEAVAGE FRACTURE OF SHIP PLATE
HATCH CORNER TESTS

by

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under Navy Contract NObs-31222

COMMITTEE ON SHIP CONSTRUCTION
DIVISION OF ENGINEERING & INDUSTRIAL RESEARCH
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Advisory to

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Serial No. SSC-1

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July 24, 1946

PREFACE

The Navy Department through the Bureau of Ships is distributing this report to those agencies and individuals that were actively associated with this research program. This report represents a part of the research work contracted for under the section of the Navy's directive "to investigate the design and construction of welded steel merchant vessels".

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S. M. Boyd 6/13/58

July 24, 1946

Chief, Bureau of Ships
Navy Department
Washington 25, D. C.

Dear Sir:

Attached is Report Serial No. SSC-1, entitled "Cleavage Fracture of Ship Plate: Hatch Corner Tests". This report has been submitted by the contractor as a progress report on the work done under Contract NObs-31222 between the Bureau of Ships, Navy Department, and the University of California.

The report has been reviewed and acceptance recommended by representatives of the Committee on Ship Construction, Division of Engineering and Industrial Research, NRC, in accordance with the terms of the contract between the Bureau of Ships, Navy Department and the National Academy of Sciences.

Very truly yours,

Frederick M. Feiker

Frederick M. Feiker
Chairman, Division of Engineering
and Industrial Research

Enclosure

PROGRESS REPORT

U.S. Navy Research Project NObs-31222

CAUSES OF CLEAVAGE FRACTURE IN SHIP PLATE

Hatch Corner Tests

September 1, 1945 to March 1, 1946

From:

University of California
Department of Engineering
M. P. O'Brien, Technical Representative

Report prepared by:

E. Paul DeGarmo
J. L. Meriam
R. C. Grassi
J. W. Harman

ABSTRACT

Six full scale specimens, similar in design to a hatch corner of a ship, were constructed from a low carbon, ship quality, semi-killed steel and tested to failure. One tested at 120° F gave a shear type fracture. All others tested at room temperature failed with cleavage type fractures. Two which were welded with preheat at 400° F showed superior performance, both in strength and energy absorption. Two which were fabricated by riveting gave inferior performance.

An investigation was conducted to determine the effects of preheat and a comparison made with the effects of 1000° F postheat treatment for 8 hours.

Studies were made of quarter scale symmetrical and asymmetrical hatch corner models to determine which type of specimen would best duplicate the stress condition existing in actual ships.

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CONTENTS

LIST OF TABLES AND ILLUSTRATIONS

LIST OF TABLES AND ILLUSTRATIONS - Cont'd.

Page No.

LIST OF TABLES AND ILLUSTRATIONS - Cont'd.

INTRODUCTION

Starting November 1, 1944, a program of research was undertaken by the University of California under a contract with the NDRC having as its title "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors (NS-336)." Work under this project continued up to August 31, 1945, and was divided into two parts as follows:

A. A determination of the influence of metallurgical factors and temperature on the cleavage fracture of ship plate containing internal notches.

B. The determination of the effect of variation of material and temperature on the tendency for cleavage fracture of welded structural specimens containing a discontinuity, such as hatch corners.

Part B of this project involved the design and testing of full scale ship sections in order to:

a. Obtain a specimen approximating an actual section of a ship, wherein restraint to plastic flow is provided by the inherent geometry of the structure rather than by artificially induced notches.

b. Correlate the effects of temperature, steel, and stress relief on these specimens with results obtained on flat plate tests by other investigators.

Since September 1, 1945, this work has been continued by the University of California under a contract with the United States Navy, Contract NObs-31222.

In previous reports,[1,2] published by the Office of Scientific Research and Development, accounts were given of the development of a hatch corner type specimen which contained a corner which had considerable restraint to plastic flow. Prior to September 1, 1945, thirteen of these large specimens were constructed and tested. Five different steels were used in constructing the various specimens.

This report covers further tests made on six additional full scale hatch corner type specimens and an investigation of the effect of preheating upon the hardness of welds and the adjacent heat affected zones.

Some questions regarding the full scale hatch corner specimen design had been raised due to the fact that the longitudinal stress distribution across a transverse section opposite the corner of the hatch and the accompanying ratios of maximum to minimum stress were not quite the same as those which had been measured on two Liberty ships, the SS. David Bushnell and SS. Philip Schuyler. It also appeared that due to the asymmetry of the specimen some distortion would occur which might not exist in the actual ship hatch corner. It had not been intended that the existing full scale specimen should duplicate exactly conditions existing in actual ships but, rather, it was to be a laboratory specimen which contained a severe design notch due to inherent geometry and construction. This was to be in contrast to notches artificially introduced by saw cuts, holes, or the like.

However, to aid in the possible interpretation of the full scale hatch corner specimen results for direct ship design purposes, it was

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[1,2] See Bibliography.

agreed that an attempt should be made, using quarter scale models, to obtain a design which more closely approached ship conditions. The models would enable comparison of the relative merits of a symmetrical versus asymmetrical specimen with respect to stress distribution, stress ratios, distortion, and adaptability to further full scale design tests. These model studies are also covered in this report.

PART I

Full Scale Specimens

Procedure

The design of the welded full scale hatch corner type specimens is shown in Fig. 1. The details of specimens 16 and 19, which were riveted, are shown in Fig. 2. In these riveted specimens an attempt was made to keep the general configuration as nearly as possible the same as for the welded specimens so as to make the only variable that of method of fabrication. For the welded specimens the welding sequence is shown in Table I.

Fig. 3 shows several views of one of the welded specimens during construction. In fabricating the riveted specimens all holes were drilled and reamed. Fig. 12 shows two views of one of the riveted specimens.

In making specimens 15 and 18, preheat was used in making all welds within two feet of the corner. Heating torches were utilized to raise the temperature of the plates within three inches of the welds to 400° F. The temperature was not allowed to fall below this value until welding was completed.

Five different steels were available for tests carried out in this project. These steels, their chemical analyses and tensile properties are shown in Tables II and III. For the six specimens discussed in this report only Steel C was used.

After construction of the specimens was completed, in order to provide transverse restraint, 3 in. x 3 in. bars were welded to the two edges of the specimens as shown in Fig. 4. Three transverse restraining beams were then attached by means of wedges between their ends and the 3 in. x 3 in. bars. These restraining beams were made of 6 in. channels with special strongbacks to prevent buckling. The wedges at the ends were driven tight until strain gages placed on the beams showed a compressive strain of 50 micro-inches per inch. It was recognized that the transverse restraint offered by these bars was not as severe as exists in ships. However, since cleavage type fractures were being obtained it was decided that the system should be used throughout the series of tests in order to keep the conditions constant.

Type SR-4 electrical resistance strain gages were attached to all specimens, except number 19, at the locations indicated in Figs. 5 and 6. Since specimen 19 was a repeat of number 16, it was not felt that it was necessary to use strain gages on this specimen. Since specimen 18 was similar to several others the gages were not read.

With the exception of number 17, over-all energy absorption was determined by taking pin-to-pin strain measurements as indicated in Fig. 7. Integration of the load-strain curves gave the energy absorbed.

For all the specimens except number 17, readings of the various gages were taken at loads of 0; 100,000; 200,000; 300,000; 600,000; 1,000,000; and 1,200,000 pounds. Beyond 1,200,000 pounds the readings of four gages were followed continuously up to failure, or until the gages became inoperative.

The purpose of testing specimen number 17 was to determine whether the strain concentrations at various locations would change if loading was repeated. Therefore, in testing this specimen the following loading schedule was used: 0; 100,000; 0; 100,000; 200,000; 0; 200,000;

300,000; 0; 300,000; 500,000; 0; 500,000; 800,000; 0; 800,000; 1,200,000; 0; 1,200,000 pounds and then to failure.

Results

The major results obtained from the tests of the full scale specimens are shown in Table IV. For convenience in comparing results Table V gives similar data for the first thirteen specimens. Photographs of the various specimens after failure are shown in Figs. 8 to 24, inclusive.

The failure of specimen 14, tested at 120° F, with a shear type fracture verified expectations, based upon previous tests, that such a fracture could be obtained in this type of specimen with Steel C if the test was conducted above 112° F.[2] It should be noted that the energy absorbed by this specimen was more than double that obtained with any previous specimen made from this steel and for which cleavage type fractures had been obtained. However, the nominal breaking stress was very nearly the same as had been obtained with cleavage type failures.

The results obtained from specimens 15 and 18 were by far the most outstanding obtained in these tests to date. The breaking stress of these specimens was about 33 per cent higher than the average breaking stress of all previous specimens, and nearly 10 per cent better than the best previous specimen (number 9) which had been given a high temperature stress relief after welding. In spite of the fact that cleavage type fractures were obtained in specimens 15 and 13, the energy absorption was very high, being more than twice as much as was measured on any previous specimen.

The performance of the welds on these preheated specimens was particularly noteworthy, In the welded specimens which were made without preheat there was always rather general failure of the welds adjacent to the fracture. This was particularly true of the weld connecting the longitudinal girder to the hatch end beam and the fillet weld between the deck and doubler plate. In these preheated specimens there was almost no failure in the welds. This is shown very clearly in Fig. 21 where the longitudinal girder plate was fractured but the weld was almost intact. In order to obtain a better picture of the reason for this superior performance the studies discussed in Part II of this report were made.

The behaviors of specimens 16 and 19 were not anticipated until load was applied. The "working" of the joints was very considerable even at low loads. This resulted in the angle at the corner opening up to quite an extent. This opening was very apparent while in welded specimens it was difficult to observe any change. The difference in the rigidity of the riveted and welded specimens was striking to all who had observed both types under load.

Fig. 25 shows the load-strain curves from which the energy absorption of the various specimens was computed. The superior performance of the two preheated specimens is apparent in this figure.

The results obtained from the test of specimen 17 by repeated loading are shown in Figs. 26, 27, and 28. As shown in Fig. 26, for loads greater than 300,000 lbs. there was, in general, less strain increment for the second application of a given load than for the first application. This was due to the permanent strain resulting from plastic flow which occurred during the first application of load. This resulted in a redistribution of stresses. As a result there was a decrease in the strain concentrations as shown in Fig. 27. The fact that strain concentrations measured in these tests are greater than those found in actual ships[1,3] may be due in part to the fact that this specimen was not as rigid as an actual hatch corner in a ship and as a result some opening of the corner angle resulted, and that both elastic and plastic strains were measured whereas in the case of at least one of the series of measurements made on ships only elastic strains were recorded.

Fig. 28 shows the behavior of gage 19H (Fig. 26) during the test. This indicates that the material at this point exhibited elastic behavior upon unloading and for reloading up to the previously applied load. As indicated, this gage failed, in that it ceased to function normally, at a load just above 800,000 pounds. The strain concentration is also indicated by the slopes of the two curves in this Figure. For example, using the slopes corresponding to the 800,000 pound load a strain concentration of approximately 8 is shown for gage 19H as compared with the average of the outboard gages.

[1,3] See Bibliography.

PART II

Effect of Preheating

Procedure

In view of the results obtained on full scale hatch corner specimen number 15 by preheating, it was evident that more basic information on the effect of preheating would be desirable. The metallurgy of welds has established the presence of a heat affected zone adjacent to the weld metal, which contains large grains and is harder than either the weld or parent metal. In an effort to obtain some details regarding the effects of preheating on the heat affected zone and the weld metal the following tests were conducted.

Two single pass weld beads, one of 3/16" E-6010 electrode at 135 amps and the other of 3/16" E-6020 electrode at 200 amps, were deposited on pieces of ship plate (Steel C) 18 in. x 18 in. x 3/4 in. as shown in Fig. 29. The beads were deposited on one specimen with the plate at a temperature of 70° F and on another after preheating the plate to 400° F. A third plate was prepared upon which beads were deposited using E-6010 and E-6020 electrodes with the plate at a temperature of 70° F. This plate with the deposited beads was then heated for 8 hours at 1000° F similar to the treatment given hatch corner specimen 9. A fourth plate upon which E-6010 and E-6020 beads were deposited was used as a control for specimen number 3. This plate was not subjected to postheat and the beads were deposited with the plate at a temperature of 70° F.

Specimens were taken from the center of each of the six weld beads. These specimens were polished, etched and subjected to microhardness (Knoop, with 500 gm. load) surveys as shown in Fig. 30. In the parent and weld metal the hardness impressions were spaced 0.25 mm.

Essentially in a weld you are quenching the heat affected zone, and the [illegible] from which [illegible] will be. Using 200 amps will give higher temp. [illegible] apart whereas in the heat affected zone the spacing was reduced to 0.10 mm.

In addition to the previously mentioned tests two multiple pass fillet welds were made as shown in Fig. 31. The first fillet was made using E-6020 electrode and the second using E-6010 with the plate being allowed to cool between each pass so that all beads were deposited with the specimen at a temperature of 70° F. Specimens were then prepared similar to the others and microhardness surveys of each pass as shown in Fig. 30 were conducted.

Results and Discussion

In Fig. 32 there is presented one of the Knoop hardness surveys with hardness plotted as a function of distance from the weld edge for the preheated and non-preheated E-6010 weld beads. The data in Table VI show clearly the increase in width and the decrease in hardness of the heat affected zone by preheating. The reduction in hardness of the weld metal, although significant, is not as much as in the heat affected zone. The maximum hardness of the heat affected zone for the preheated specimens is practically the same for both the electrodes used. In spite of the fact that the maximum hardness of the heat affected zone for the E-6010 electrode is greater than that for the E-6020 electrode as deposited without preheat, the hardness of the weld bead itself is not influenced by the type of electrode. The results of specimens 3 and 4 show that heating of the weld beads for 8 hours at 1000° F reduces maximum hardness of the heat affected zone and the average hardness of the parent and weld metal. The width of the heat affected zone, of course, was not changed as a result of the heating.

An examination of the microstructures reveals the reasons for some of the results presented in Table VI. Referring to Figs. 33 and 34, the effects of the different cooling rates which accompany welding with or without preheating, are apparent. The heat affected zone of the preheated specimen shows evidence of the intermediate transformation products which were able to form during the slower cooling from the Austenitic phase. At a lower magnification (X500) such as in Figs. 35, 36, 37, and 38 the presence of more free ferrite in the preheated welds is apparent. The change in width of the heat affected zones as a result of preheating is shown in Figs. 39, 40, 41, and 42. Figs. 43 to 50, inclusive, show the effect of postheating on the microstructure of the weld metal and the heat affected zones for the E-6010 and E-6020 weld beads. The effect is more pronounced for the E-6010 heat affected zone than for the E-6020.

The effect of multiple passes on the maximum hardness of the heat affected zone and the average hardness of the weld is shown in Table VII. The hardness generally increases with each pass as the heat from each succeeding bead reduces the maximum hardness in the heat affected zone of the preceding bead. The initial hardness of the heat affected zone for the first fillet weld (E-6020) was reduced in the process of welding the second fillet (E-6010) and in the same manner the average weld hardness was probably reduced.

In analyzing the results obtained there seems to be little doubt that changes brought about in the structure and hardness were attributable to the reduction in the severity of the quenching effect normally produced by the metal surrounding the weld. Although no quantitative data were obtained with regards to the cooling rates present in a non-preheated weld, observations of the microstructure in Fig. 33 showed that the quenching effect must have been of the order of magnitude of a water quench.

As stated previously, it was not intended to make a complete investigation of the effects of preheat and postheat, but, to investigate some of the effects. From the tests conducted it is apparent that preheating does produce marked changes in the hardness of the weld material and the heat affected zone and increases the width of the latter. It is also evident that postheating at 1000° F for eight hours is not as effective as preheating at 400° F in reducing the hardness of the weld metal and the heat affected zone and does not widen the heat affected zone. Just how much these changes are responsible for the improved performance of preheated and postheated specimens is not yet known. Undoubtedly other effects, such as change in chemical composition and impact properties, also result. Further study of this entire subject, particularly the effects of preheating, is needed.

PART III

Model Studies

Procedure

A series of asymmetrical and symmetrical models were constructed and tested in an effort to obtain one model of each type which approximated the Bushnell and Schuyler data as closely as possible. Comparison of the two was then made.

In the asymmetrical model, various factors were altered after each successive test to improve the stress distributions. The following factors were investigated.

a. The location of the line of applied load with respect to the corner of the hatch,

b. the extent of attachment of end tab to coaming,

c. effect of transverse restraint and omission of transverse restraining bars,

d. increased end tab width with corresponding fillet between end tab and specimen edge,

e. increased stiffness of end tabs with heavier center plate.

From the results of these changes the model shown in Fig. 51 was constructed and tested.

For the symmetrical design a celluloid model was first built and Stresscoat (brittle coating) was applied to obtain a preliminary indication of the stress distribution. From these results it was apparent that a transverse slot would have to be cut between the end tab and the hatch opening in order to achieve the desired distribution of stress near the corner of the hatch. With this information as a guide several symmetrical specimens were constructed and tested. The factors which were investigated during the tests were

a. length of transverse slot,

b. fillet radius between end tabs and specimen edge,

c. size and stiffness of end tabs.

The specimen design resulting from these preliminary tests is shown in Fig.52, and the resulting model was constructed and tested.

Results

The strain distributions for both tests on the final designs are shown in Fig. 53 along the transverse section AB for the small loading of 6,000 psi nominal stress and for a higher load of 13,750 psi. Figure 54 shows the principal stresses and their directions for the two models under the applied nominal stress of 6,000 psi for both.

An indication of the distortions as the models were loaded to failure is given in Fig. 55. Although the deflections shown are not exactly comparable measurements for the two specimens, they do give an indication that there is less movement in the symmetrical specimen than in the asymmetrical one.

The two specimens after failure are shown in Figs. 56 and 57. For the asymmetrical one the maximum load was 192,800 lbs. which gave a nominal stress computed over the net load carrying section at the hatch corner of 48,500 psi. For the symmetrical specimen the maximum load was 424,000 lbs. which gave a nominal stress of 53,000 psi. However, as can be seen from Figs. 56 and 57, the failure occurred at the slot. It would be necessary to reinforce the ends of the slot for any subsequent tests of this design.

The transverse loading device[1] used on the first quarter scale asymmetrical models did not introduce significant change in the stress ratios near the corner. The subsequent tests were conducted without this bar. An additional reason for leaving off this bar was that the rather heavy bars welded to the sides of the specimen against which the transverse member acted were found to have considerable effect on the stress distribution in the deck.

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1 See Bibliography

CONCLUSIONS

1. Steel C when used in the hatch corner specimen has a transition from cleavage to shear at slightly below 120° F.

2. Using preheat at 400° F is the most effective procedure yet tried both as to strength and energy absorption, being more effective than stress relief at 1000° F for 8 hours or the use of 25-20 electrode. It results in about 30 per cent increase in maximum strength and superior performance of the welds as compared with specimens welded in the usual manner. Preheating does not appear to influence the type of fracture.

3. Riveting as used in this particular design gave inferior results in so far as strength is concerned.

4. Preheating at 400° F reduces the hardness and increases the width of the heat affected zone and produces a somewhat different microstructure of both the weld and heat affected zones.

5. Post heat treatment at 1000° F for 8 hours results in a decreased hardness in both the heat affected zone and the weld metal and a change in the microstructure. This treatment does not result in any change in the width of the heat affected zone.

6. The greater stress concentration and the somewhat less distortion for the symmetrical quarter scale model as compared with the asymmetrical one is an indication of a more severe stress condition in the former.

7. In view of this conclusion, it follows that the full scale asymmetrical model used for the main tests may not represent a condition as severe as would exist for a full scale symmetrical specimen or for the ship itself.

8. Due to the size of the symmetrical quarter scale model resulting from this investigation it is apparent that the space limitations of the available testing equipment prohibit the testing of a full scale symmetrical specimen. In view of this and the lack of time, it was decided that no further work would be done on models by this project.

Bibliography

1 Progress Report on "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors (NS-336): Hatch Corner Specimen Tests", OSRD No. 5352, Serial No. M-512, July 21, 1945.

2 Final Report on "Cleavage Fracture of Ship Plate as Influenced by Design and Metallurgical Factors (NS-336): Hatch Corner Specimen Tests," OSRD No. 6387, Serial No. M-607, December 4, 1945.

3 Report: Structural Tests on the S.S. Philip Schuyler. U. S. Maritime Commission; June, 1945.

TABLE I

Welding Sequence - Hatch Corner Specimens

Units	Position	Electrode
A. Place, tack and weld 8 to 2; and 7 to 3	Horizontal	E-6020
Jig Horizontal, Bottom Side Up		
B. Place, tack and weld end tabs to deck plate 1	Flat	"
Jig Horizontal, Top Side Up		
C. Place, tack and weld end tabs to deck plate 1	"	"
Jig Horizontal, Bottom Side Up		
D. Place, tack and weld 4A and 4F to 1	Horizontal	"
E. " " " " 6 to 1	"	"
F. Place and tack 5 to 1 and 6	"	"
G. Weld 5 to 1	"	"
H. Weld 4F to 6	Vertical & Horizontal	E-6010
I. Weld 5 to 6	" "	"
J. Place unit 8 and 2 to 1 and 6; tack 2 to 6 (outboard) and 2 to 1 (outboard)	Horizontal & Vertical	"
K. Weld 2 to 6 (outboard)	Vertical	"
L. Weld 2 to 1 (aft & fwd; 2 sides simultaneously)	Horizontal	E-6020
M. Tack and weld 2 to 1 (inboard)	"	"
Jig Vertical		
N. Place and tack unit 7 and 3 to 1 and 2	Horizontal & Vertical	E-6010
O. Weld 6 to 2 and 3 to 2; simultaneously	Horizontal	E-6020
P. Weld 6 to 8 (inboard then outboard)	Horizontal & Overhead	E-6010 E-6020
Q. Complete welding 4F and 5 to 6	Overhead, Horizontal	E-6010 E-6020
R. Tack 9 to 6	Horizontal	"
Jig Horizontal, Bottom Side Up		
S. Weld 9 to 8 (bottom)	"	"
T. Weld 3 to 2 (outboard)	Vertical	E-6010
U. Weld 3 to 1	Horizontal	E-6020
V. Weld 4A to 3	Vertical & Horizontal	E-6010 E-6020
W. Weld 7 to 2	Horizontal &Overhead	E-6010 E-6020
Jig Vertical Position		
X. Tack and weld 3 to 3A (inboard)	Flat	"
Jig Horizontal Position, Bottom Side Up		
Y. Backchip and weld 3 to 3A (deck to bottom)	"	"
Jig Horizontal Position, Top Side Up		
Z. Weld 9 to 8 (top side)	"	"
Remove Specimen From Jig		
AA. Backchip and weld 3 to 3A (deck to top)	Vertical	E-6010
BB. Weld one pass 3 to 2	"	E-6010
CC. Fill deck corner void with weld	Flat	E-6020
DD. Weld 5 passes 3 to 2	Vertical	E-6010
EE. Weld 2 to 1 and 3 to 1; simultaneously	Horizontal	E-6020
FF. Place and tack 10 to 1, 2, 3, and weld 1 pass	"	"
GG Complete weld 10 to 1	"	"
HH. Complete weld 10 to 2, 3	"	"
II. Weld 9 to 6	"	"
JJ. Weld restraining bars to 1	"	"

TABLE II

Analysis of Steels

Steel	% C	% Mn.	% P	% S	% Si.
A*	.23	.47	0.011	0.042	0.02
B*	0.15	0.76	.010	0.030	.04
C*	0.24	0.49	0.015	0.033	
D	0.19	0.52	0.01	0.02	0.24
E*	0.23	0.39	0.019	0.032	0.008

* Supplier's analysis

TABLE III

Tensile and Hardness Properties

Steels for Hatch Corner Specimens

Plate No.	Direc.	Tensile Data (.505 Bars) Yield (PSI)	Ultimate (PSI)	Break (PSI)	Elongation (% in 2")	Reduction in Area (%)	Hardness (Rockwell "B")
A-57*	Long.	35,500	61,200	47,400	39.5	59.6	
	Trans.	38,100	60,400	48,800	36.2	56.3	
B-1 As rolled	Long.	35,050	56,900	38,600	40.9	67.6	62
	Trans.	34,000	57,000	47,500	39.6	58.6	
B-6 Normalized	Long.	36.900	59,500	43,400	39.3	64.0	64
	Trans.	36,500	57,200	43,500	38.5	63.0	
C-1	Long.	35,230	68,700	55,300	36.0	59.6	71
	Trans	35,750	68,000	57,050	33.6	52.5	
D-2	Long.	37,800	63,700	46,900	37.2	62.8	68
	Trans.	40,600	63,600	48,600	36.6	59.6	
E-2	Long.	35,000	58,900	45,300	37.2	59.6	
	Trans.	35,300	58,200	46,200	35.6	58.0	
		Tensile Data (Full Thickness)					
A-57	Long.	35,100	61,400	47,900	49.2	58.7	
	Trans.	34,800	59,800	49,000	46.1	56.3	
B-1 As rolled	Long.	31,000	56,500	43,700	53.2	66.6	
	Trans.	31,400	56,400	45,600	48.7	58.4	
B-6 Normalized	Long.	32,200	56,900	41,100	52.0	64.0	
	Trans.	32,000	56,500	43,400	51.6	60.5	
C-1	Long.	37,500	66,500	53,600	45.5	56.5	
	Trans.	34,100	66,200	56,600	32.5	50.4	
D-2	Long.	35,900	61,300	45,800	47.1	62.3	
	Trans.	36,100	60,500	47,600	46.4	59.2	
E-2	Long.	31,400	57,200	44,500	49.1	59.1	
	Trans.	31,000	56,600	45,600	45.5	58.0	

* Letter in plate number refers to type of steel.

RESULTS, FULL SCALE HATCH CORNER TESTS

SPECIMEN NO.	KIND OF [4] STEEL (AS ROLLED UNLESS NOTED)	TEST TEMP. °F.	NOMINAL STRESS AT [1] FAILURE LB IN²	LONGITUDINAL STRESS CONCENTRATION BASED ON 200,000 LB. LOAD [2] — GAGES: 5	6	7	8	9	10	17	18	19 H/V
14	C	120	(AT MAX. LOAD) 25,600	2.0	2.1	1.5	2.4	2.2		2.0	2.7	14 3.6
15	C 400° PREHEAT	70	32,600			1.6	2.5	2.3	1.9	-1.5	2.7	16 4.0
16	C RIVETED	70	20,900	2.0	1.9	2.4	2.4	2.7			1.2	
17	C	72	24,800	.9	1.2	.9	1.5	1.2	.7	-1.0	1.5	3.0 2.6
18	C 400° PREHEAT	70	32,800									
19	C RIVETED	70	(AT MAX. LOAD) 20,600									

STRAIN CONCENTRATIONS [3] FOR 200,000 LB. LOAD / 1,200,000 LB. LOAD

SPECIMEN NO.	GAGES: 5L	6L	7L	8L	9L	12T/12B	13	14T/14B	15T/15B	16T/16B	17H/17V	18L	19H/19V
14	2.0	2.1	1.6	2.5	2.2	3.5 3.5		0.5 0.9	4.4 3.8	1.3 1.5	-2.3 1.4	2.9	13.5 -0.5
	2.2	2.7	1.3	2.9	1.9	3.5 7.0	15	-1.0 0.2	3.2 6.0	1.5 0.5	-2.5 0	3.3	15.0 1.2
15			1.6	2.1	2.2	3.2 2.8	1.6	0.7 0.4	3.4 3.4	1.6 1.0	-1.9 1.9	2.9	15 -0.7
			1.2	2.2	2.1	4.0 4.2	7.8	-0.5 1.2	5.1 6.5	3.7 1.4	-1.9 1.2	3.0	19 -1.6
16	2.0	2.2	2.3	2.3	2.7							2.0	
	1.8	.9	.4	5.7	3.9							.4	
17	1.0	1.3	1.1	1.5	1.3	2.7 1.9	2.1	0.3 0.3	2.6 2.0	1.1 0.7	-1.2 0.8	1.7	9.3
	2.0	2.3	1.5	3.4	3.3	1.6 3.1		-.6 -.7	1.7 4.1	6.9	-1.8 0.7	2.4	0.9
18													
19													

SPECIMEN NO.	TOTAL ENERGY ABSORBED PIN TO PIN IN.LB. — AT MAX. LOAD	AT FAIL.
14	284,000	484,000 (AT FAILURE OF LONGITUDINAL GIRDER)
15	1,046,000	
16	790,000	
17		
18	1,358,000	
19	① 412,000	② 588,000 SEE REMARKS

STRAIN RATIOS LONG./TRANS. 200,000 LB. LOAD / 1,200,000 LB. LOAD

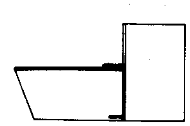
SPECIMEN NO.	GAGES: 5	6	7	8	9	10	11 [5]	19H/19V	17H/17V
14	-11.2	-5.5	-3.3	11	-6.8		-8.3	-29	-1.6
	3.5	-4.5	-3.0	-7.8	-3.7		12	12	89
15			-3.1	3.0	-6.1	5.4	5.7	-21	-1.0
			-9.8	2.6	-17	17	-2.8	12	-1.7
16	-4.4	-1.7	-13	-13	-3.1		2.5		
	-2.0	-5.9	-7.1	-9.8	-12.7		.3		
17	-6.9	-3.6	-2.0	2.1	-6.2	5.2	-4.6		-1.6
	-3.9	-3.3	-3.0		-14	-6.1			-2.6
18									
19									

SPECIMEN NO.	STRAINS AT OR NEAR FAILURE MICRO IN IN — GAGES: 12B	15B	18L	19H
14	8,400	6,600	MAX. STRAIN 1,800	12,000+
15	11,000+	13,000+	13,000+	20,000+
16			1,000	
17	1,100	800	1,400	1,500
18				
19				

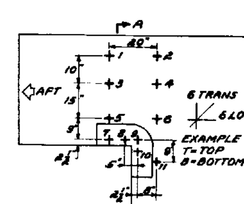
SPECIMEN NO.	THICKNESS REDUCTION AT FRACTURE % — DISTANCE FROM CORNER IN.	FRACTURE EDGE IN. 1/16	1/4	1/2	3/4	1	REMARKS
14		SHEAR					SHEAR FAILURE AT CORNER.
15	13	0.8	0.3	0	0	0	CLEAVAGE FAILURE AT CORNER. (SHEAR IN WELDS)
	34	1.8	0.1	0	0	0	
16							CLEAVAGE FAILURE AT CORNER. VALUES SHOWN ARE FOR GAGES 3 OR MORE DIAMETERS FROM RIVET HOLE.
17	19	2.7	2.3	1.7	1.2	0.5	SUBJECTED TO REPEATED LOADING CLEAVAGE FAILURE AT CORNER. SEE NOTE 6. AT BOTTOM OF TABLE
	34	1.4	1.4	1.3	1.0	0.5	
18							CLEAVAGE FAILURE AT CORNER. NO GAGE READINGS TAKEN.
19							CLEAVAGE FAILURE AT CORNER. NO GAGE READINGS TAKEN. ① FAILURE PROCEEDED HALFWAY THROUGH DOUBLER & LATER CONTINUED TO SECOND RIVET HOLE. ②

NOTES:

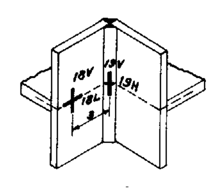
1. BASED ON LOAD CARRYING SECTION OF DECK, DOUBLER, LONGITUDINAL COAMING BELOW DECK.
2. BASED ON AVERAGE OF LONGITUDINAL STRESSES FOR GAGES 1-2-3-4 TOP & BOTTOM.
3. BASED ON AVERAGE OF LONGITUDINAL STRAINS FOR GAGES 1-2-3-4 TOP & BOTTOM.
4. E-6010 & E-6020 ELECTRODE USED UNLESS NOTED
5. READINGS QUESTIONABLE. GAGE #11 VERY CLOSE TO DOUBLER WELD.

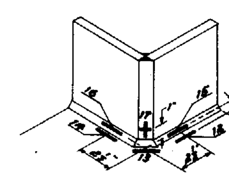


LOAD CARRYING SECTION A-1



GAGE LOCATION PLAN





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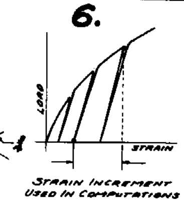


TABLE IV

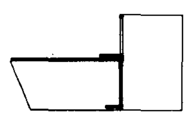
RESULTS, FULL SCALE HATCH CORNER TESTS

Specimen No.	Kind of Steel[4] (as rolled unless noted)	Test Temp °F	Nominal Stress at Failure[1] LB/IN²	Longitudinal Stress Concentration Based on 200,000 LB. Load[2] — Gages: 5	6	7	8	9	10	17H	18	19V	Strain Concentrations[3] for 200,000 LB. Load / 1,200,000 LB. Load — Gages: 5L	6L	7L	8L	9L	12T/12B	13	14T/14B	15T/15B	16T/16B	17H/17V	18L	19H/19V
1	A	32	24,200	1.5	1.8	1.3	2.0	2.0	1.3	-1.7	1.9	6.2	1.4	1.8	1.4	1.8	2.0	2.5/2.4	2.7	0.9/0.5	3.0/—	1.6/—	-1.6/0.3	2.1	5.6/0.3
												2.1	1,000,000 LB. 1.8	2.3	1.3	0.9	1.9	1.7/4.0	14.4	-0.1/-0.1	2.1/—	3.2/—	-1.4/0.1	3.3	6.9/0.2
2	C	32	23,200	—	1.6	—	—	—	—	—	—	—	—	1.6	—	—	0.8	—/—	—	—/—	—/—	—/—	—/—	—	—/—
													—	2.0	—	—	1,250,000 LB. —	—/—	—	—/—	—/—	—/—	—/—	—	—/—
5	C	68	24,000	1.6	2.0	1.2	2.1	2.3	1.5	-1.9	2.6	10.4	1.6	2.0	1.3	2.0	2.2	4.5/3.0	3.0	0.9/0.3	4.7/3.9	3.2/1.5	-2.1/0.9	2.8	9.9/0.5
												3.4	2.0	2.0	1.1	2.0	2.9	2.0/4.4	11.9	-0.5/-0.3	2.3/6.5	—/2.5	-1.5/0.4	2.1	10.6/-8.2
10	C MUREX H.T.S.	32	23,600	1.5	2.0	1.7	2.5	2.1	1.6	-1.9	2.5	13.8	1.5	1.9	1.8	2.2	1.9	3.4/2.6	2.7	0.3/0.5	3.4/3.5	1.3/1.1	-2.3/1.8	2.7	13/0.3
												4.3	2.2	2.5	1.4	5.2 ←8 ONLY→	4.0	—/11.5	—	—/2.1	—/12.2	—/0.8	-2.9/-0.2	5.8	17/1.0
9	C STR. REL. AFT. WELD	72	MAX. STRESS 30,000 29,400	1.5	1.8	1.7	2.4	2.4	1.8	-1.5	2.6	8.4	1.4	1.8	1.8	2.1	2.3	2.9/2.9	1.2	1.1/0.4	2.9/3.4	1.2/1.1	-1.9/1.7	2.8	7.9/0.2
												2.6	1.6	2.0	1.5	3.6	2.0	2.0/6.5	7.1	0/0.1	2.3/5.0	1.9/1.0	-1.6/0.8	2.2	14.3/0.1
13	C 25-20 ELECTR.	32	27,700	1.7	2.0	1.8	2.7	2.4	1.6	-1.7	2.7	7.1	1.6	2.0	1.7	2.3	2.2	3.5/1.5	—	1.0/1.0	3.5/2.8	1.6/0.5	-2.2/2.3	2.8	6.7/-1.3
												0.7	1.9	2.2	1.5	3.3	2.4	6.4/7.2		1.5/4.3	8.7/6.2	3.4/0.7	-3.1/3.7	5.0	5.3/-3.1
11	B	32	MAX. STRESS 25,700 25,600	1.6	—	1.6	2.2	2.3	1.2	-1.1	2.7	8.9	1.7	1.9	1.7	2.2	2.4	4.2/3.3	1.7	0.6/1.0	5.0/3.8	1.3/1.4	-1.6/1.3	3.1	9.6/-0.2
												2.4	2.1	2.0	1.3	5.8	2.2	8.5/12.6	2.9	-0.2/1.0	9.1/9.9	-2.4/0.2	-1.2/1.5	6.6	4.4/-1.9
8	B	66	MAX. STRESS 27,000 26,100	2.0	2.3	2.0	2.9	2.9	1.8	-2.7	3.0	18.9	2.0	2.2	2.0	2.6	2.6	4.5/3.8	3.6	0.2/1.0	5.3/4.3	1.3/1.3	-2.6/1.8	3.2	17.3/0
												5.5	2.2	2.0	1.4	7.4	4.2	6.7/17.9	19.8	-1.4/1.4	7.6/18.3	-2.0/-0.1	-2.2/1.3	7.5	1.5/-0.8
3	B NORMALIZED	32	MAX. STRESS 26,900 23,500	1.4	2.1	1.5	2.3	2.1	1.6	-0.8	2.5	5.1	1.4	2.1	1.5	2.1	2.1	2.6/2.5	1.8	0.6/—	—/—	—/—	-1.1/1.2	2.6	4.8/0.2
												1.7	1.7	2.4	1.5	4.0	2.3	3.1/7.4	10.0	0/—	—/—	—/—	-4.1/2.0	3.3	4.0/-0.7
4	D NORMALIZED	32	25,900	1.4	1.7	0.9	2.2	2.0	1.5	-0.8	1.9	—	1.4	1.7	1.0	2.0	1.9	2.6/—	1.7	0.4/0.2	3.0/—	1.6/0.7	-1.2/1.3	2.3	—/-1.0
												—	1.8	2.4	1.1	3.4	2.4	4.8/—	6.4	0.2/-0.1	3.6/—	4.2/1.6	-1.4/1.1	3.4	—/-1.9
7	D NORMALIZED	72																							
12	D NORMALIZED	72	MAX. STRESS 27,800	1.5	1.5	1.7	2.4	—	1.3	-1.4	3.5	14	1.5	1.6	1.6	2.2	—	3.0/2.8	1.6	0.9/0.5	3.3/3.3	1.5/0.6	-1.8/1.7	3.6	1.3/-0.4
												3.6	1.8	2.1	1.7	3.7	—	3.6/5.9	11.7	-0.8/-0.2	4.2/7.0	8.7/0.6	-2.4/0.5	4.7	12.4/-0.5
6	E	32	23,100	1.5	1.7	1.4	2.1	2.0	1.4	-1.1	1.8	5.9	1.4	1.7	1.5	1.9	2.0	2.6/2.4	2.5	0.2/0.3	2.9/2.8	1.6/1.1	-1.3/0.8	2.0	5.9/-1.0
												0.7	2.0	2.1	1.5	3.1	2.5	3.9/5.9	12.0	-0.2/0.1	3.9/6.9	2.7/3.5	-1.5/0.7	1.0	6.6/-1.3

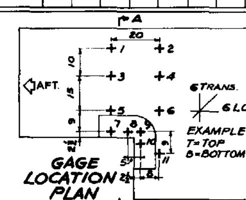
Specimen No.	Total Energy Absorbed Pin to Pin IN. LB. — At Max Load	At Fail.	Strain Ratios Long./Trans. 200,000 LB. Load / 1,200,000 LB. Load — Gages: 5	6	7	8	9	10	11[5]	19H/19V	17H/17V	Strains at or near Failure Micro IN/IN — Gages: 12B	15B	18L	19H	Thickness Reduction at Fracture % — Distance from Corner IN.	Fracture Edge IN. 1/16	1/4	1/2	3/4	1	Remarks
1			-6.3	-3.7	-2.6	—	-4.7	6.7	-3.5	20.2	-4.8					20	24	1.5	0.7	—	—	CLEAVAGE FAILURE. STEEL A USED FOR DECK ONLY.
			1,000,000 LB. -4.0	-2.5	-3.3	8.2	-5.5	3.4	-5.7	32.2	-11.9					32	32	2.1	0.8	—	—	
2			—	-2.8	—	—	0.9	—	-4.2	—/—	—/—					16	1.1	0.2	0	—	—	CLEAVAGE FAILURE. GAGE READINGS UNRELIABLE DUE TO DIFFICULTIES IN SWITCHING CIRCUITS.
			—	-4.3	—	1,250,000 LB. —	—	—	136	—/—	—/—					32	1.2	0.5	0	—	—	
5			-8.1	-4.2	-2.6	12.0	-11.0	4.7	-7.2	21.7	-2.3	3600	5000	—	7000 +	19	1.9	1.0	0.3	0	0	CLEAVAGE FAILURE. SLIGHT AM'T OF SHEAR AT TOP & BOTTOM EDGES ALONG FRACTURE.
			-7.4	-75.4	-4.3	10.8	-17.1	—	79.4	-1.3	-3.5					34	2.3	0.9	0.1	0	0	
10			-7.6	-6.4	-4.7	7.4	—	7.2	1.3	48	-13	9,200	8800	4400	13,800	19	1.5	0.9	0.4	0	0	CLEAVAGE FAILURE. SMALL CRACK IN DOUBLER OCCURED AT 400,000 LBS. PASSING DIRECTLY THROUGH GAGE #13.
	180,000	180,000	-4.0	-5.5	-4.2	10.1 ←8	-7.1 ONLY	-15.5 →	—	-17	13					34	2.0	1.3	0.5	0.1	0	
9			—	-3.7	-4.5	4.8	—	5.7	-3.7	36	-1.1	12,300 +	15,200	9200	14,300 +	19	1.9	1.1	0.3	0.2	0.1	CLEAVAGE FAILURE. FILLET WELD BETWEEN TRANSVERSE COAMING AND DOUBLER FAILED PRIOR TO MAIN FAILURE.
			-7.3	-3.5	-3.6	12	-15	6.3	-18	300	-2.1					34	1.9	1.2	0.7	0.4	0.2	
13			-5.1	-3.7	-2.9	10.4	-7.2	1.1	-7.7	-5.2	-1.0	9400	8,300	6,200	—	19	0.5	0.3	0.1	0	0	PULLING TAB FAILED AT 1,595,000 LB. TAB REPAIRED AND SPECIMEN RELOADED. CLEAVAGE FAILURE OCCURED AT HATCH CORNER.
	232,000	232,000	-4.1	-4.1	-2.8	6.0	-14.4	-10.6	-24.1	-1.7	-0.8					34	1.5	0.8	0.1	0	0	
11			—	—	—	4.2	—	2.0	10.8	-4.8	-1.2	13,500	7,900 +	7,300	5,500	19	1.3	1.1	0.7	0.5	0.3	CLEAVAGE FAILURE.
	340,000	522,000	-4.0	—	-6.0	13.0	-7.4	-2.6	11.3	-2.4	-0.8					34	3.3	2.5	1.5	0.7	0.1	
8			-6.5	-4.3	-3.3	8.5	—	6.0	-6.4	—	-1.5	14,400 +	13,200 +	7,800	15,000 +	NO MEASUREMENTS POSSIBLE. PART SHEAR, PART CLEAVAGE. SEE PHOTOGRAPHS						DECK FAILURE EXTENDED ABOUT 3" FROM CORNER IN SHEAR, THEN SUDDEN CLEAVAGE FAILURE OCCURED EXTENDING ABT. 18" FROM CORNER, ENDING IN SHEAR
			-3.0	-7.5	-2.4	6.5	-11.7	-0.6	5.8	-1.9	-1.7											
3			-10.2	-6.7	-5.6	4.6	—	3.1	—	23	-0.9					16	2.9	1.9	1.3	—	—	SUDDEN NOISE AT 1,600,000 LB. LOAD DROPPED & CLEAVAGE FAILURE OCCURED AT 1,400,000 LB. NO TRANSVERSE BARS USED. DECK LAMINATED.
			-3.0	-7.4	-3.0	—	-10.8	5.7	—	-5.7	-2.1					34	1.9	0.8	0.4	—	—	
4			-7.0	-4.8	-2.6	5.5	—	8.3	—	—	-0.9					19	1.2	0.7	0.5	0.3	0.2	CLEAVAGE FAILURE
			-4.6	-4.2	-2.2	14.0	-32.2	4.4	30.1	—	-1.3					34	2.5	0.7	0.5	0.4	0.3	
7																						TEST INVALID DUE TO WELDING DIFFICULTIES.
12			-5.7	-3.1	-4.8	7.5	—	0.9	-3.5	-2.9	-1.1	7,300	6,700	4000	10,700	SHEAR FAILURE						SHEAR FAILURE AT CORNER.
	514,000	1,196,000 +	-3.4	-2.9	-4.0	9.4	—	1.8	-1.8	-2.3	-4.6	(AT MAX. LOAD)				SEE PHOTOGRAPHS						
6			—	-6.9	-5.4	9.0	-12.3	—	—	-5.8	-1.6	4400	5000	500	9400	19	0.3	0	0	0	0	CLEAVAGE FAILURE.
			-3.5	-5.6	-3.4	-6.1	—	—	24.0	-5.0	-2.2					34	1.6	0.8	0.1	0	0	

NOTES

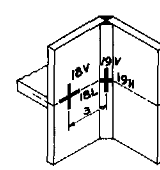
1. BASED ON LOAD CARRYING SECTION OF DECK, DOUBLER, LONGITUDINAL COAMING BELOW DECK.
2. BASED ON AVERAGE OF LONGITUDINAL STRESSES FOR GAGES 1-2-3-4 TOP AND BOTTOM.
3. BASED ON AVERAGE OF LONGITUDINAL STRAINS FOR GAGES 1-2-3-4 TOP AND BOTTOM.
4. E-6010 & E-6020 ELECTRODE USED UNLESS NOTED.
5. READINGS QUESTIONABLE. GAGE #11 VERY CLOSE TO DOUBLER WELD.



LOAD CARRYING SECTION A-1



GAGE LOCATION PLAN



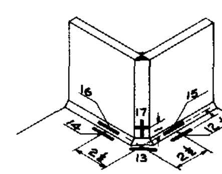


TABLE V

TABLE VI

Single Pass Specimens

Electrode	Spec. No.	Plate Temp. ^{o}F	Max.Hardness Heat Affected Zone - Knoop **	Av. Weld Hardness Knoop **	Av. Width of Heat Affected Zone - MM	Av. Parent Metal Hardness - Knoop **
E-6010	1	70	433	239	2.08	178
E-6010	2	400	290	215	3.82	199
E-6020	1	70	368	237	2.97	206
E-6020	2	400	292	206	4.15	175
E-6010*	3	70	284	225	1.80	158
E-6010	4	70	484	256	1.73	184
E-6020*	3	70	232	194	2.92	153
E-6020	4	70	298	213	2.85	185

* Plate specimen with deposited beads annealed at 1000° F for 8 hours.

**Several hardness traverses were made in each case. "Max. Hardness" is the maximum value found. "Av. Hardness" is the average of all the values measured in the area specified (from 20 to 60 readings).

TABLE VII

Multiple Pass Specimen

Electrode	Order of Passes	Max. Hardness Heat Affected Zone - Knoop	Average Weld Hardness Knoop
E-6020	1	258	215
E-6020	2	298	217
E-6020	3	328	214
E-6010	4	271	213
E-6010	5	508	238
E-6010	6	452	235

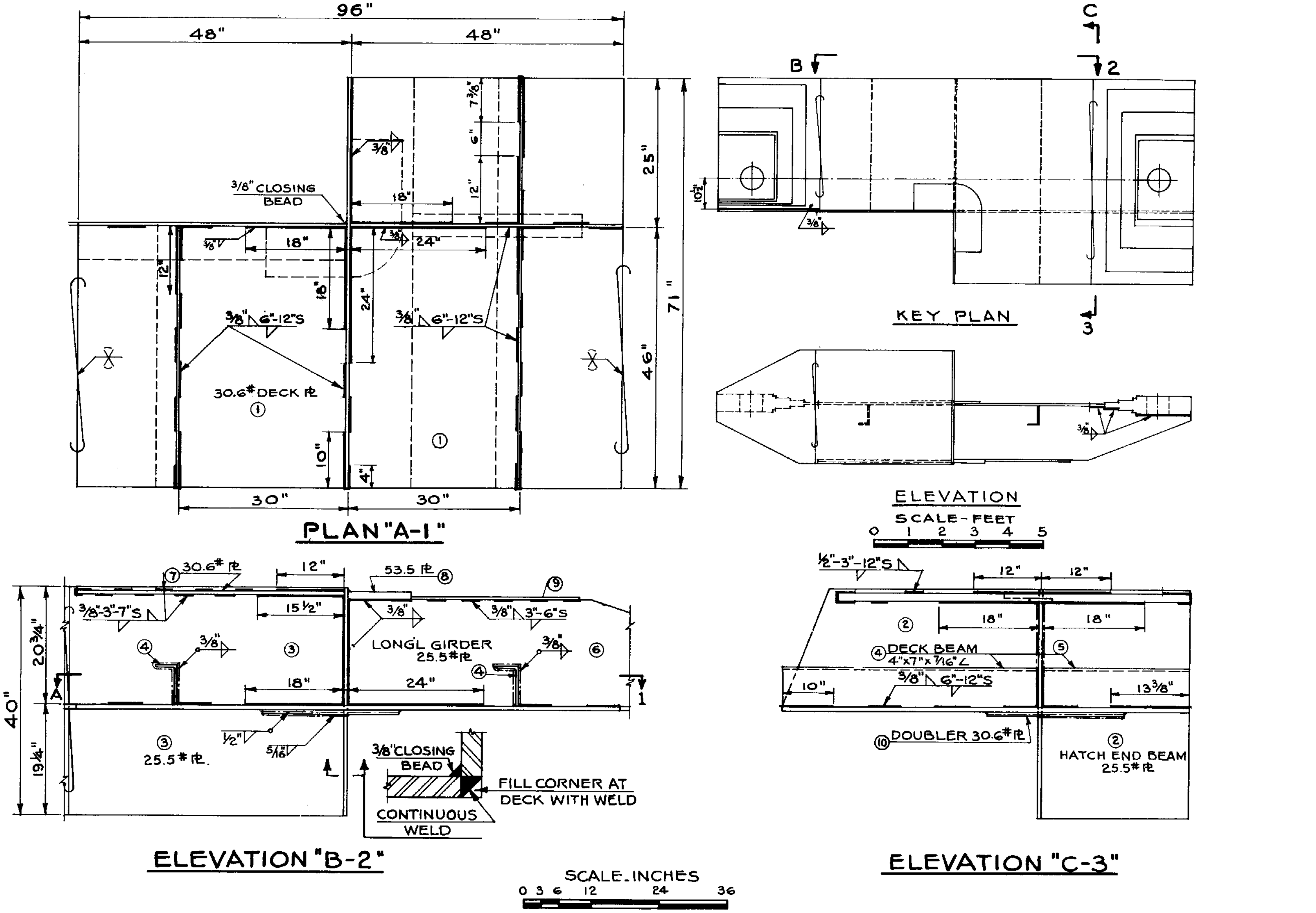
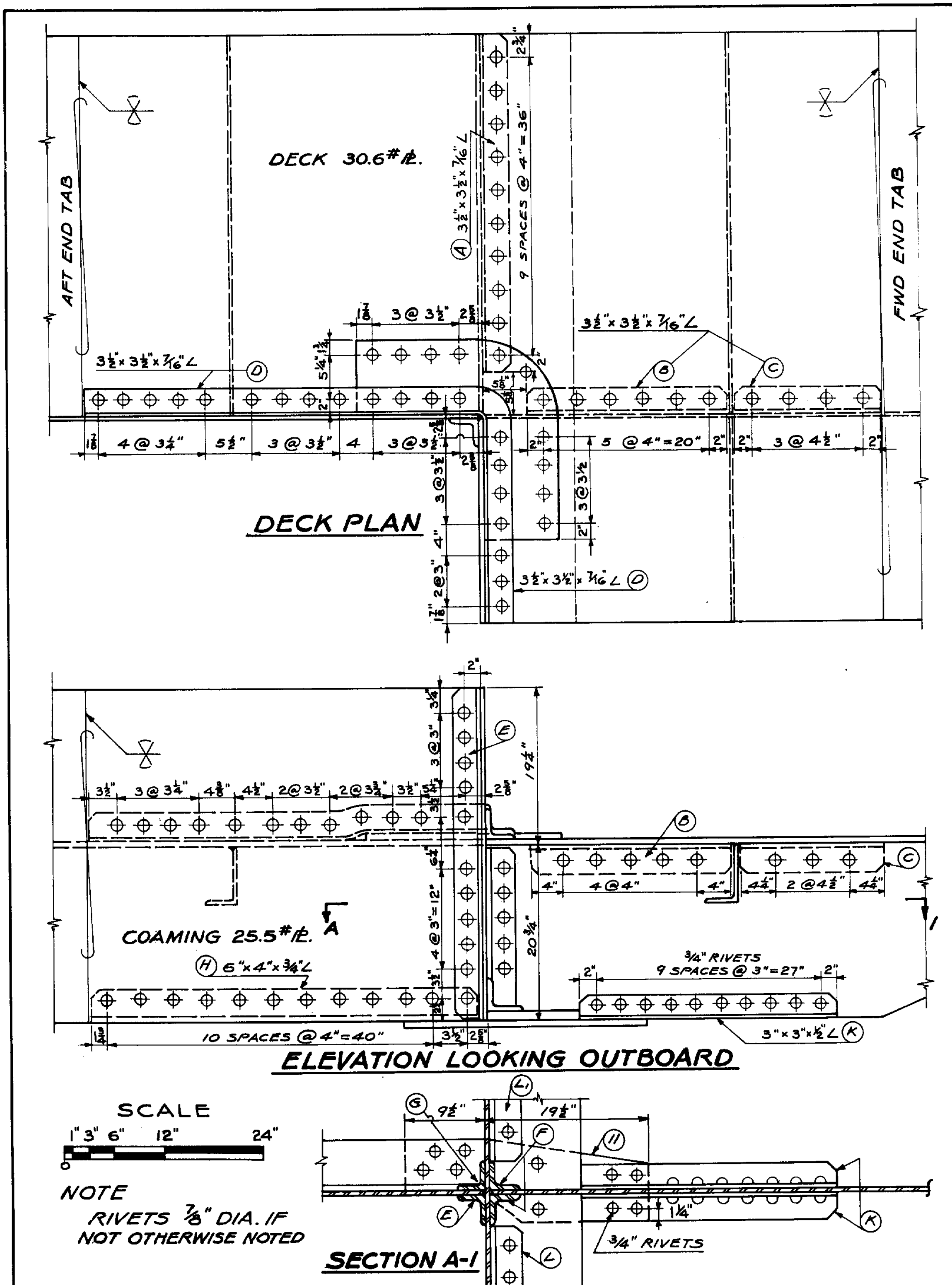


FIG. 1

25

UNIVERSITY OF CALIFORNIA WELDING RESEARCH-NRC- 92 B 310 ENGINEERING BLDG. BERKELEY, CALIF.	REVISED DESIGN OF THE "FULL SCALE HATCH CORNER MODEL	SCALE AS SHOWN DR. BY R. SISSON CH. BY	APPROVED 6/11/45 / /	DWG R-301 PANEL



UNIVERSITY OF CALIFORNIA WELDING RESEARCH BERKELEY, CALIFORNIA	DESIGN OF RIVETED HATCH CORNER SPECIMEN	DR. BY R.C.S. 3/28/46 CHK. BY APPVD.	FIG. 2 DWG. No. R-302

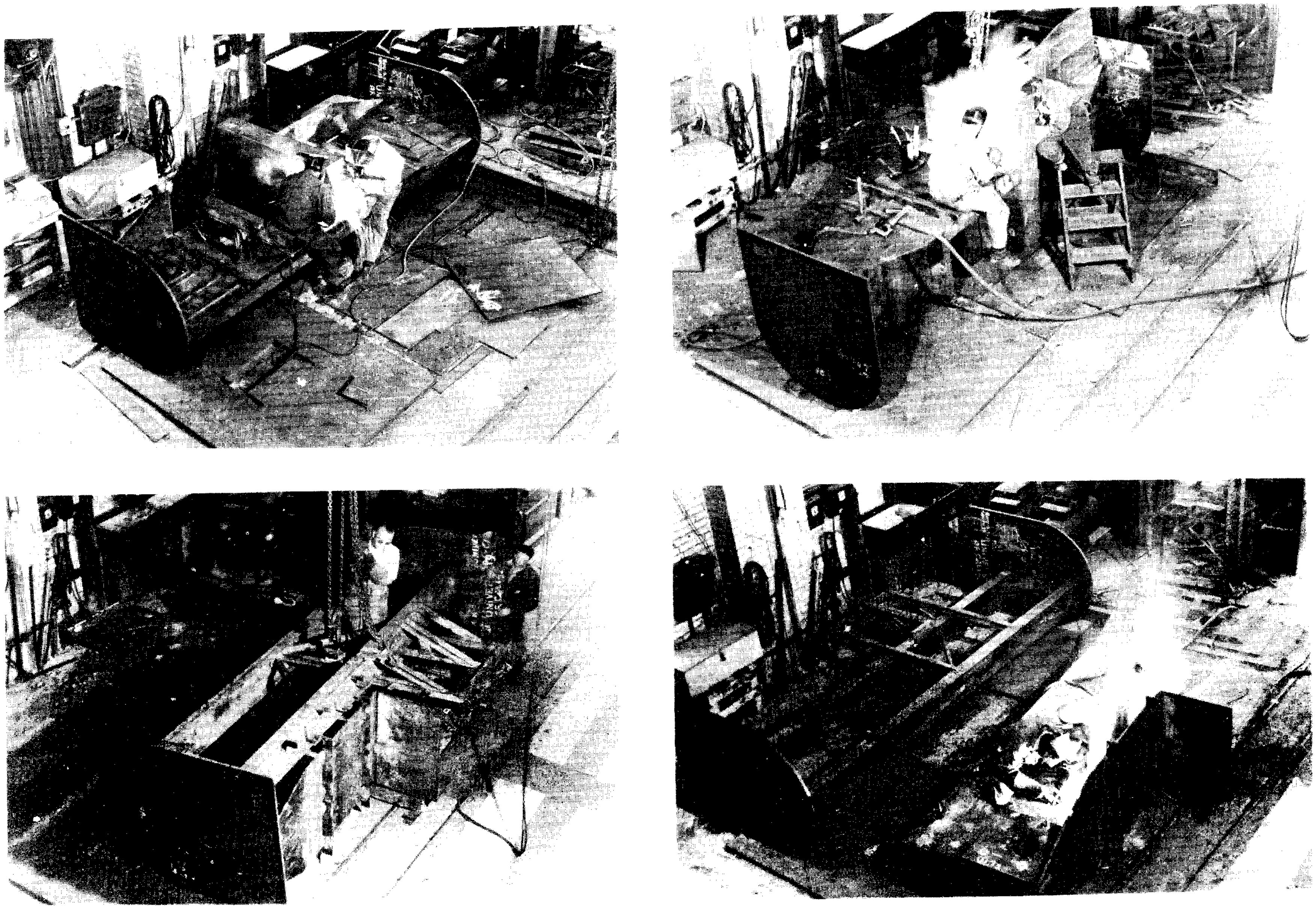


FIGURE 3 - WELDING JIG FOR FABRICATION OF HATCH CORNER SPECIMEN

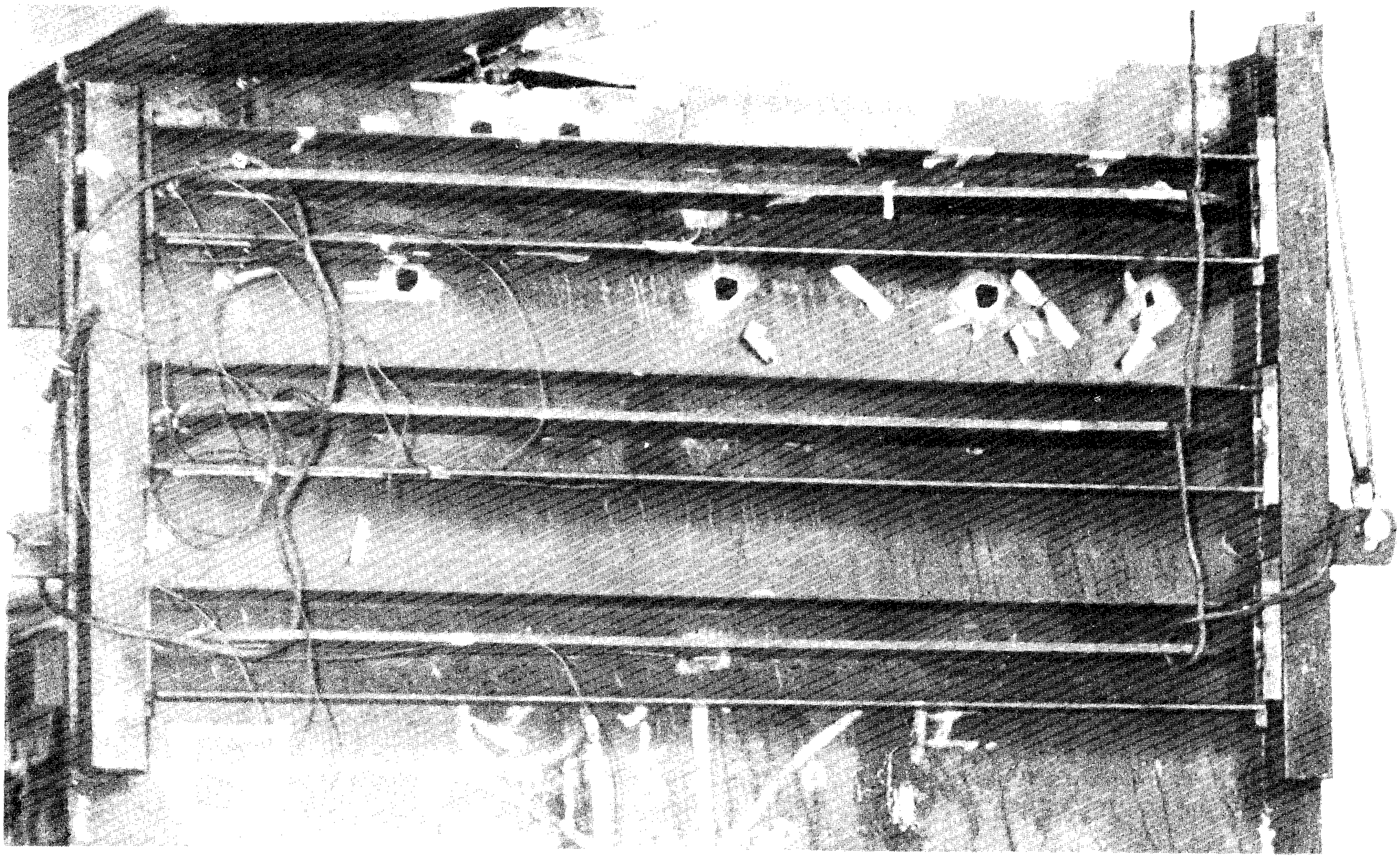
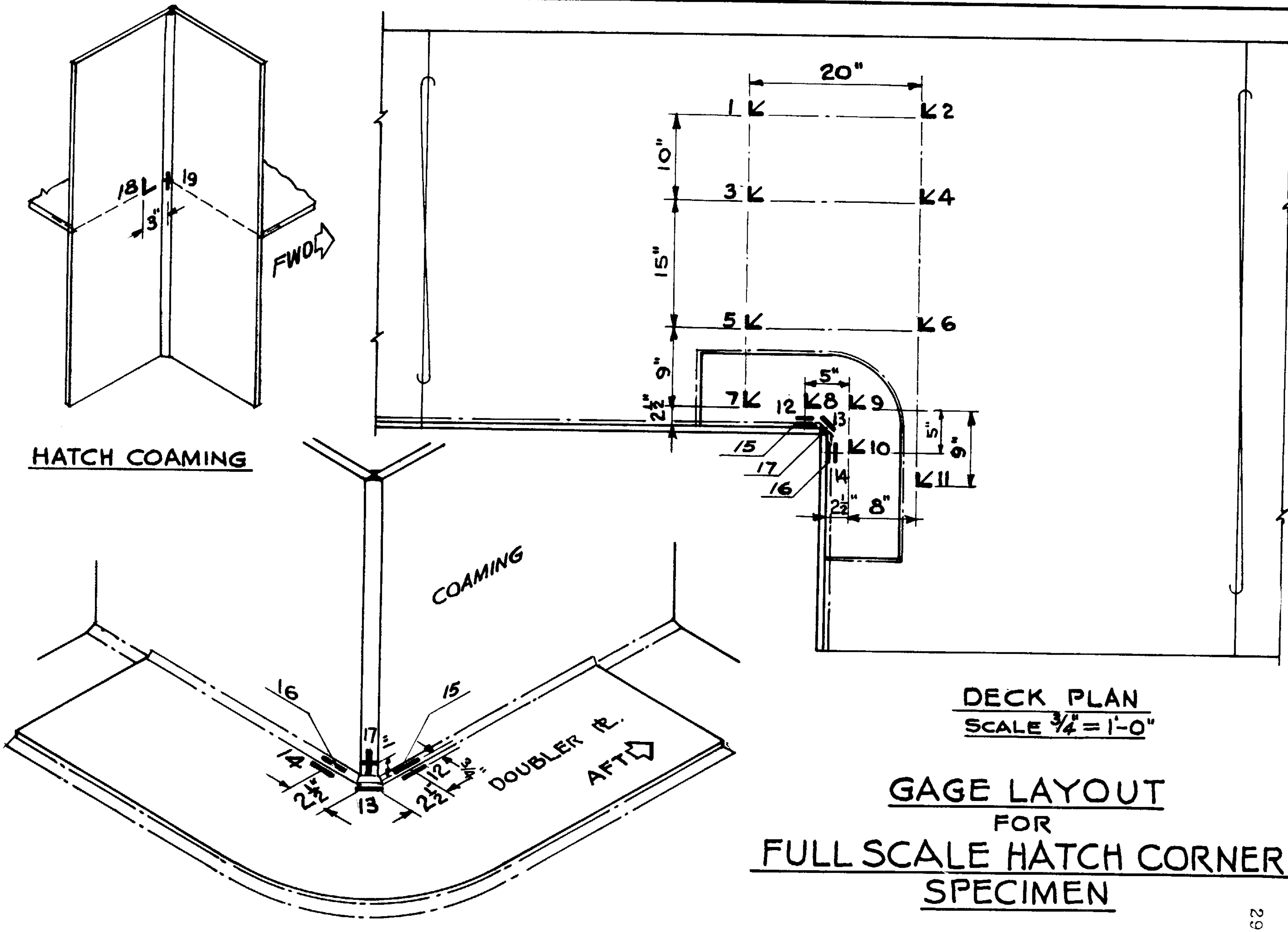


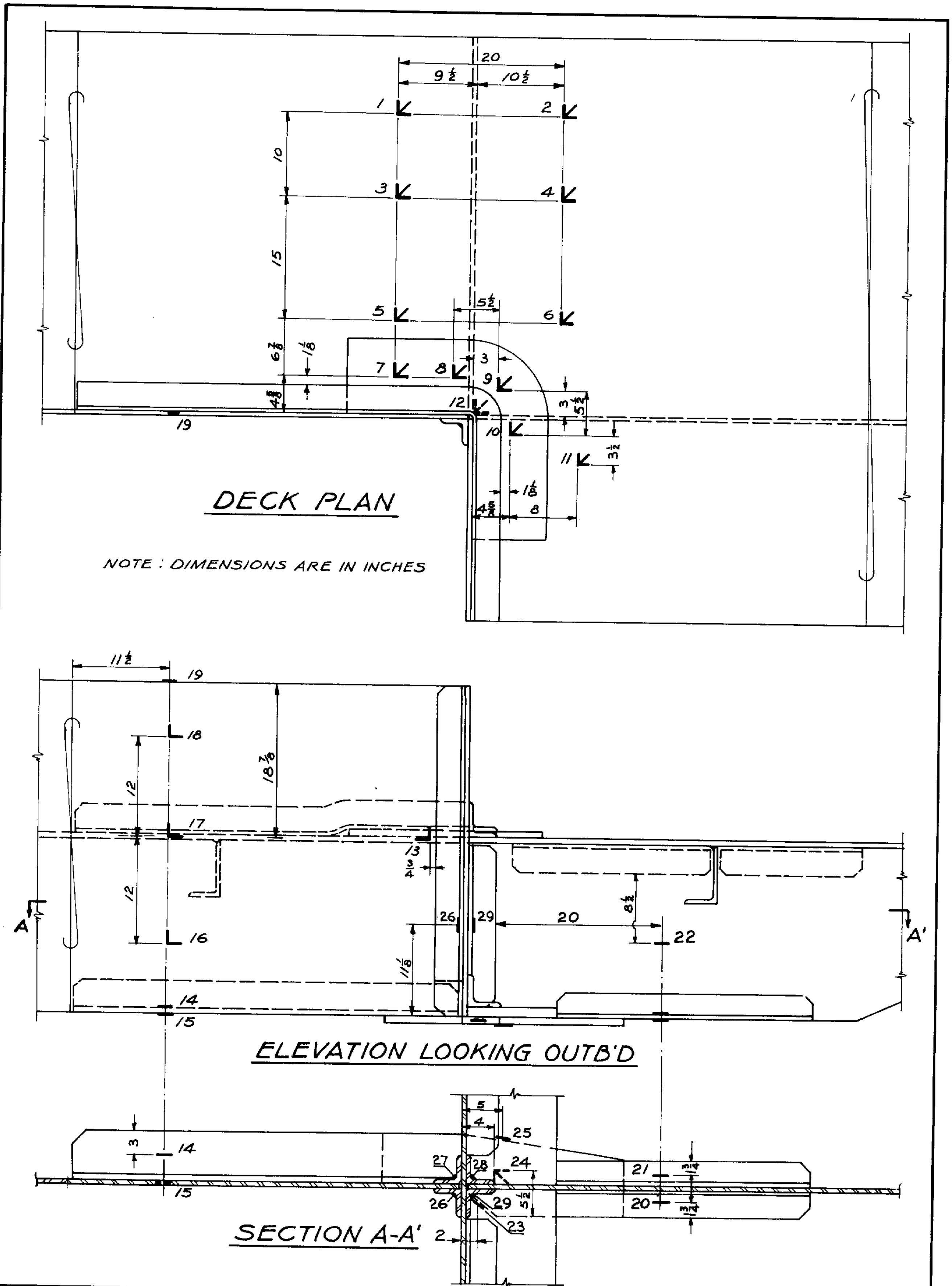
FIGURE 4 - TRANSVERSE RESTRAINING BEAMS



GAGE LAYOUT
FOR
FULL SCALE HATCH CORNER
SPECIMEN

FIG. 5

R-305



UNIVERSITY OF CALIFORNIA WELDING RESEARCH BERKELEY, CALIFORNIA.	GAGE LAYOUT OF RIVETED SPECIMEN	DR. BY R.C.S. 3/29/46 CHK. BY APPVD.	FIG. 6 DWG. NO. R-306

R-307

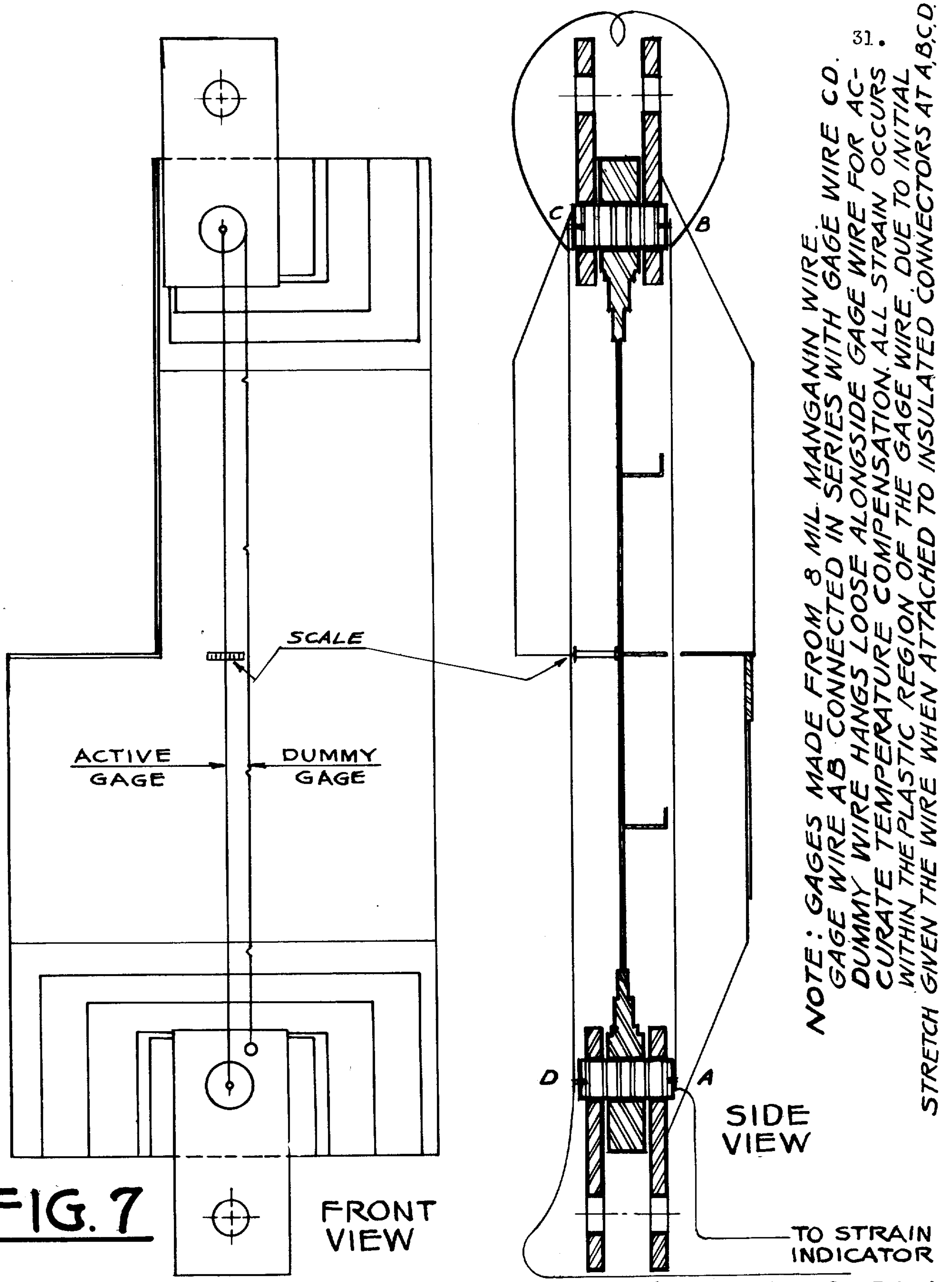
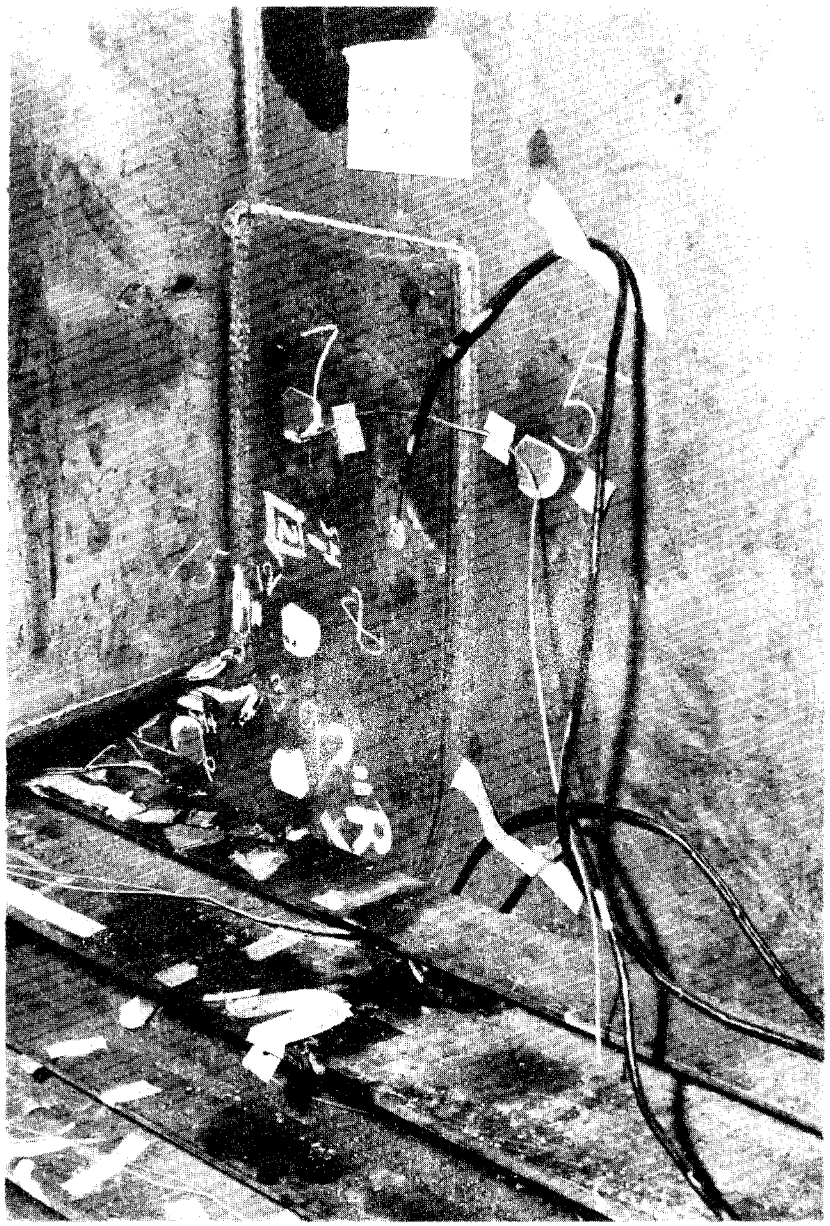
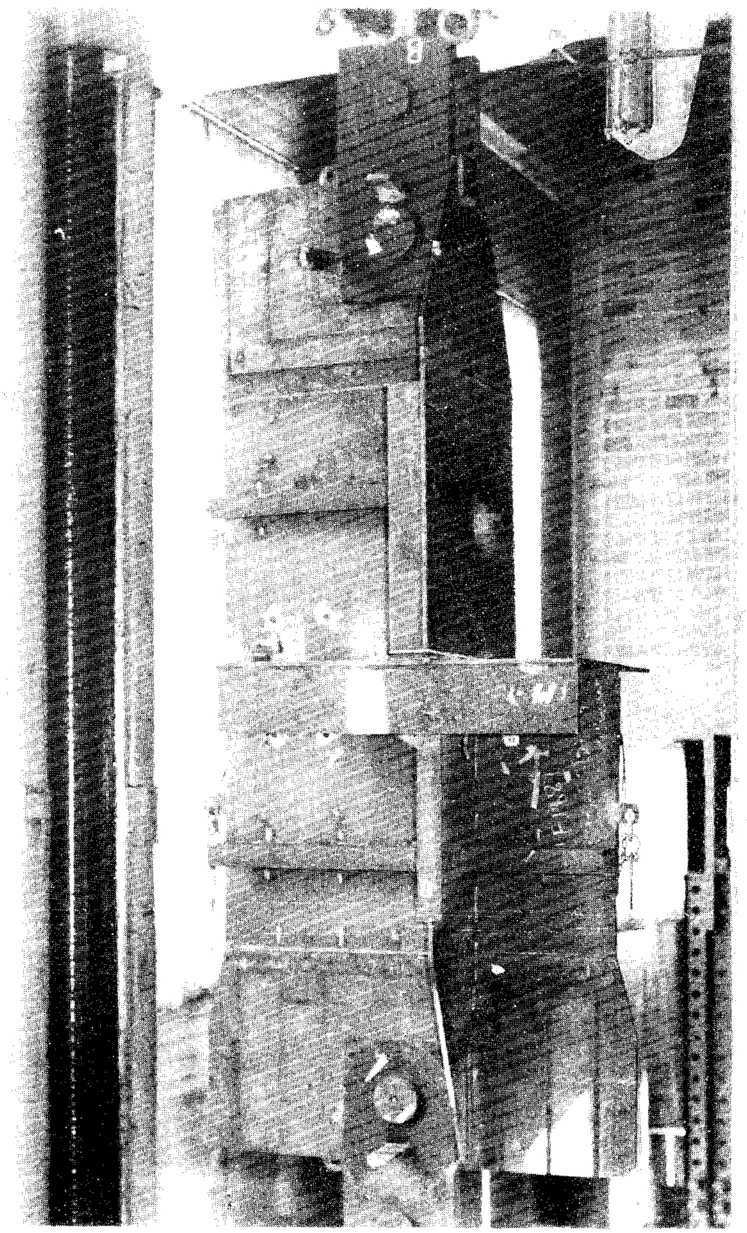


FIG. 7

DEVICE FOR MEASURING TOTAL PIN TO PIN STRAIN - FOR ENERGY CALCULATION

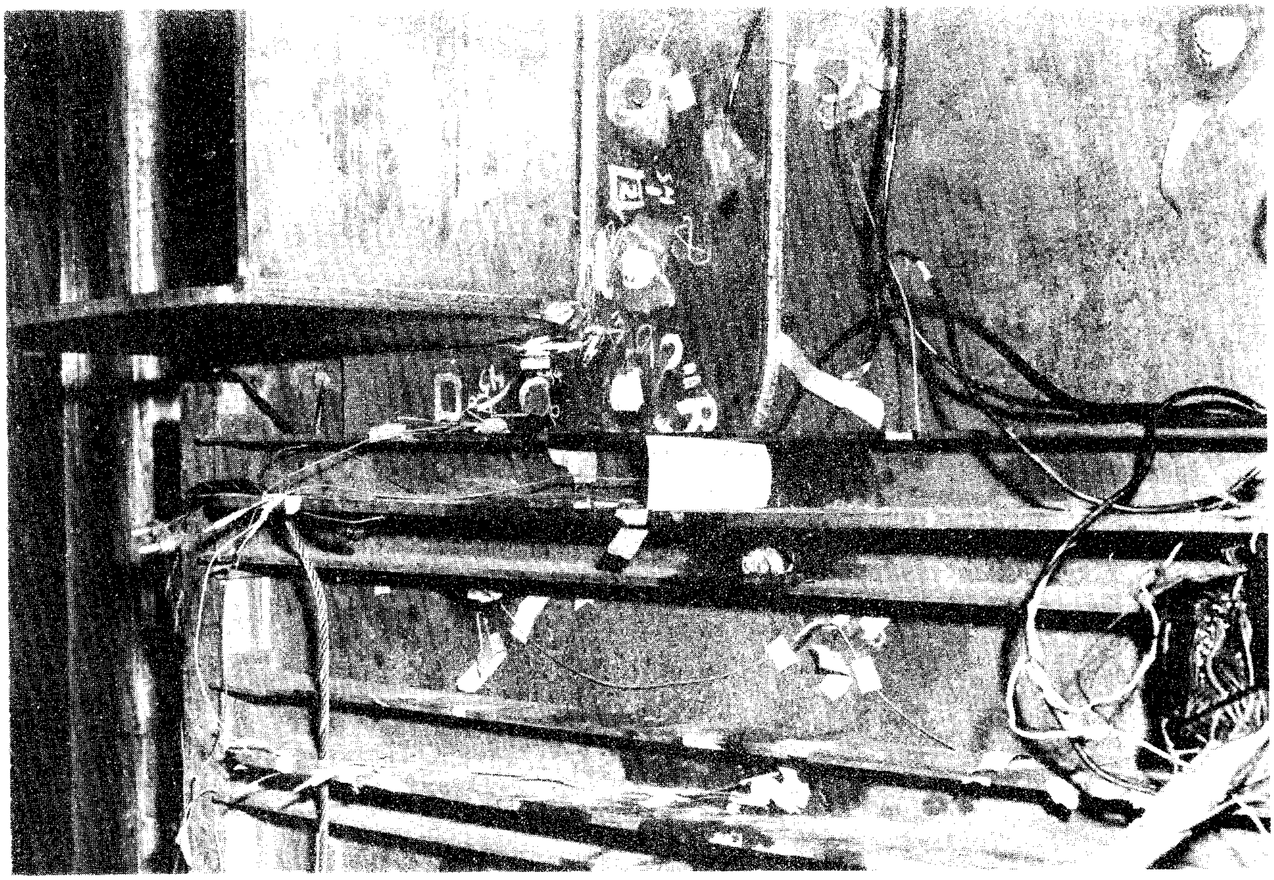


Crack in doubler-deck weld

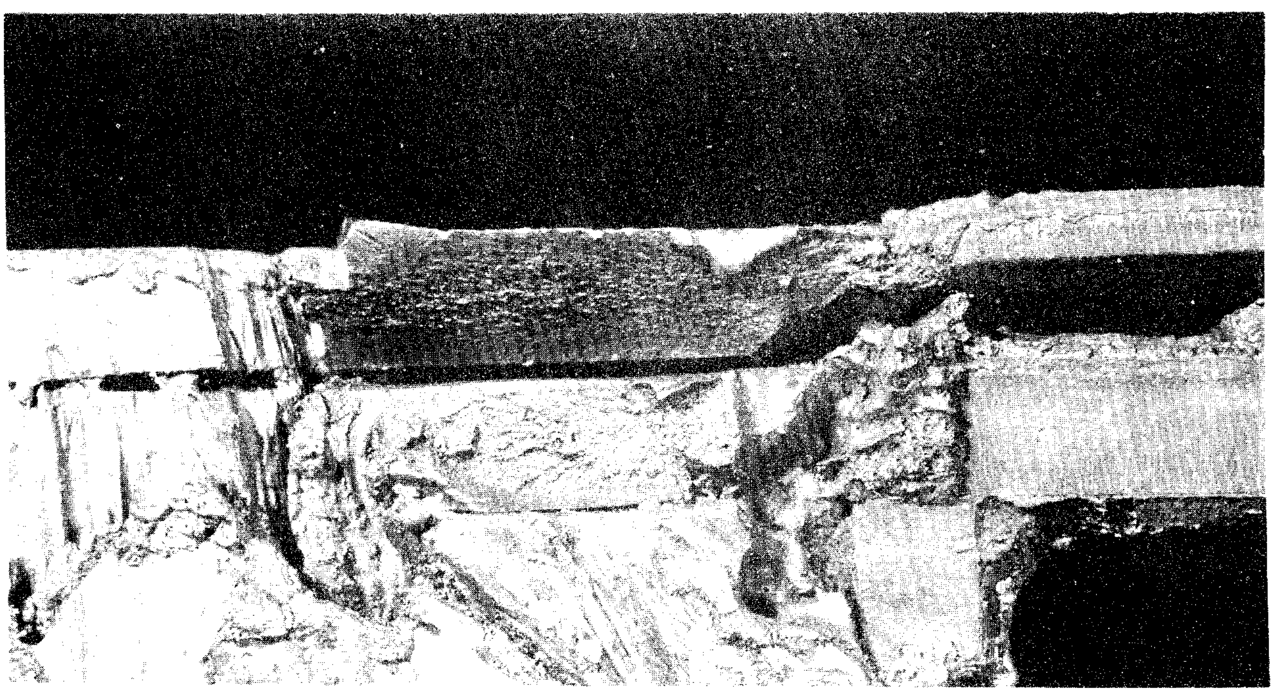


Overall view - below deck

FIG. 8 - SPECIMEN 14

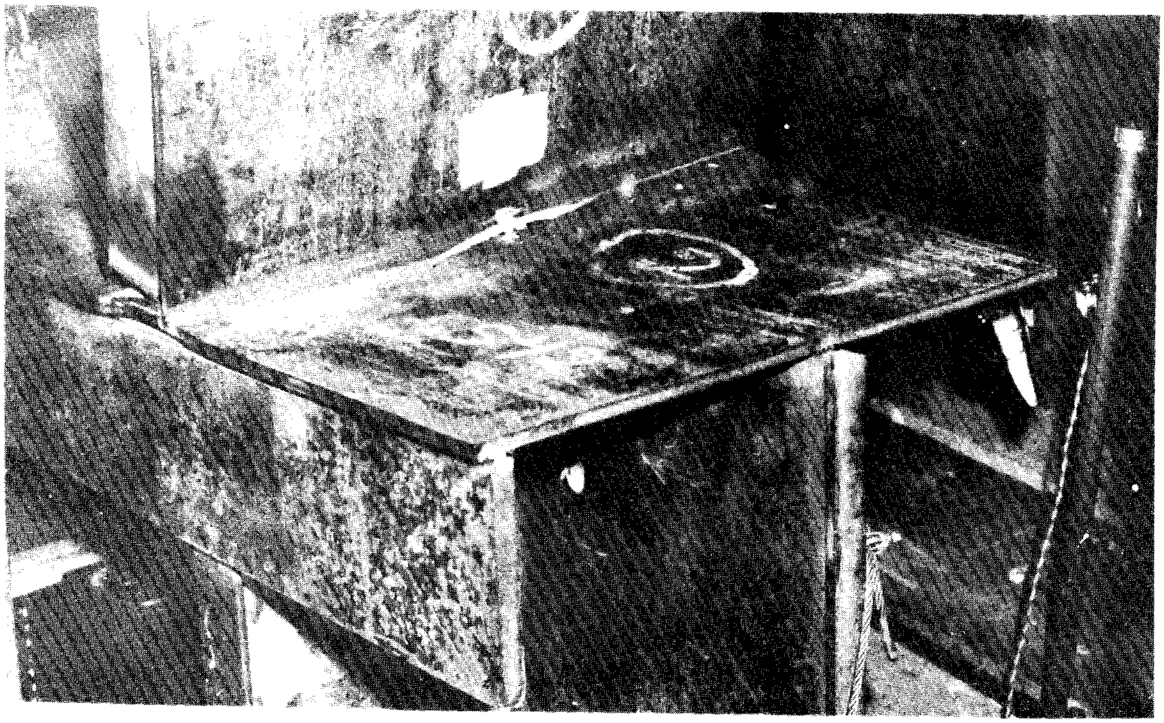


Fracture in doubler



Deck and doubler fractures, looking fwd.

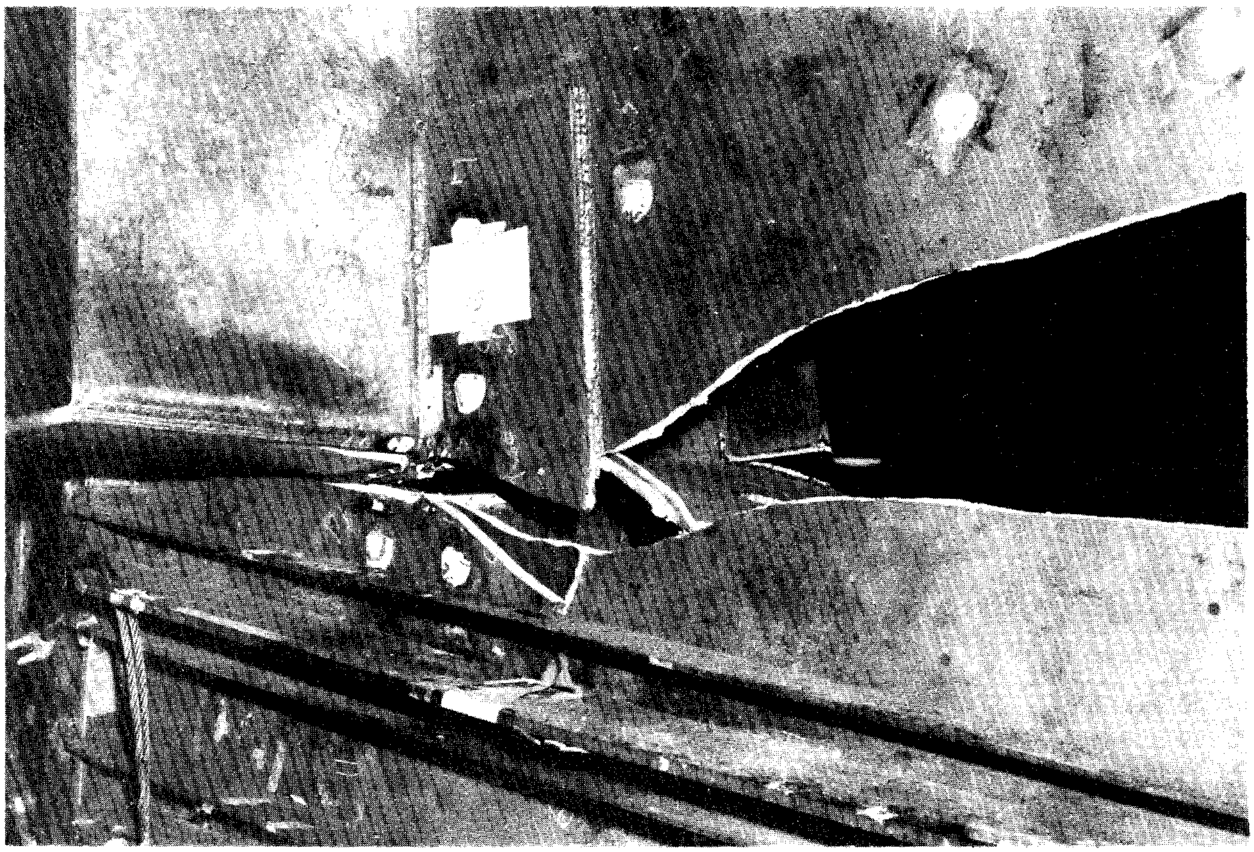
FIGURE 9 - SPECIMEN 14



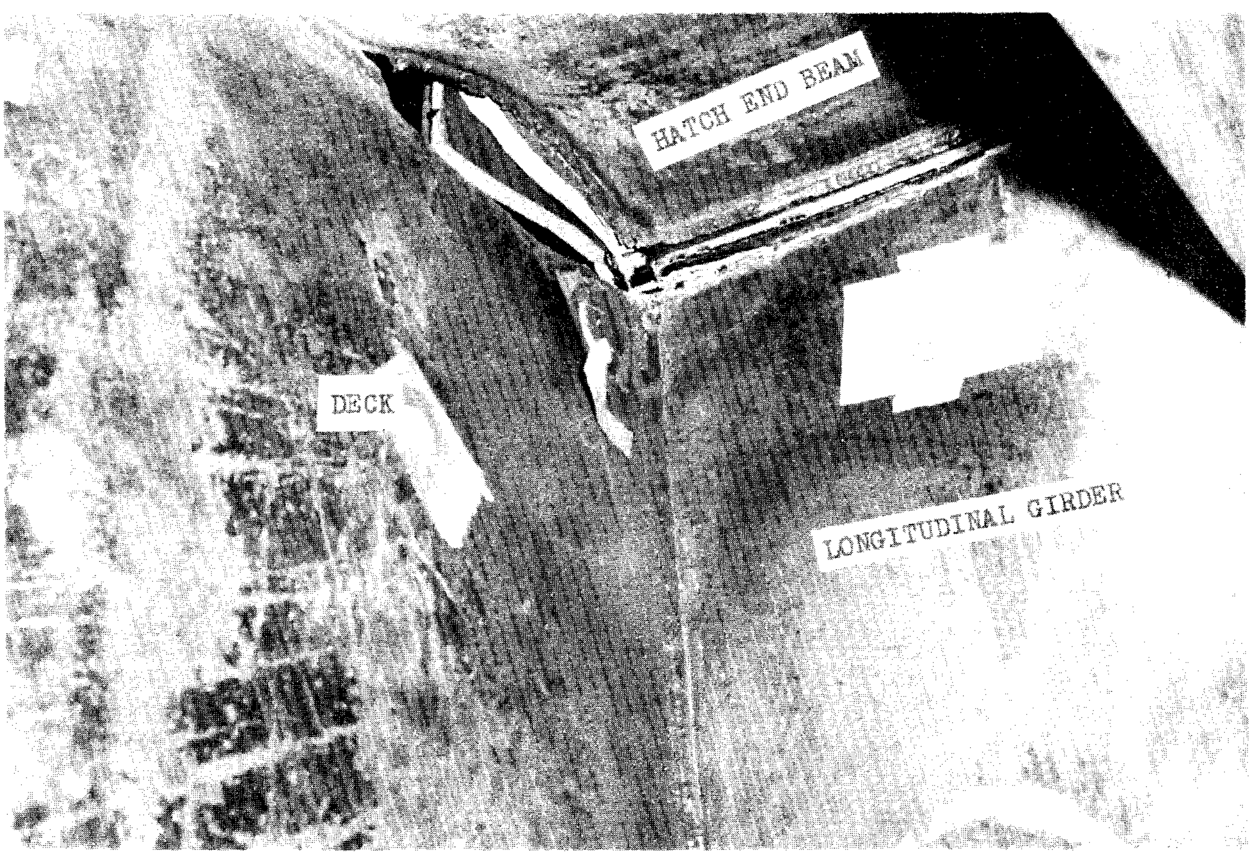
Fracture in corner - viewed from inside of hatch

Deck and doubler fracture patterns, looking aft.

FIG. 10 - SPECIMEN 15

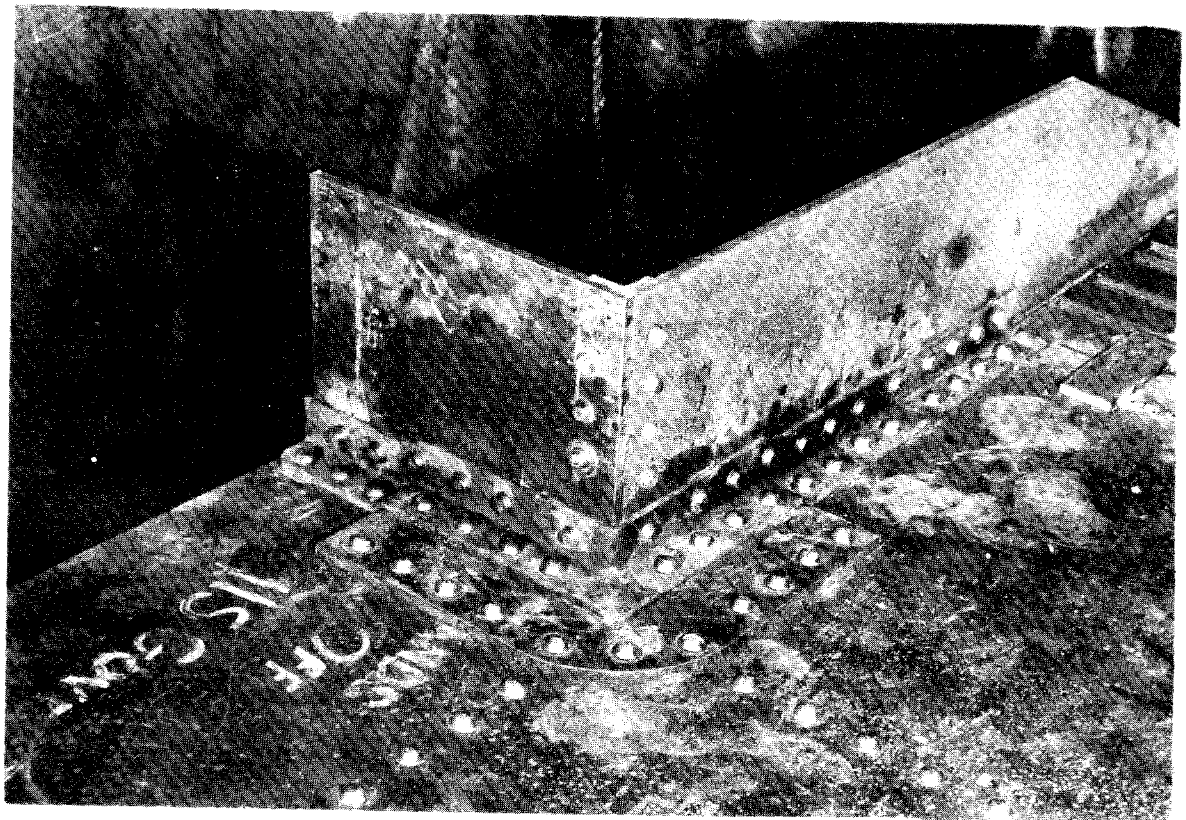


Fractures viewed from above deck

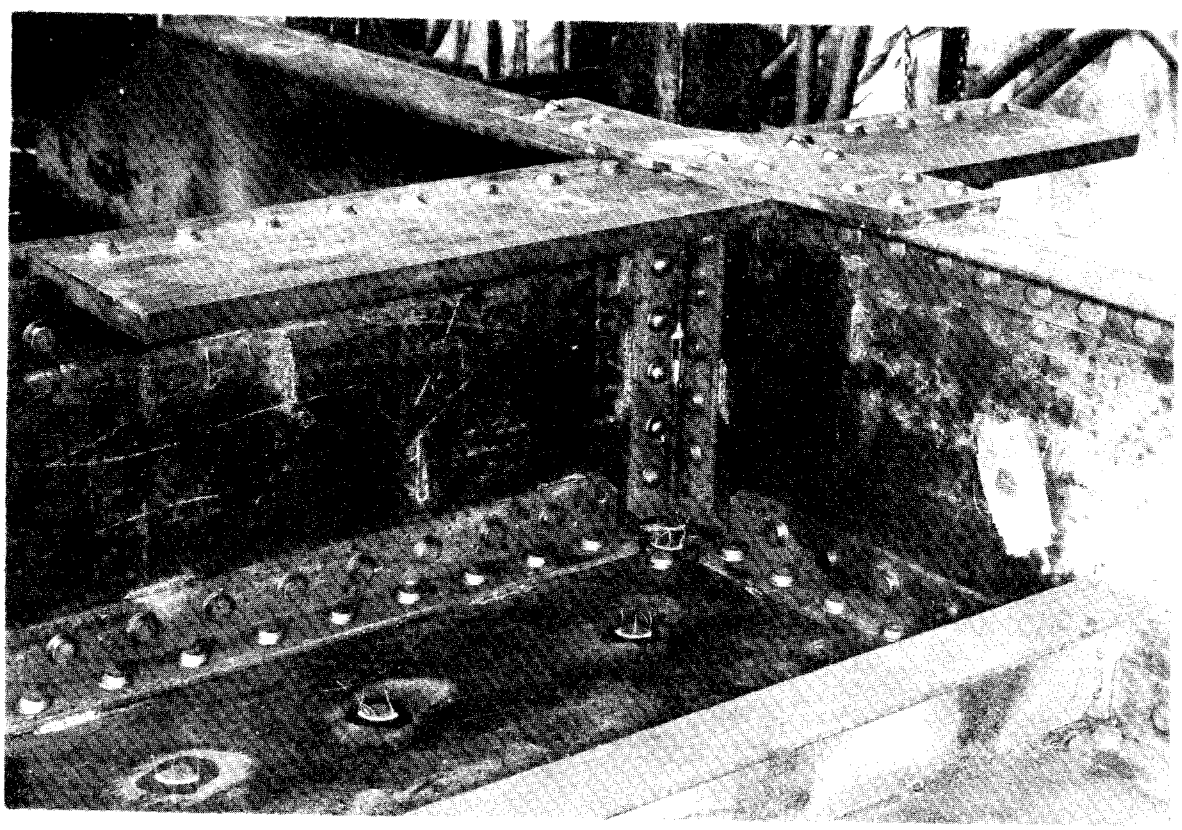


Fractures viewed from below deck, outboard and forward of hatch end beam.

FIG. 11 - SPECIMEN 15

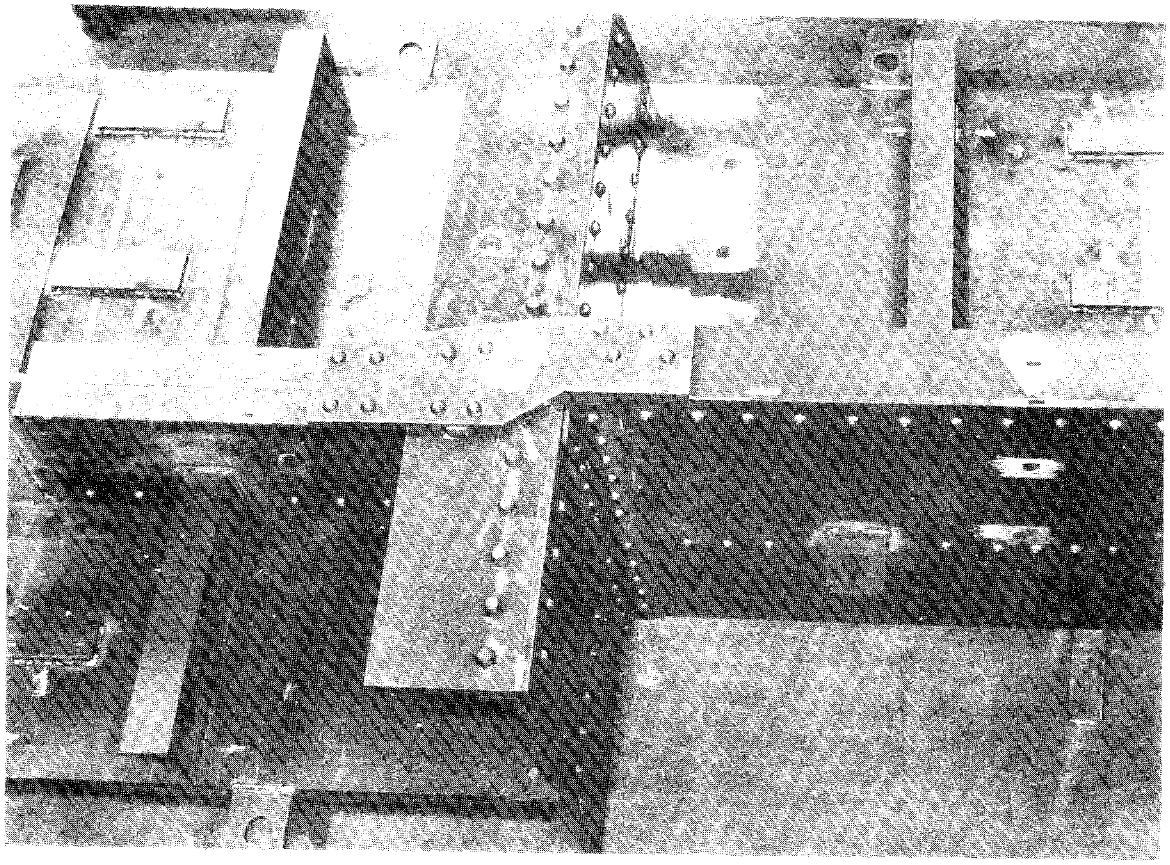


Before failure: View of corner from above deck

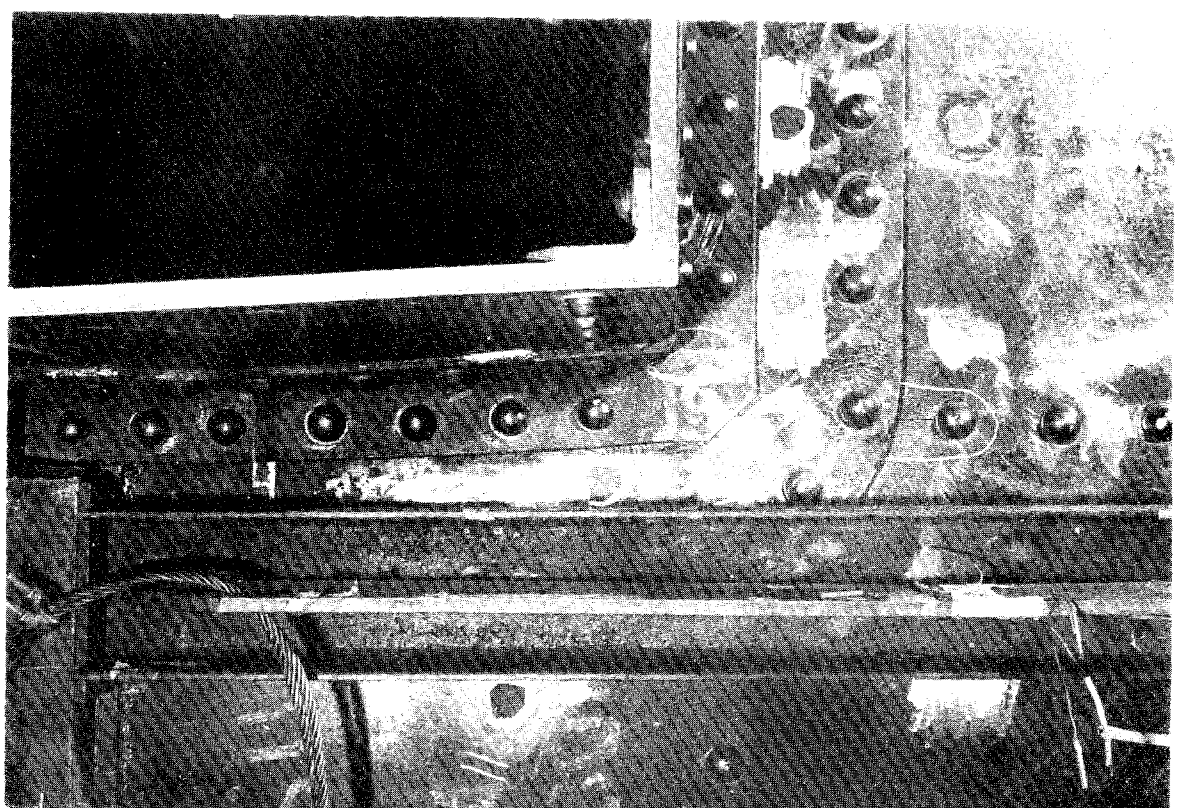


Before failure: Below deck, looking aft and inboard

FIG. 12 - SPECIMEN 16

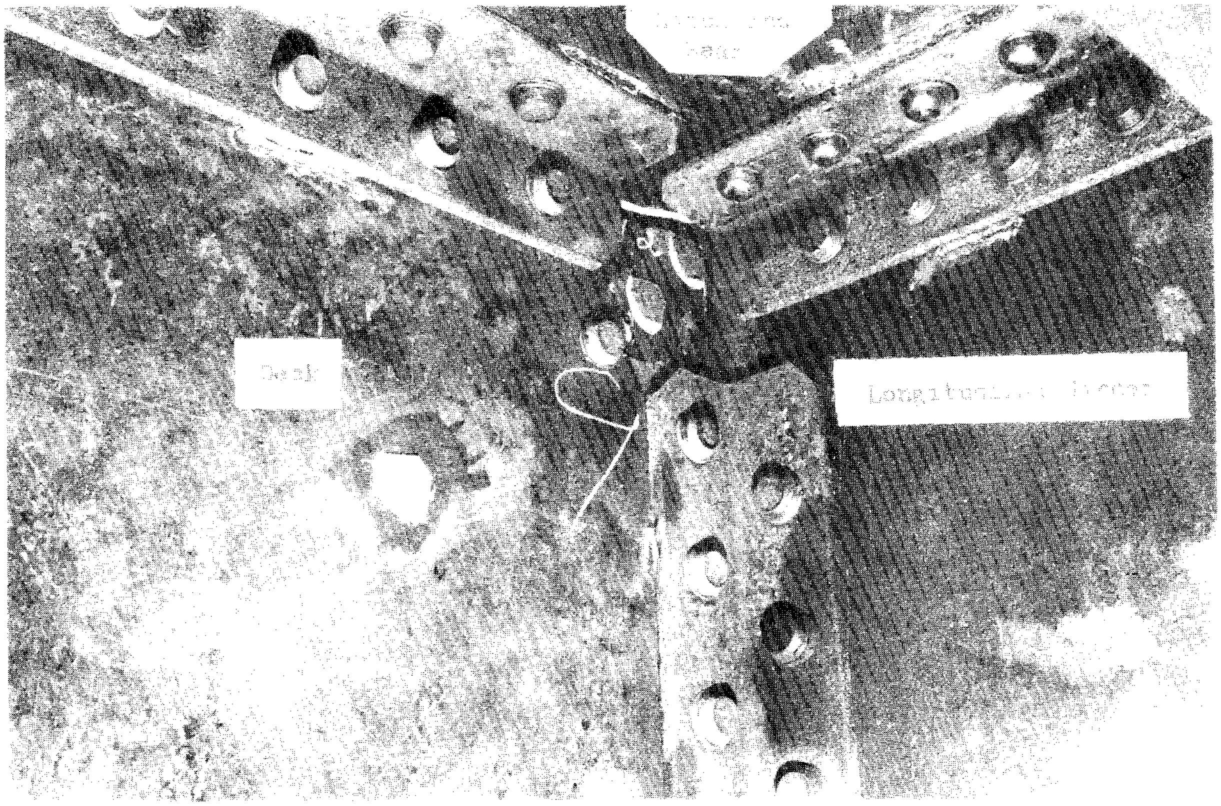


Before failure: Overall view - below deck

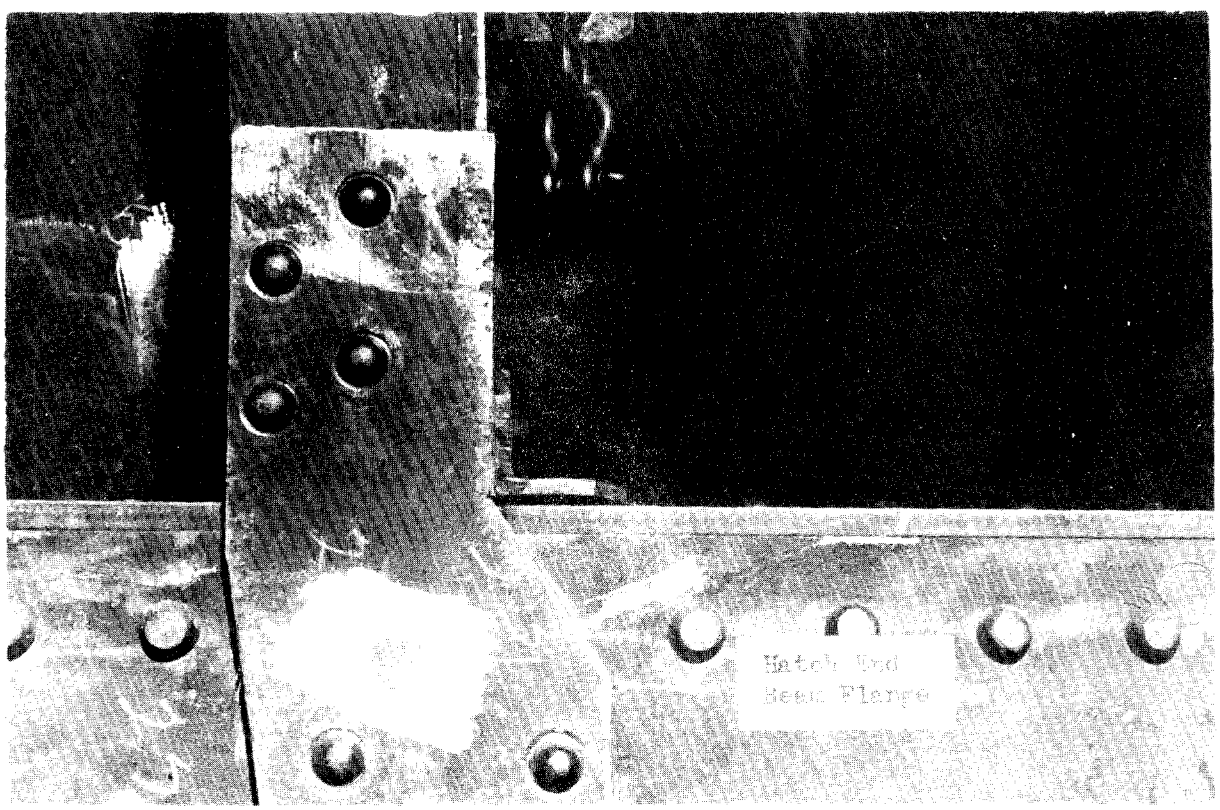


After failure: View from above deck

FIG. 13 - SPECIMEN 16

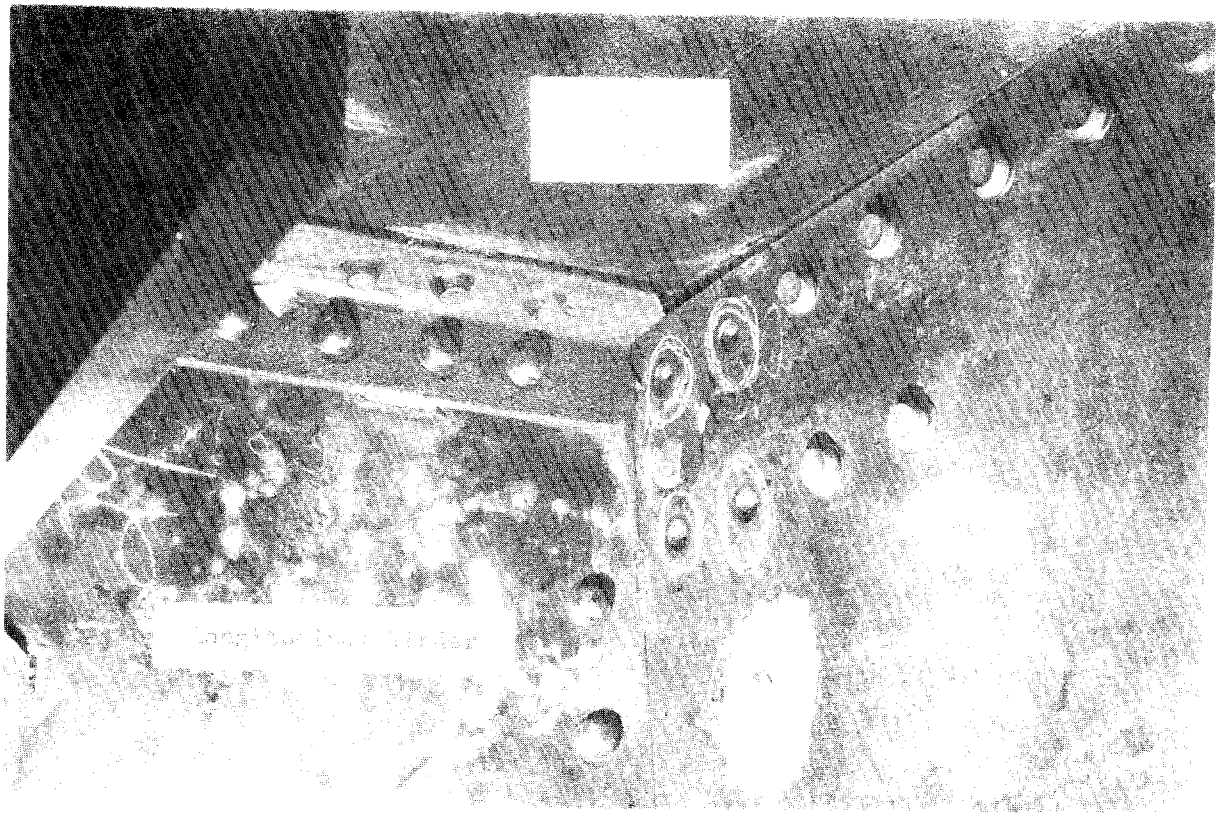


Fracture in deck: Viewed from below deck, outboard, and fwd. of hatch end beam

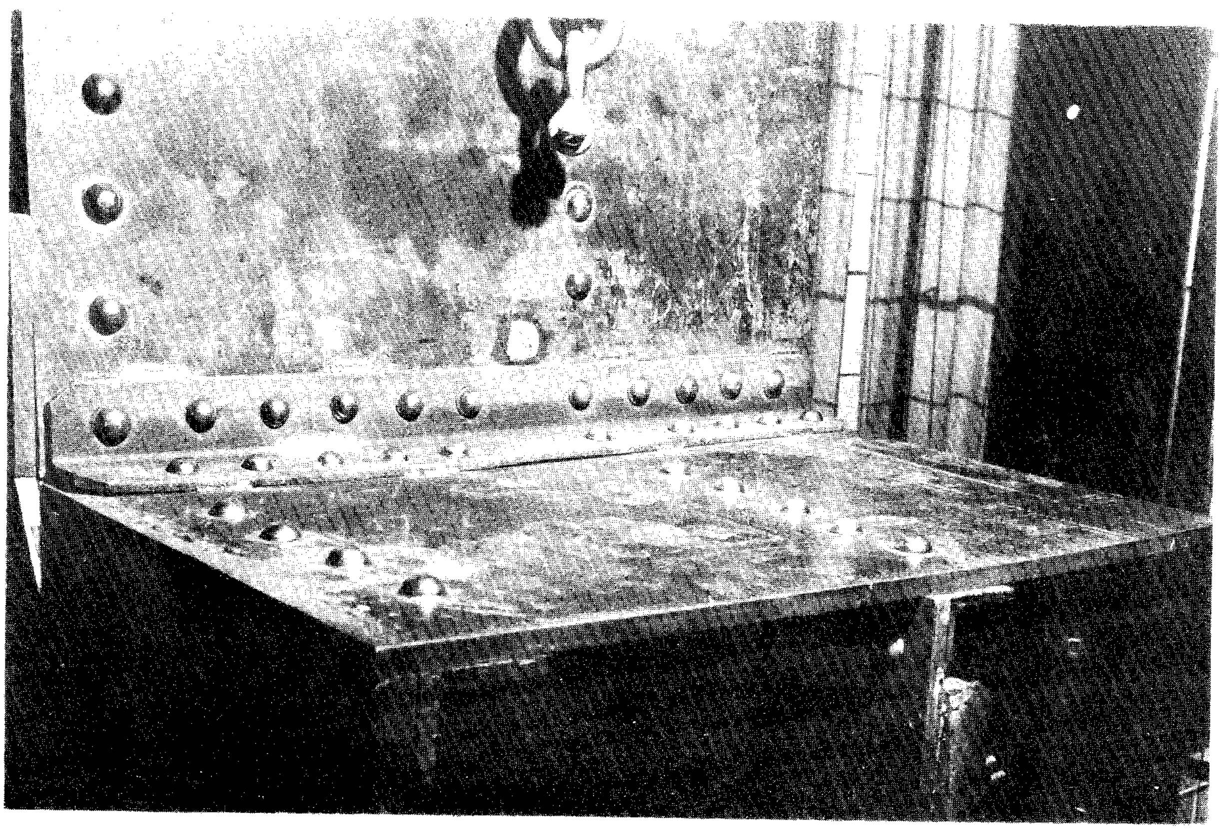


After failure: Close-up of tie-plate

FIG. 14 - SPECIMEN 16

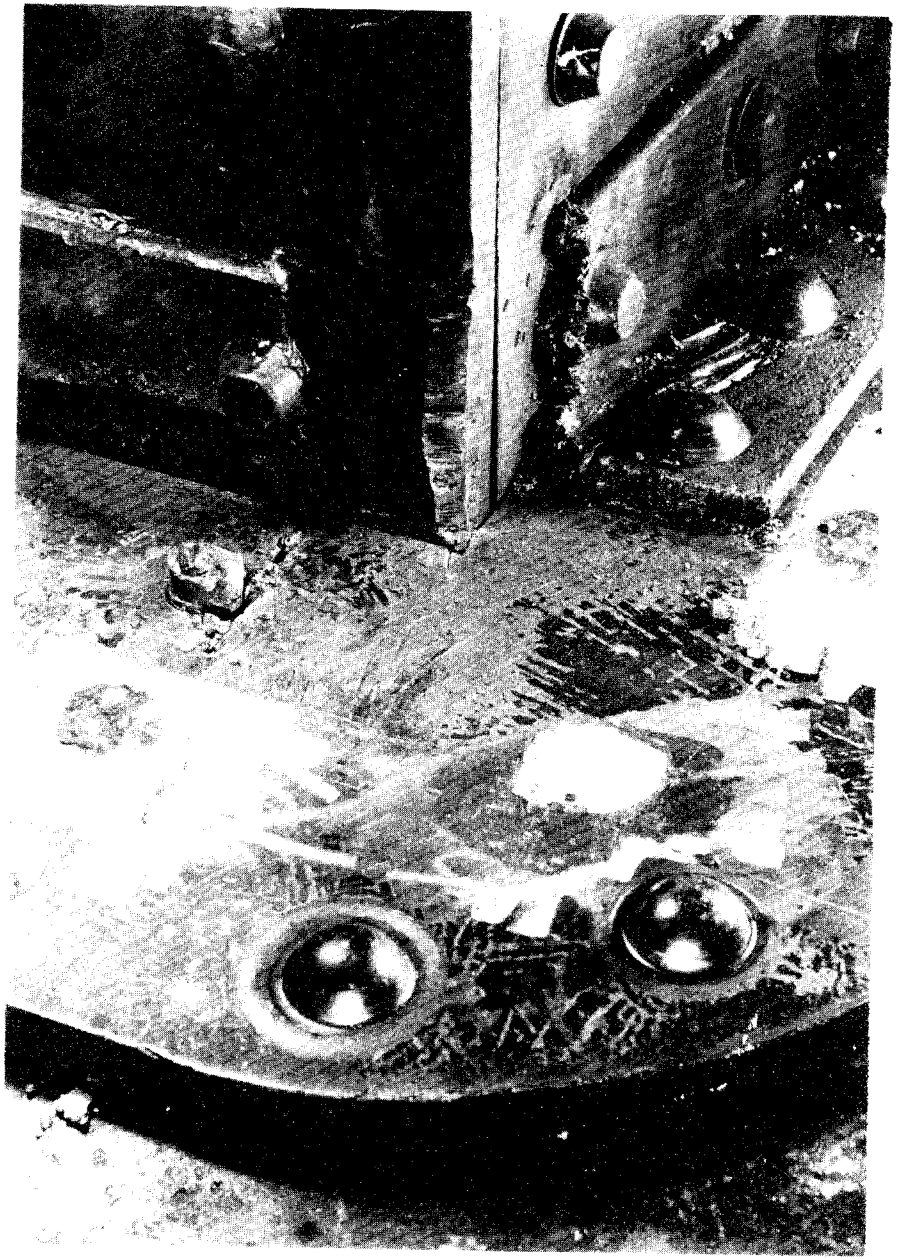


After failure: View from below deck, inboard, and fwd. of hatch end beam

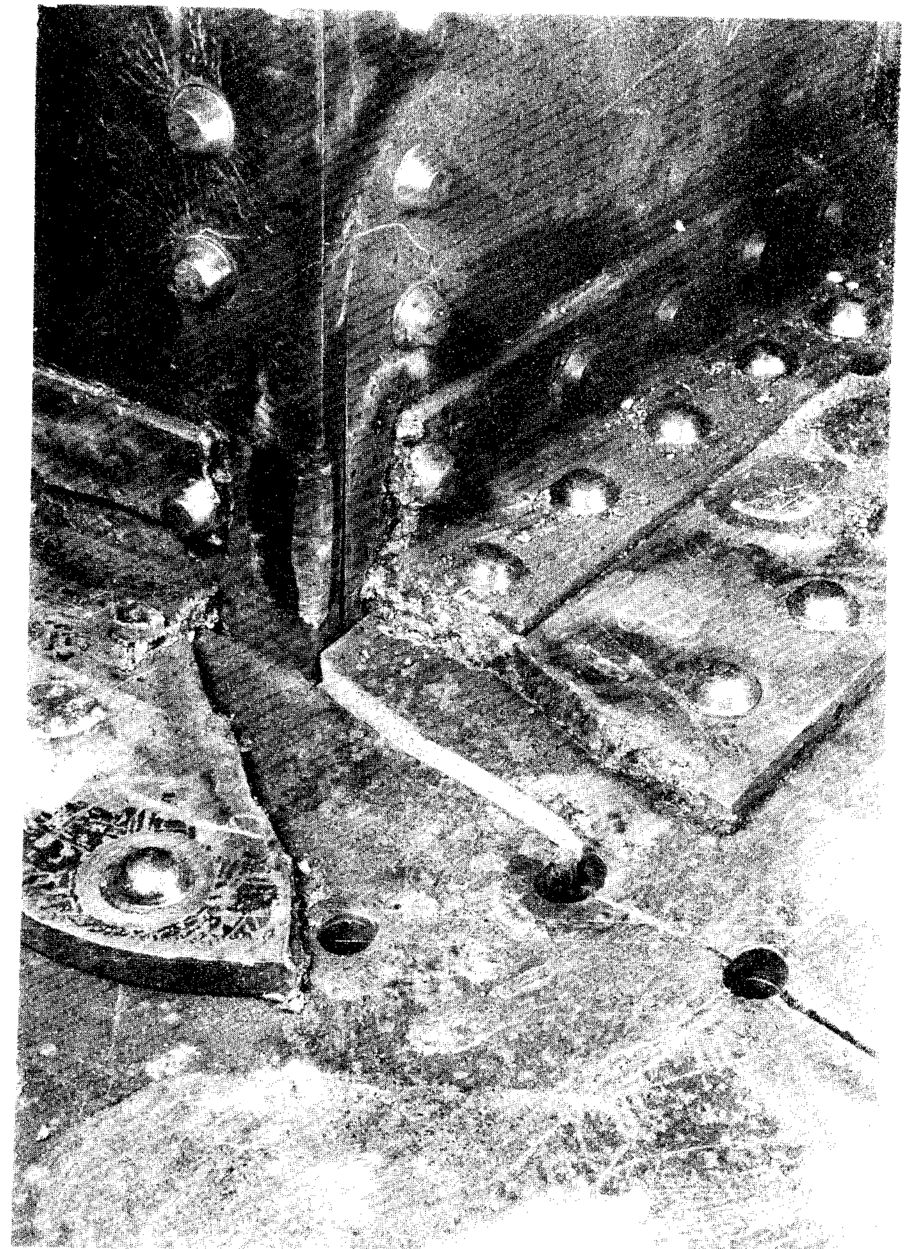


After failure: Corner viewed from inside of hatch

FIG. 15 - SPECIMEN 16

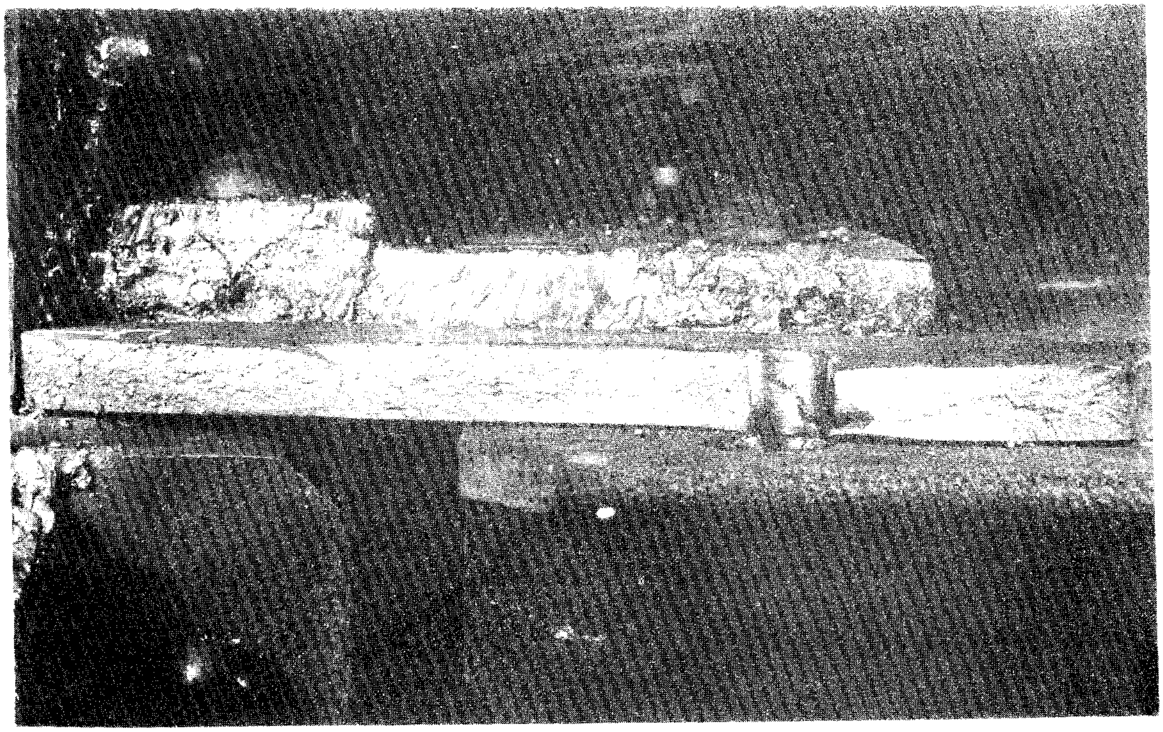


Fracture in Doubler (angle cut away)

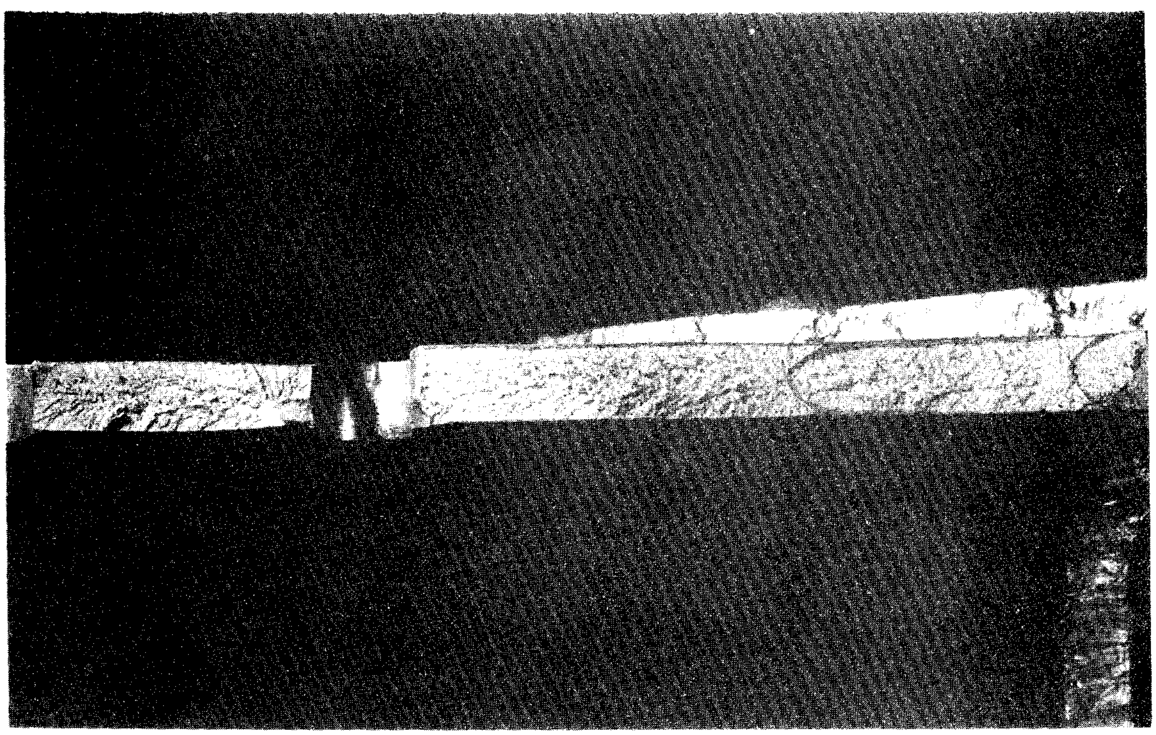


Fracture in deck (doubler cut away)

FIGURE 16 - SPECIMEN 16

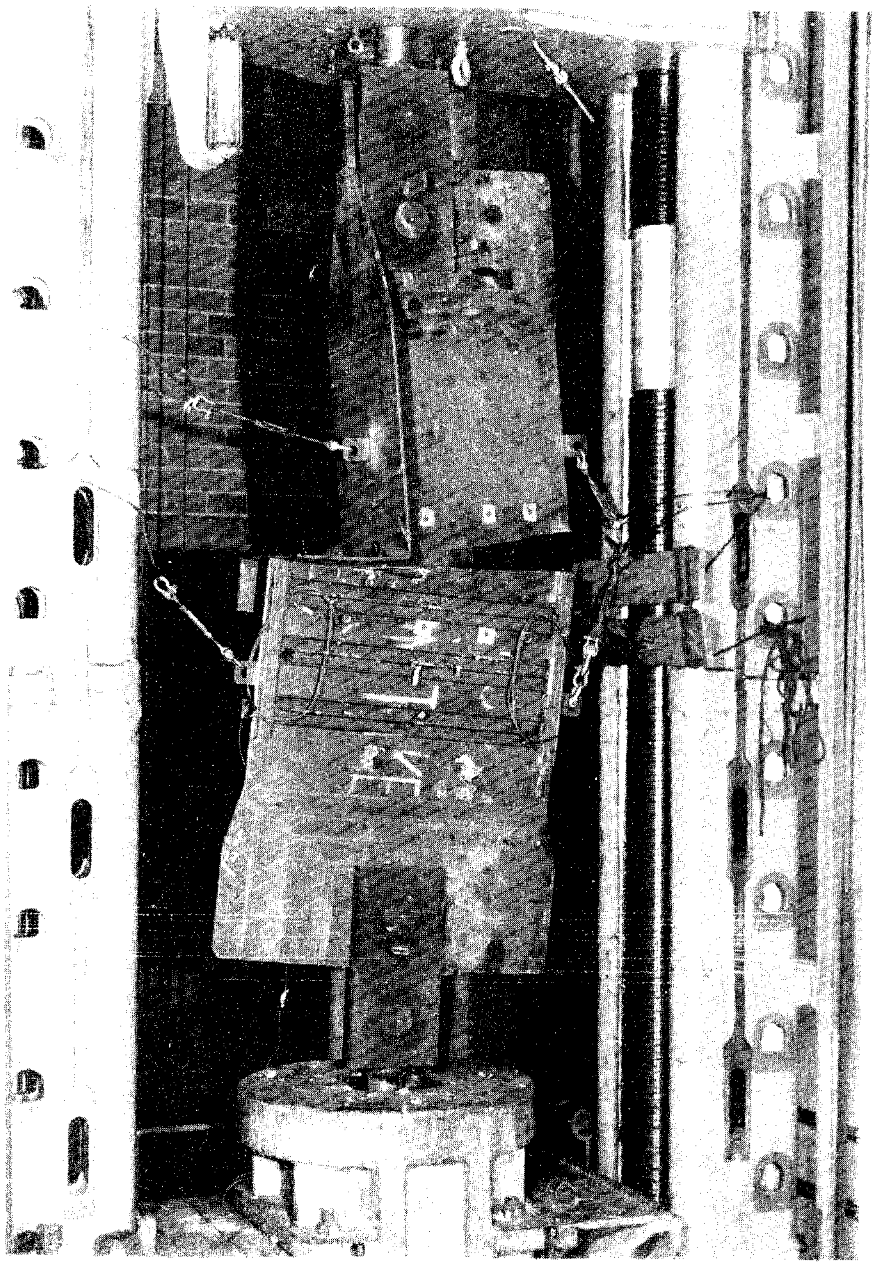


Pattern in deck - looking aft

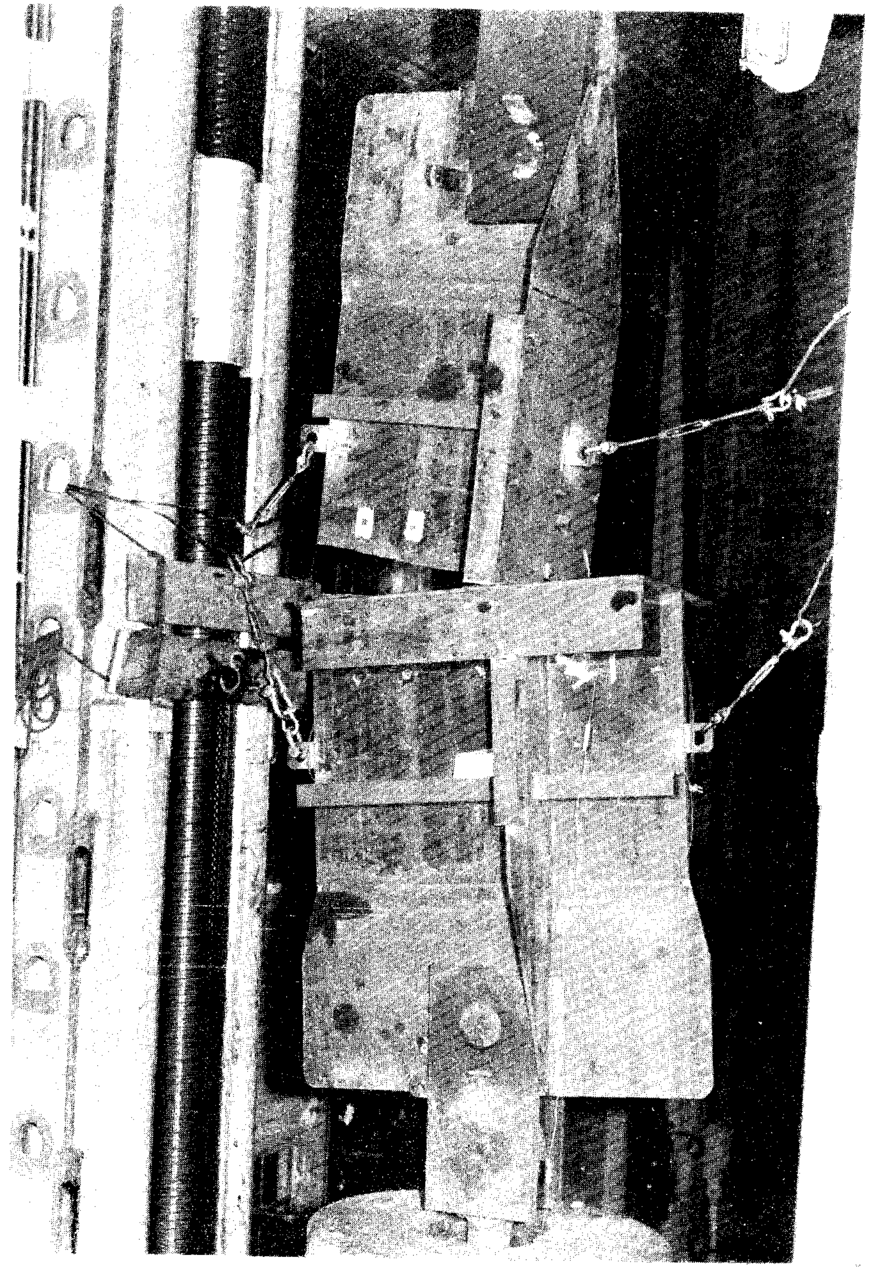


Pattern in deck - looking fwd.

FIG. 17 - SPECIMEN 16

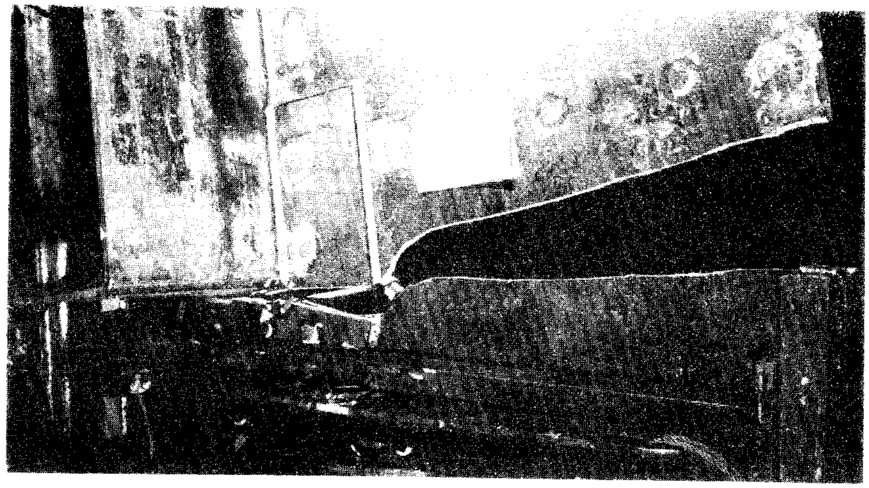


Overall view - above deck



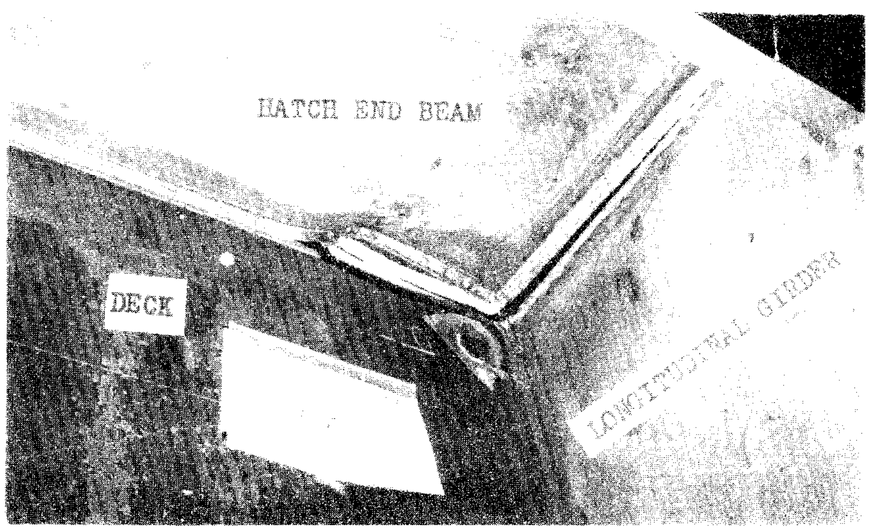
Overall view - below deck

FIG. 18 - SPECIMEN 17



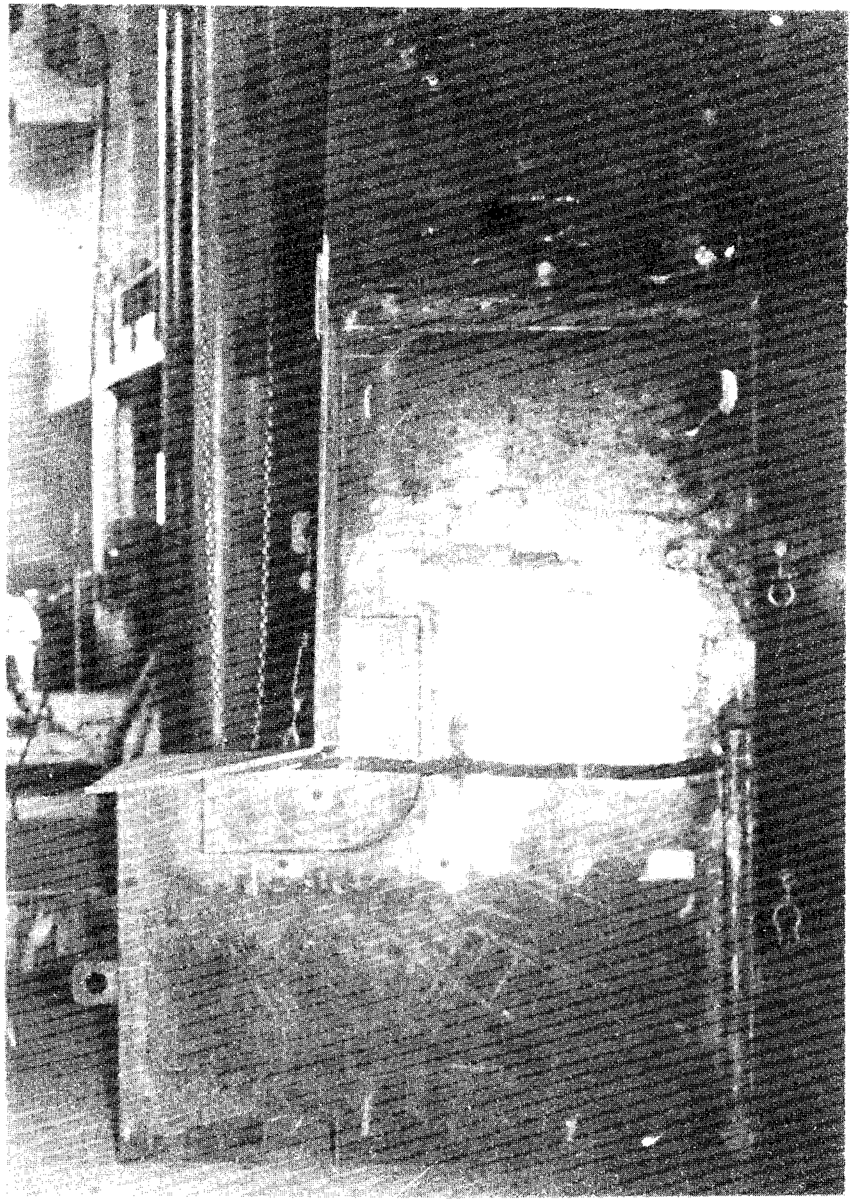
Fractures: Viewed from above deck

Fractures: Viewed from below deck, outboard, and aft of hatch end beam

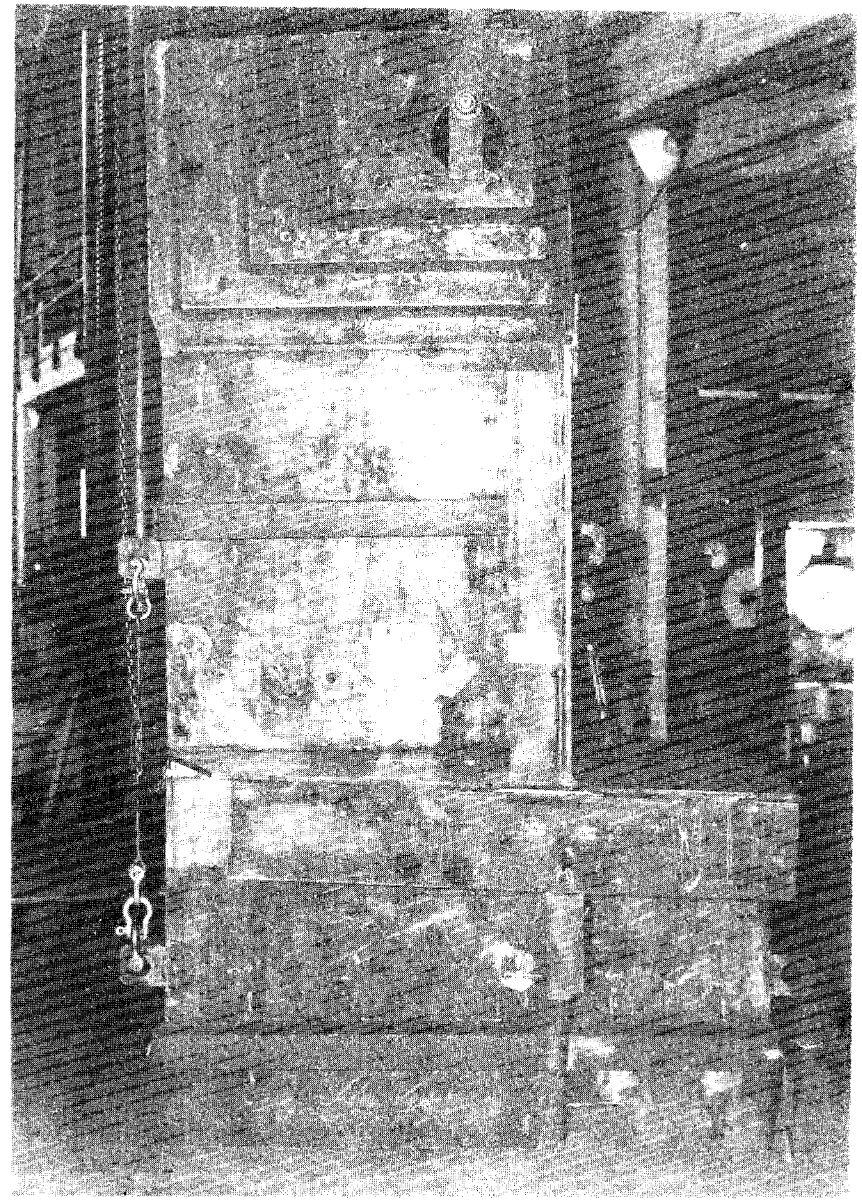


Fractures: Viewed from below deck, outboard, and fwd. of hatch end beam

FIG. 19 - SPECIMEN 17

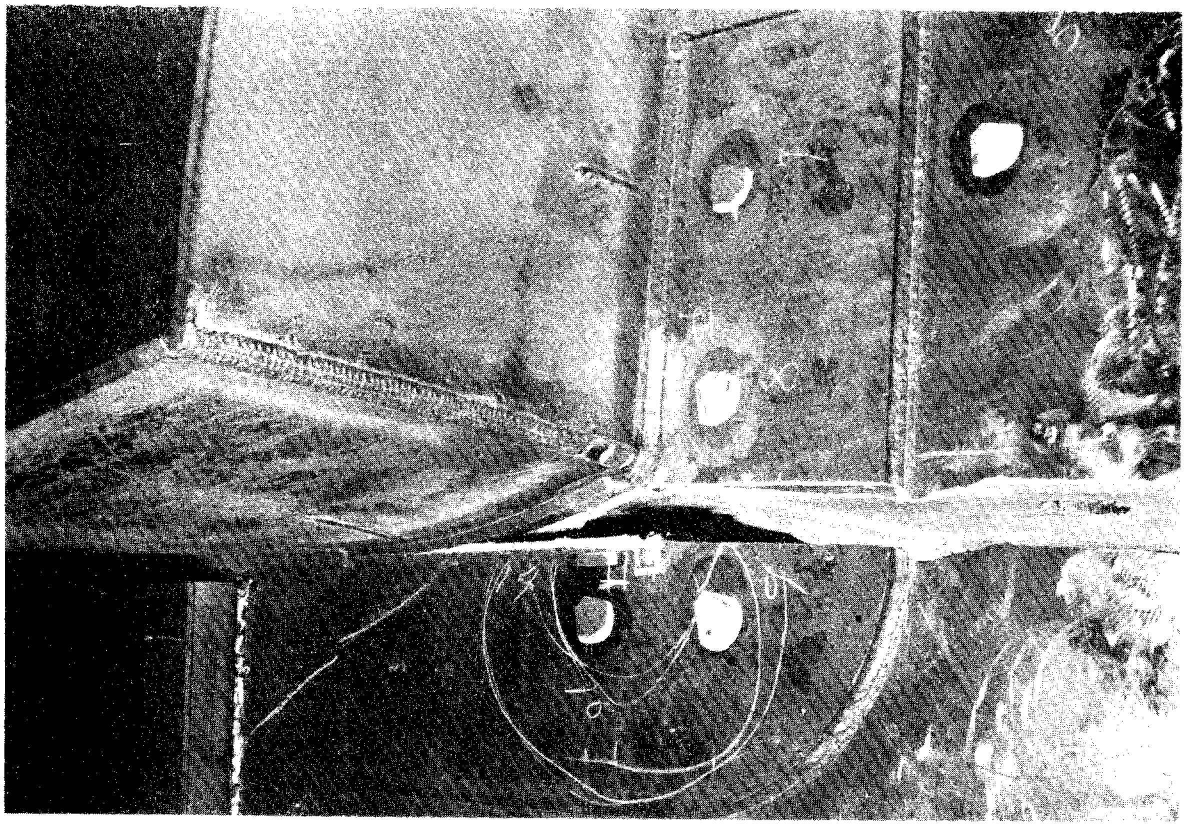


Overall view - above deck

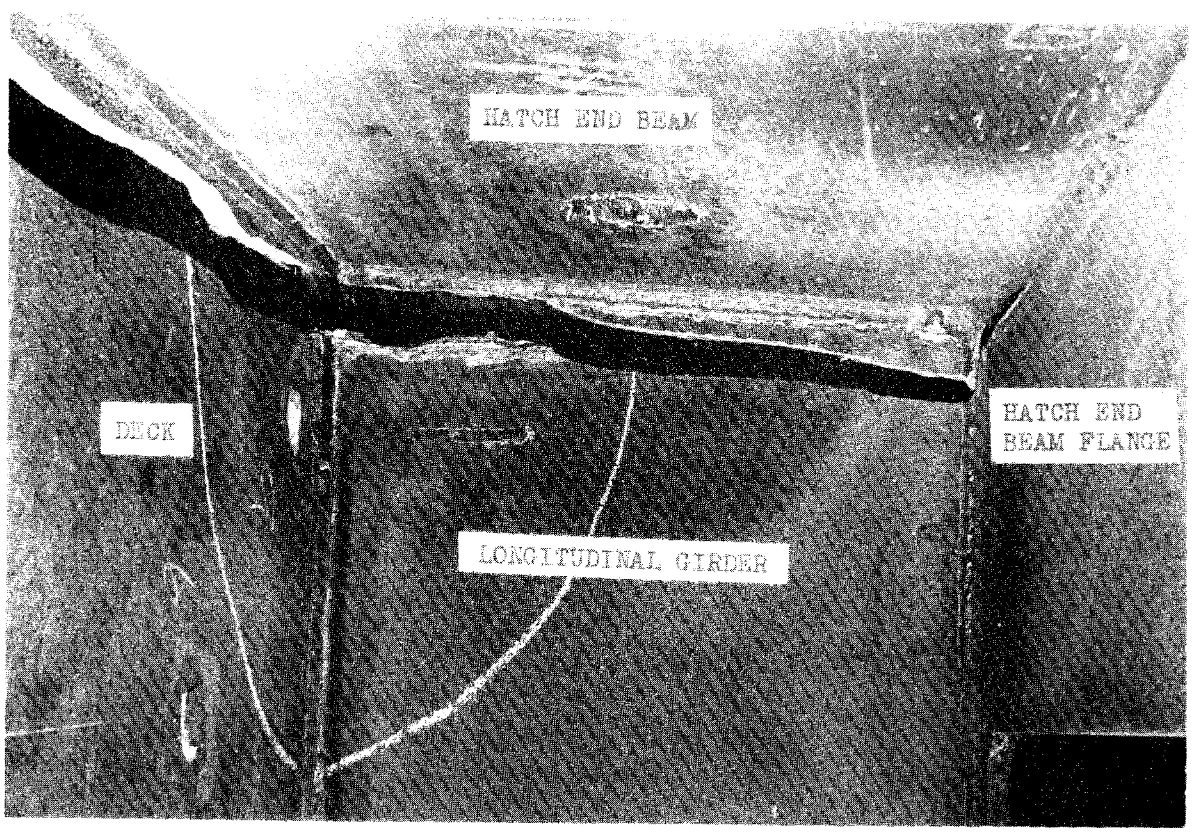


Overall view - below deck

FIG. 20 - SPECIMEN 18

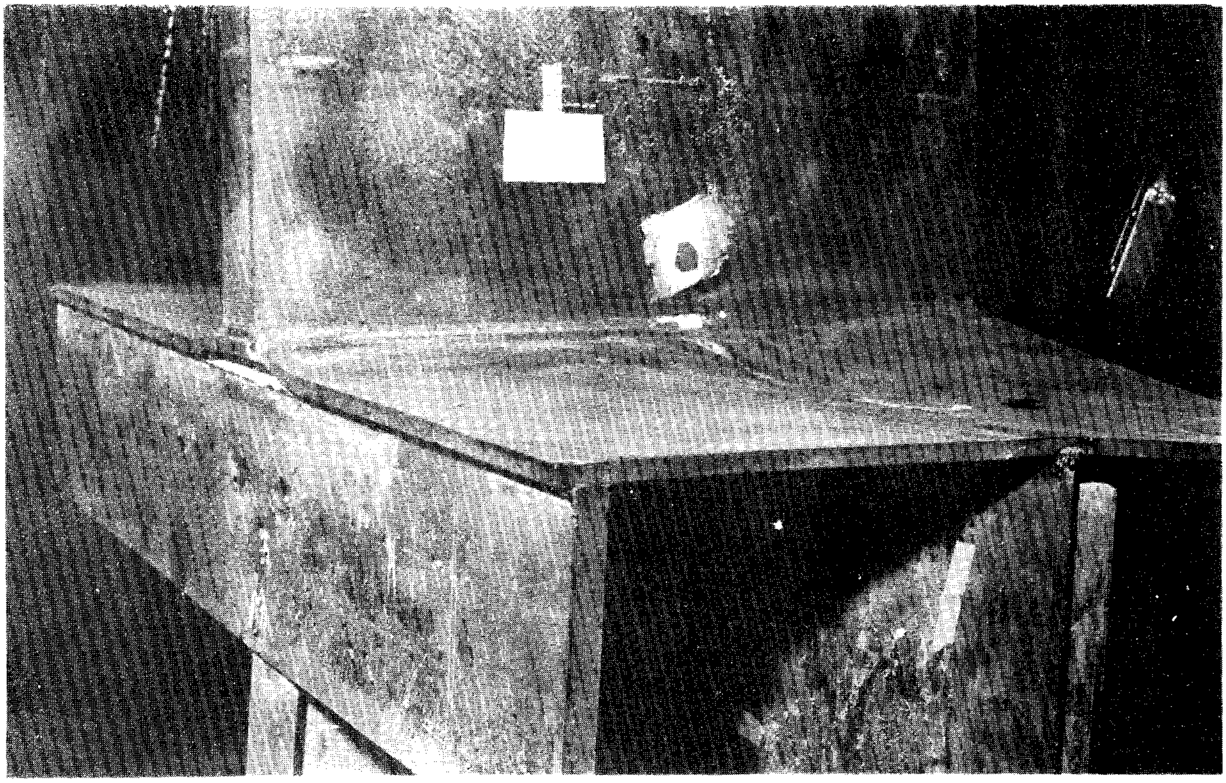


Fractures: Viewed from above deck

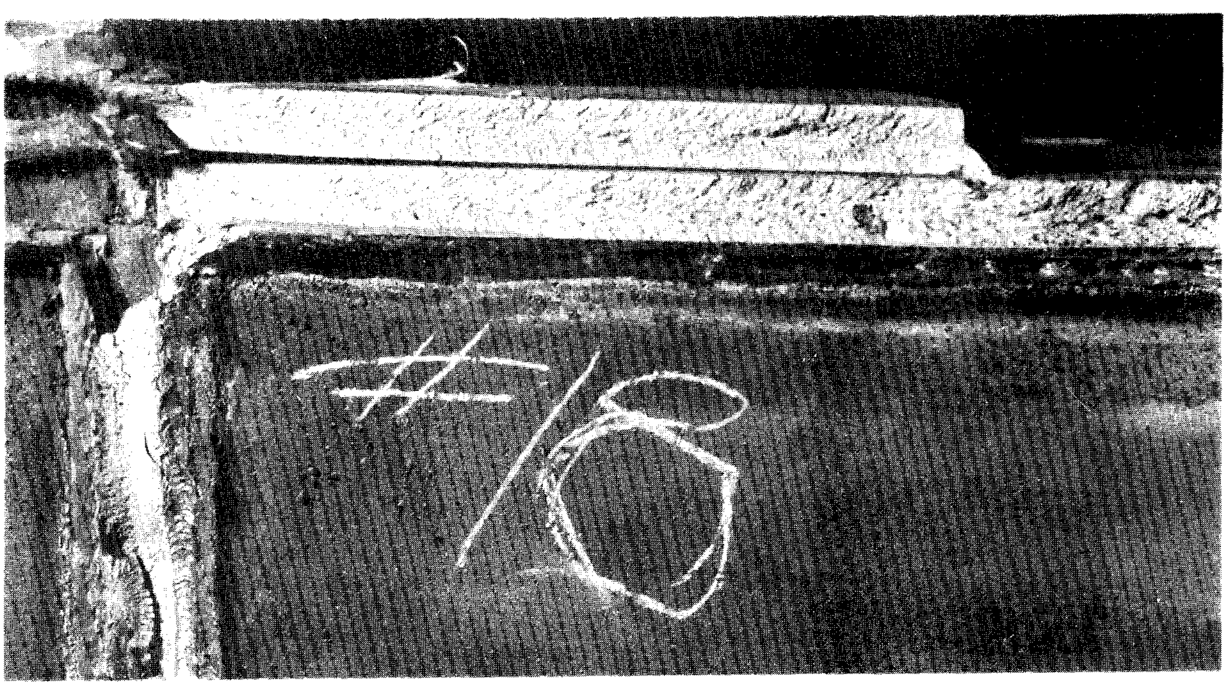


Fractures: Viewed from below deck, outboard, and fwd. of hatch end beam

FIG. 21 - SPECIMEN 18

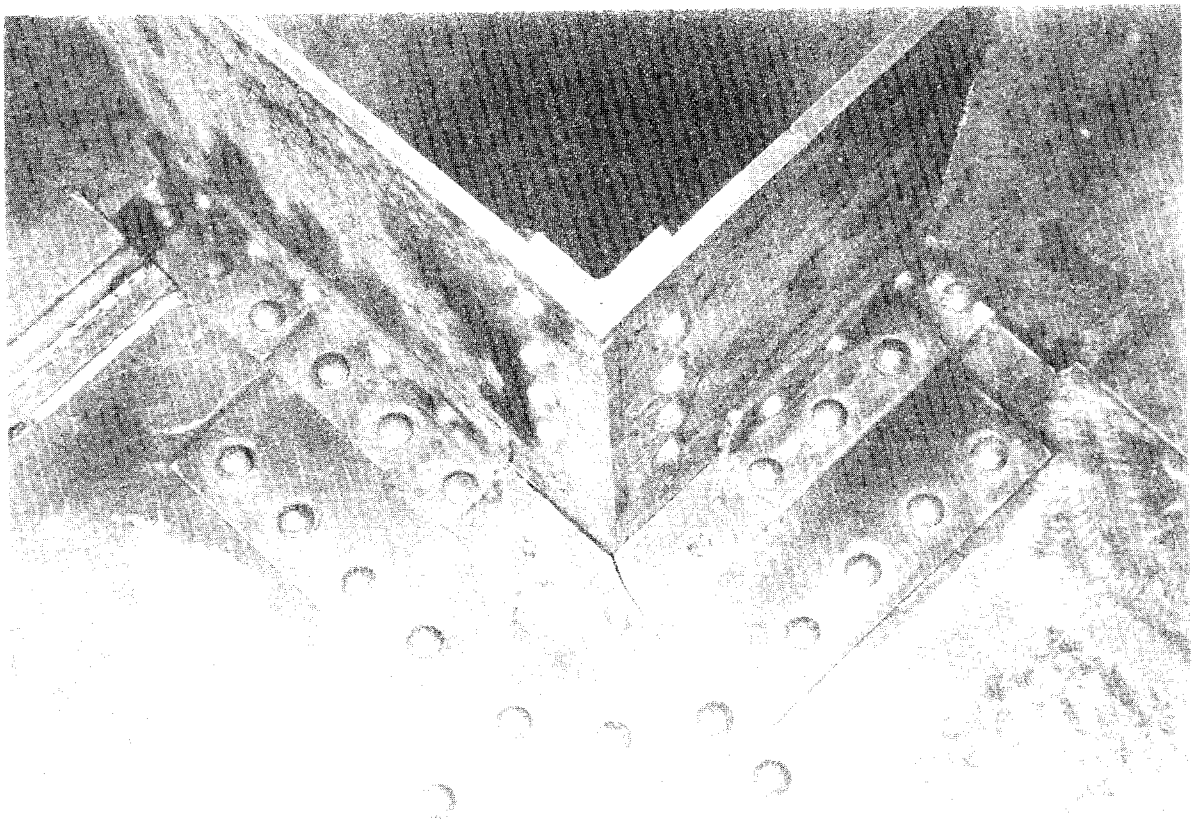


Corner viewed from inside of hatch

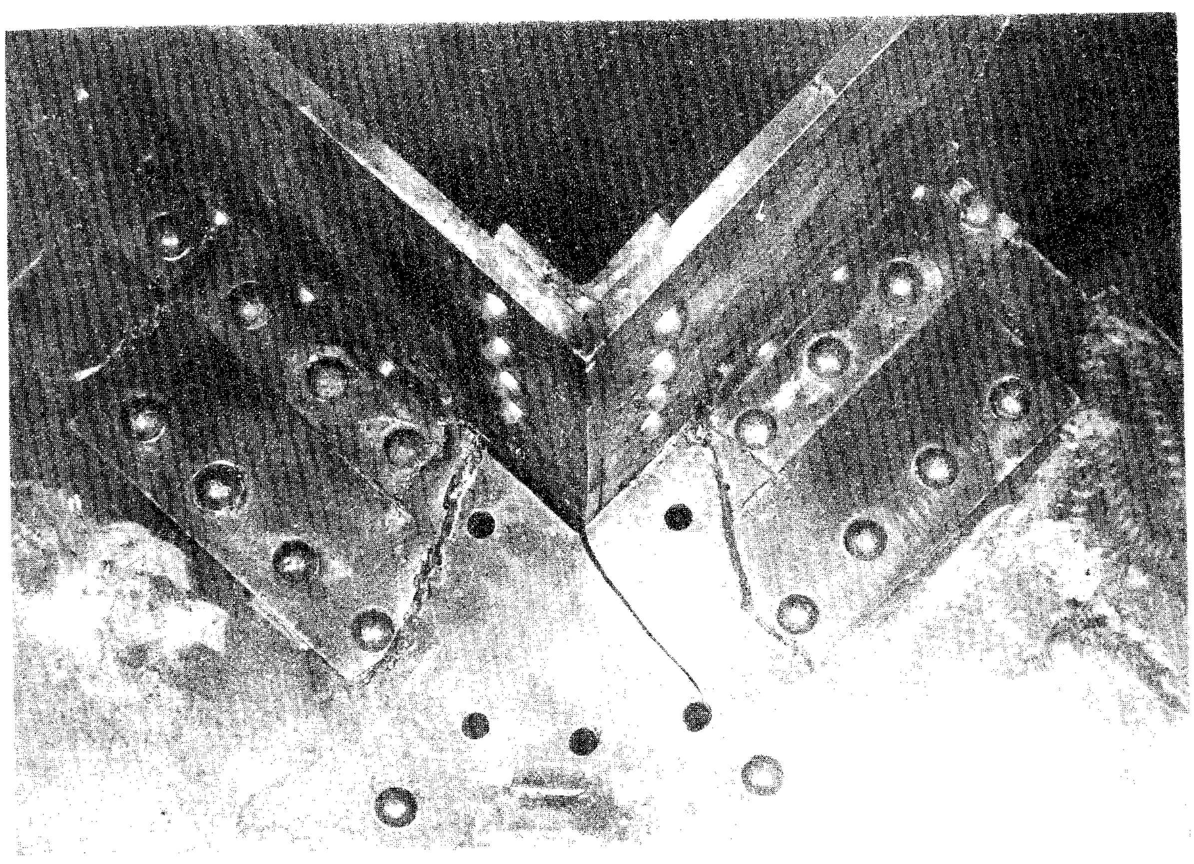


Deck and doubler fracture patterns - looking aft

FIG. 22 - SPECIMEN 18

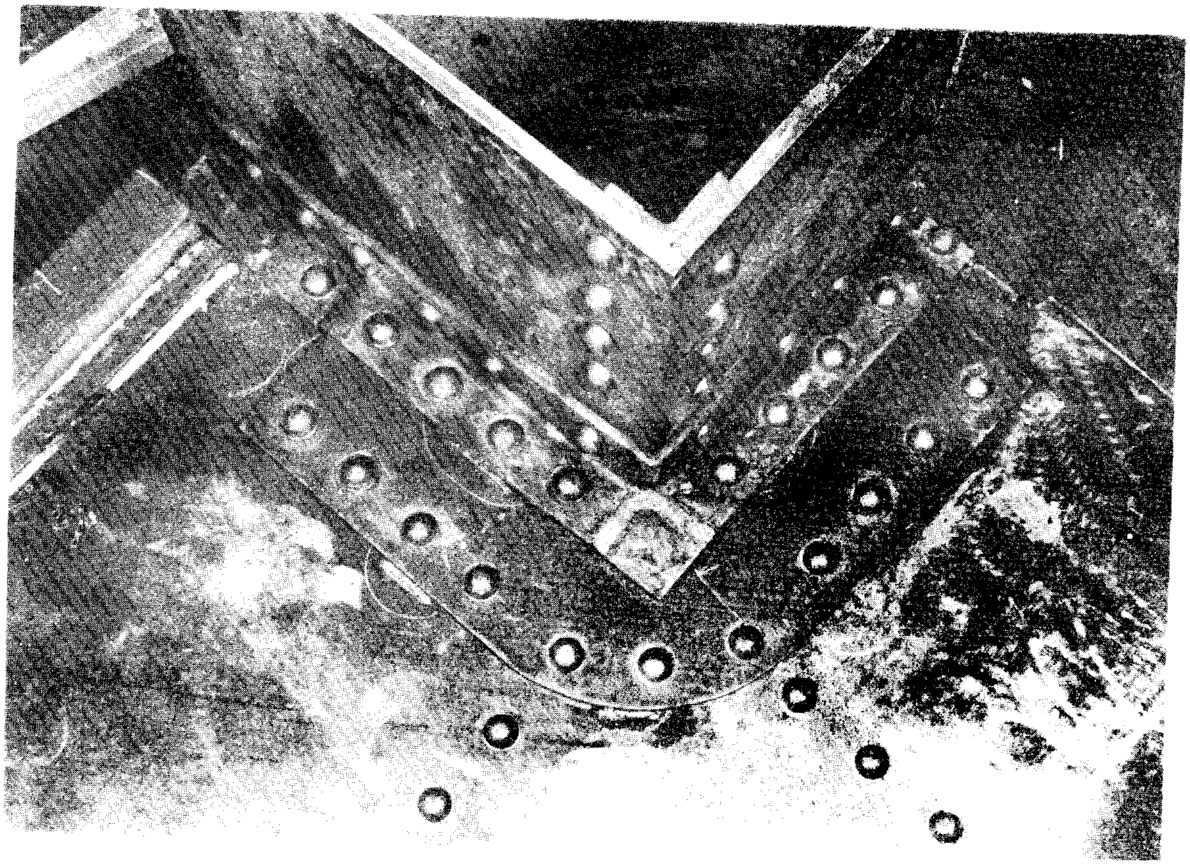


Fracture in doubler (angle cut away)
Arrow indicates extent of first fracture.

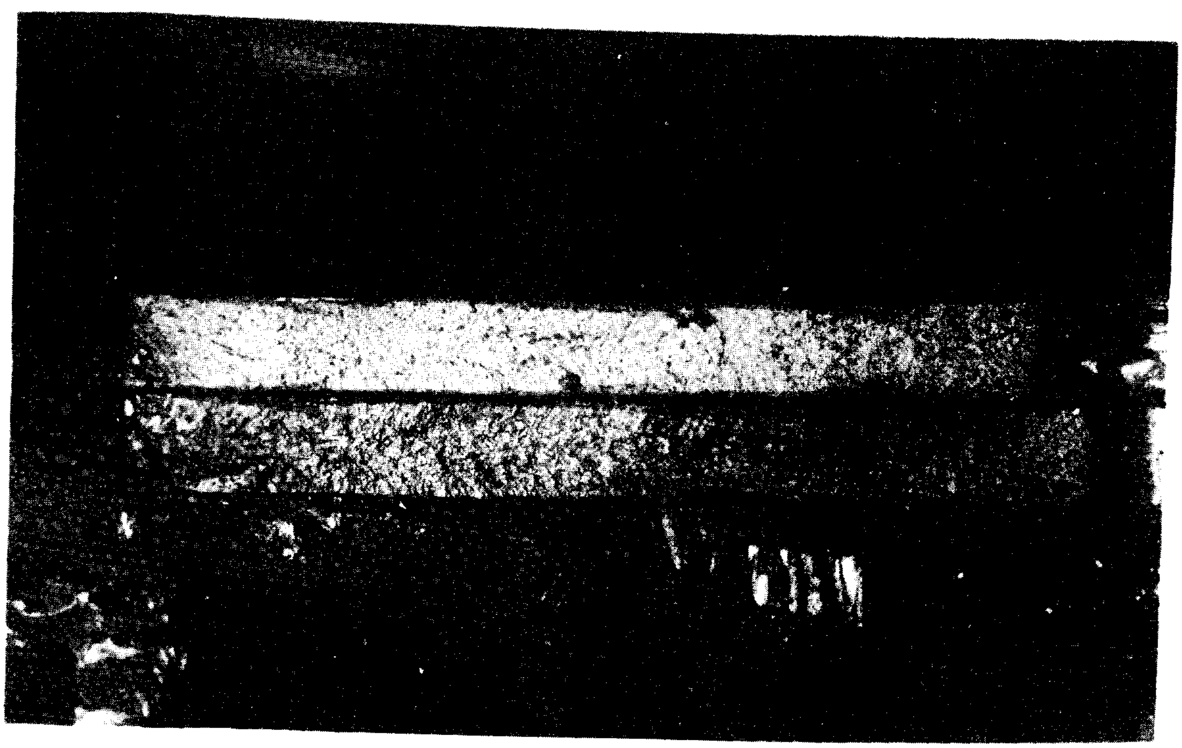


Fracture in deck (doubler cut away)

FIG. 23 - SPECIMEN 19



View of corner - after failure



Deck and doubler fracture patterns - looking aft

FIG. 24 - SPECIMEN 19

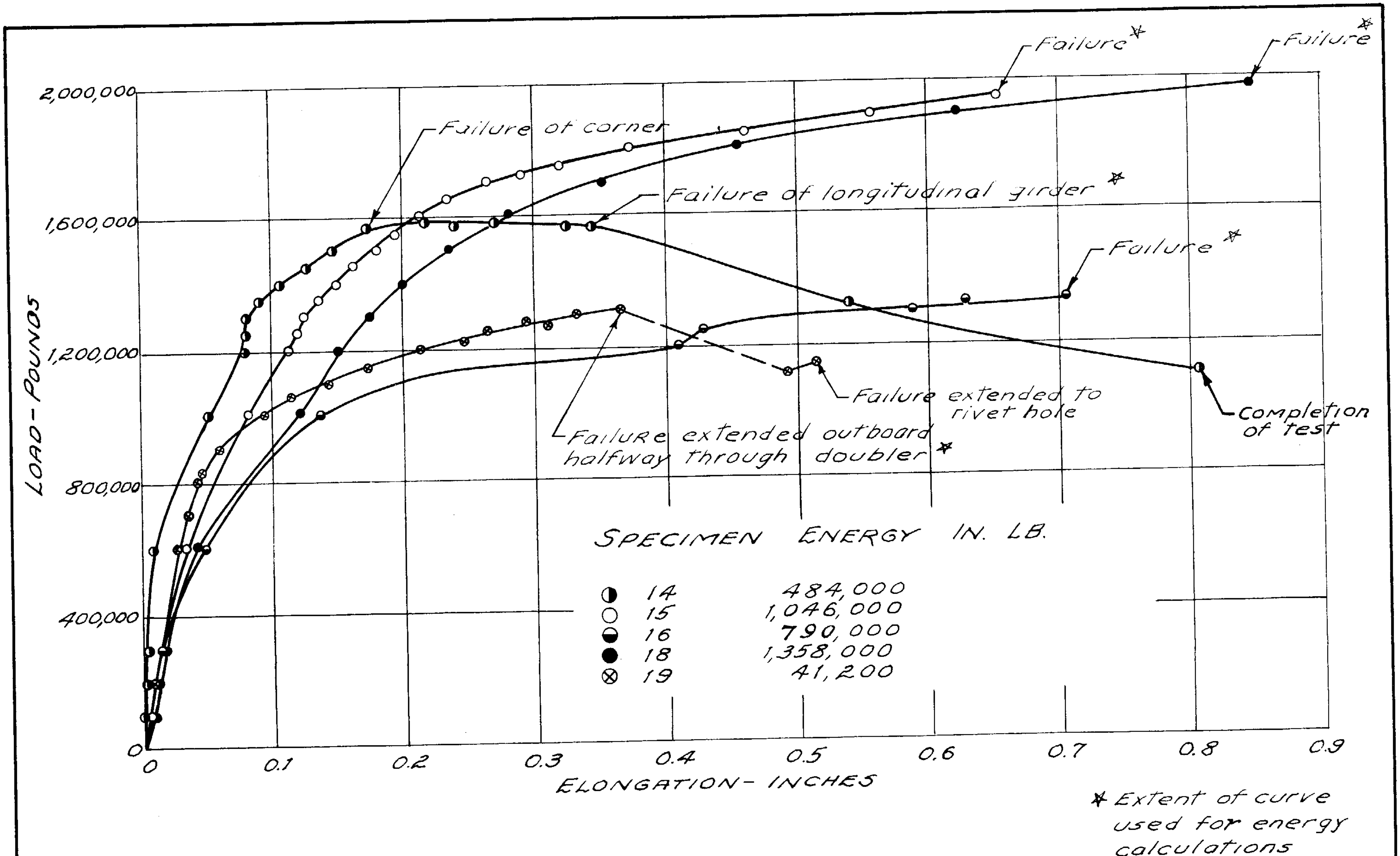


FIG. 25 LOAD ELONGATION CURVES
(PIN TO PIN MEASUREMENTS).

R-325

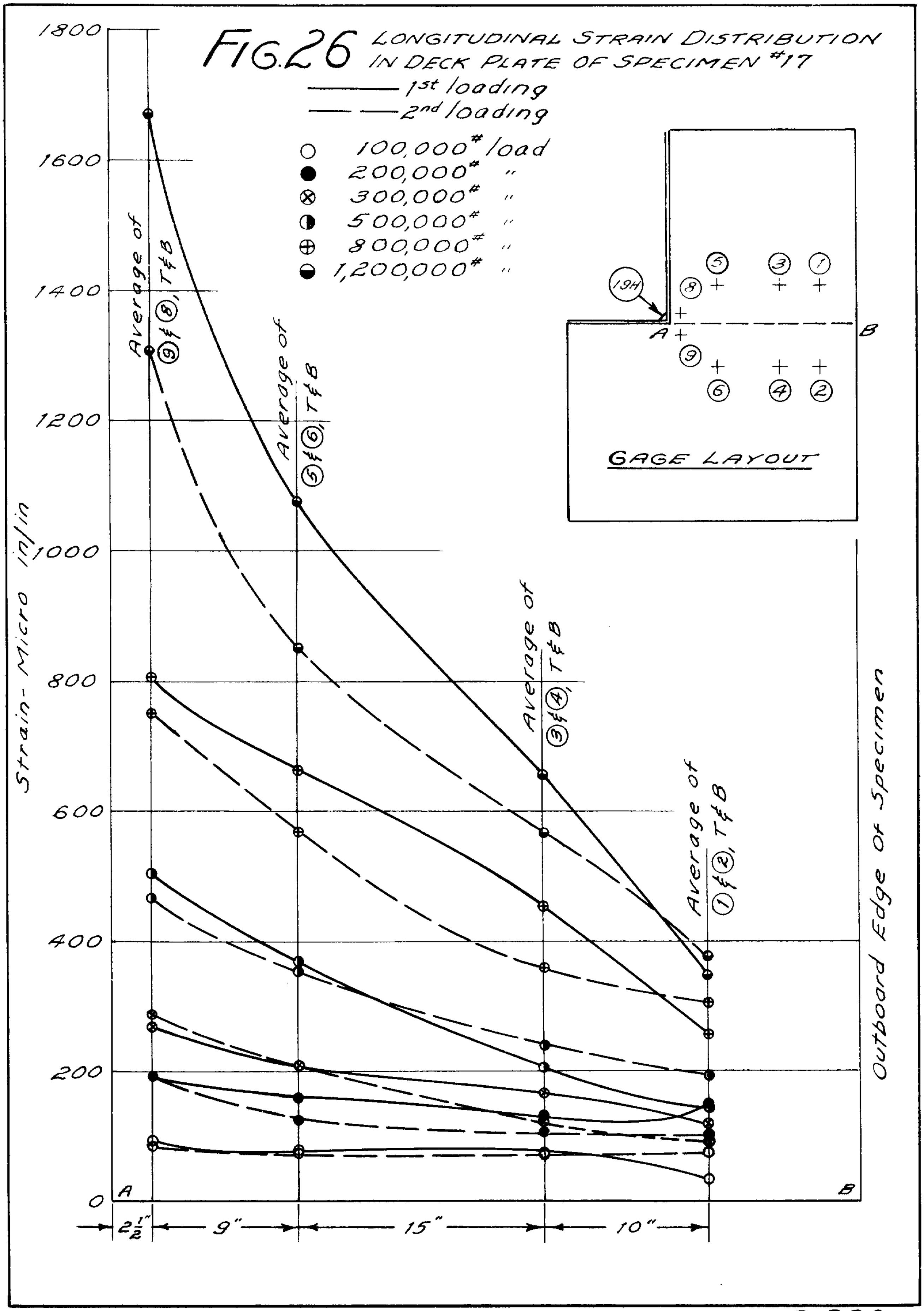
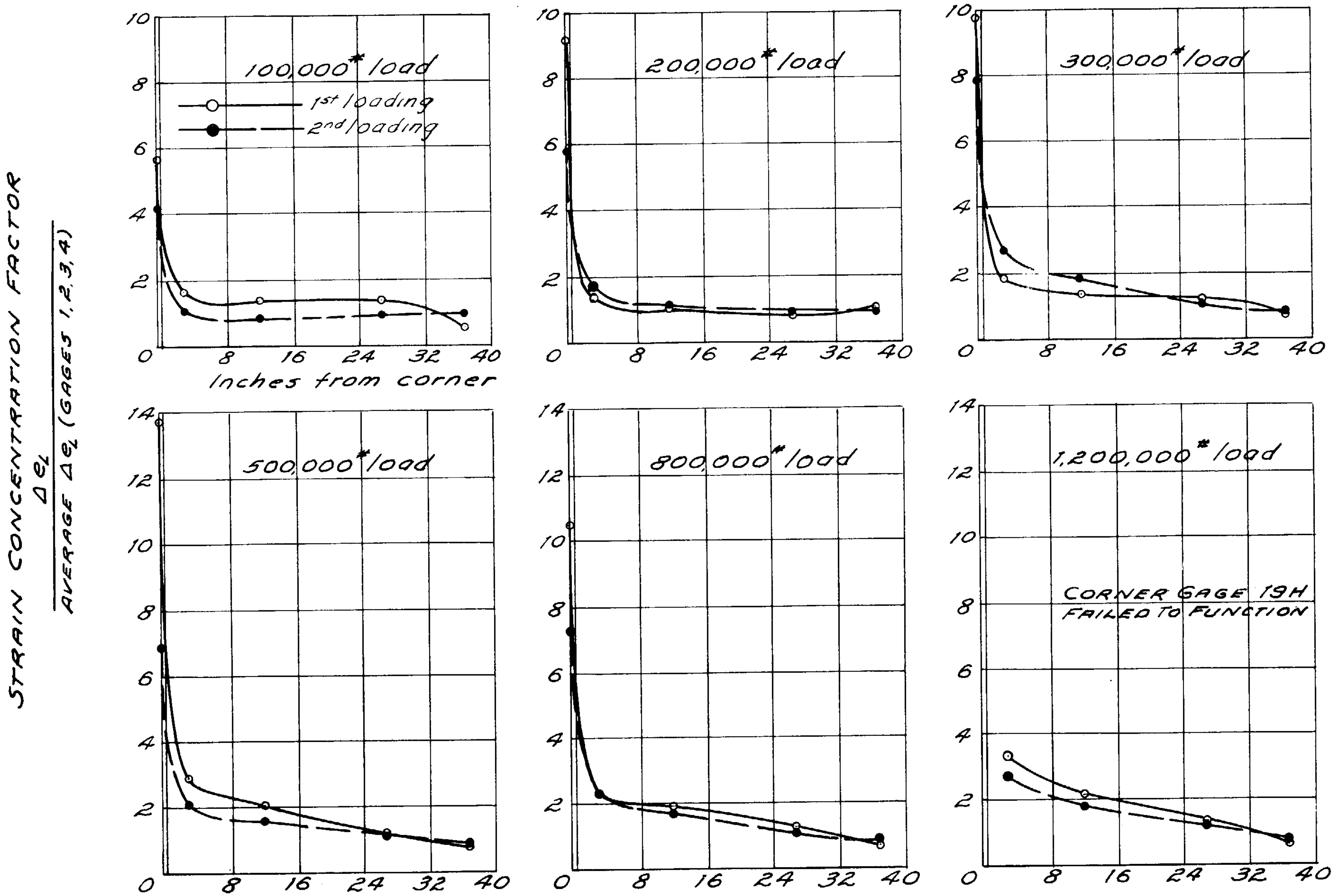


FIG. 26 LONGITUDINAL STRAIN DISTRIBUTION IN DECK PLATE OF SPECIMEN #17
1st loading
2nd loading
100,000# load
200,000# "
300,000# "
500,000# "
800,000# "
1,200,000# "
Strain - Micro in/in
1800
1600
1400
1200
1000
800
600
400
200
0
Average of 9 & 8, T & B
Average of 5 & 6, T & B
Average of 3 & 4, T & B
Average of 1 & 2, T & B
Outboard Edge of Specimen
A
B
2 1/2"
9"
15"
10"
GAGE LAYOUT
194
1 2 3 4 5 6 8 9
A
B



NOTE: For gage layout, see Fig. 26

FIG. 27 STRAIN CONCENTRATIONS IN DECK PLATE, SPECIMEN 17

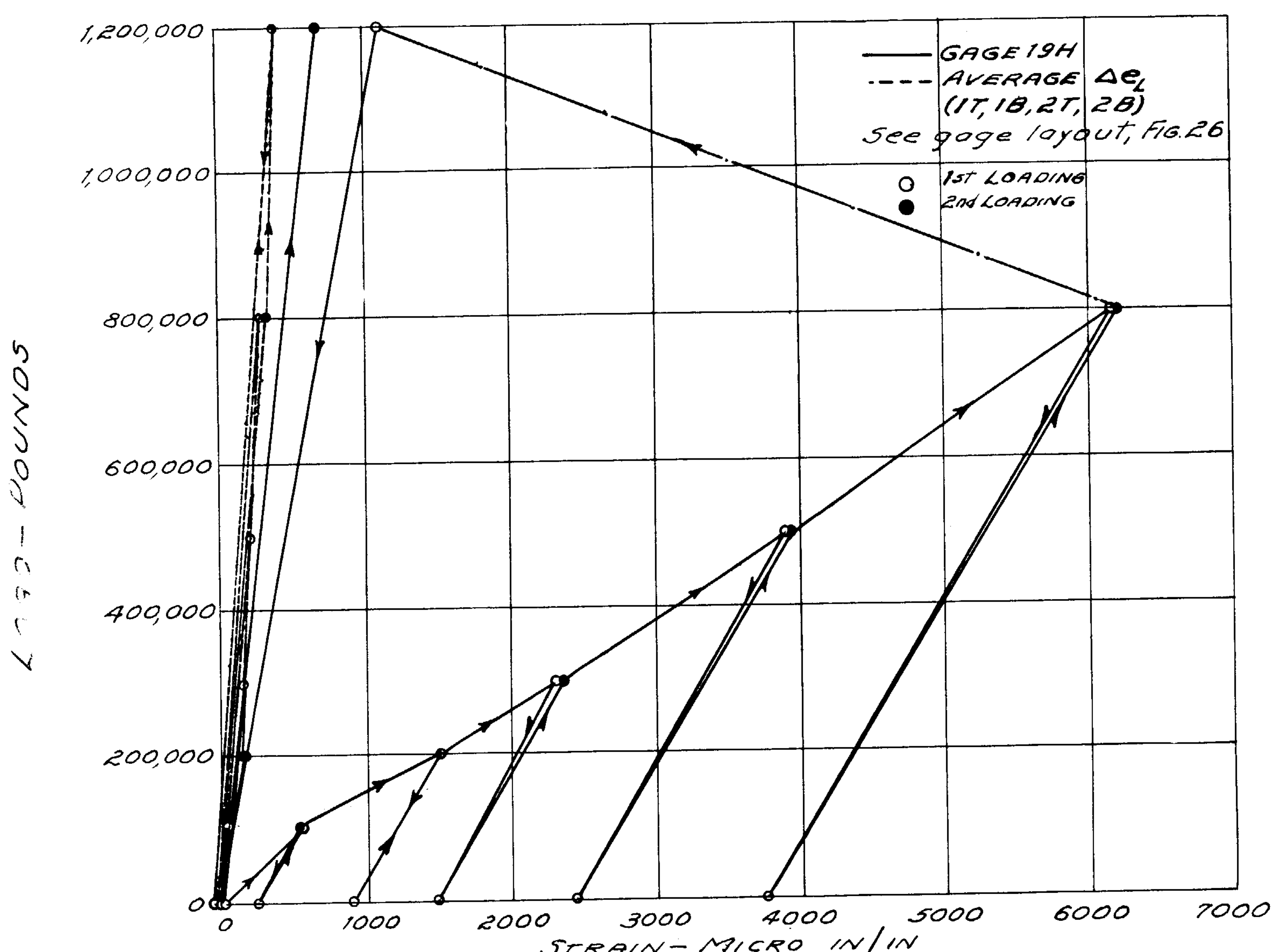


FIG. 28 LOAD-STRAIN CURVES: SPECIMEN 17

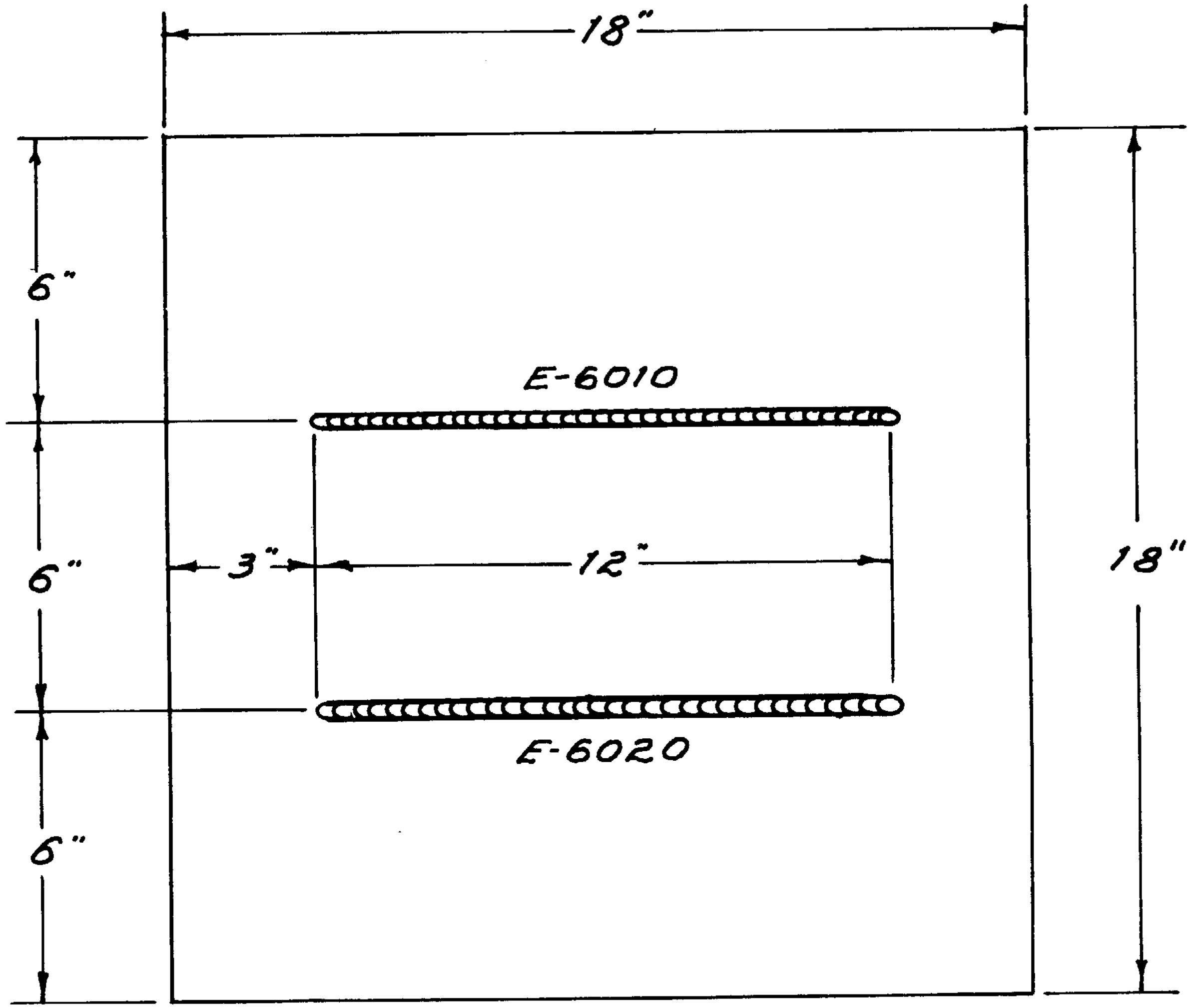


FIG. 29 $\frac{3}{4}$" PLATE SPECIMEN USED FOR DEPOSITION OF WELD BEADS

R-329

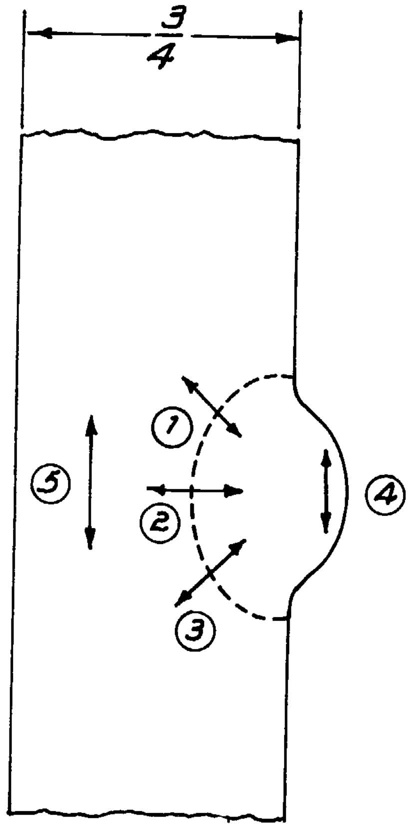
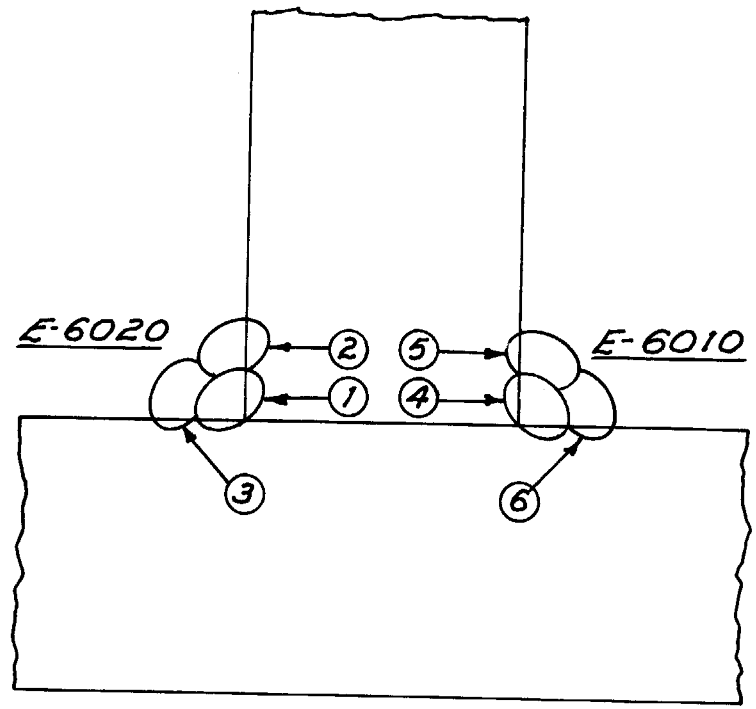


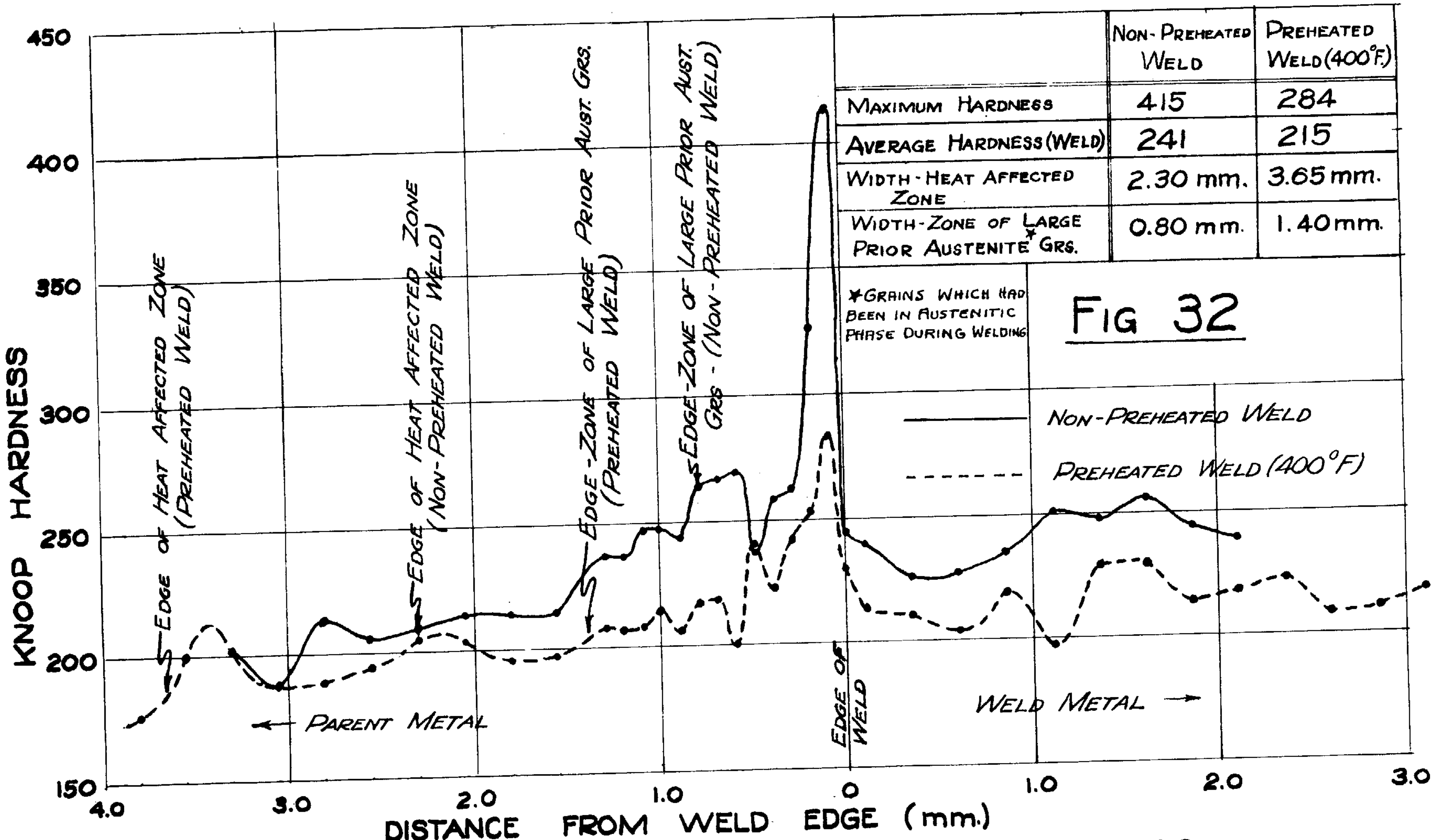
FIG. 30 MICROHARDNESS SURVEYS RUN ON EACH SPECIMEN



NOTE: NUMBERS REFER TO ORDER OF PASSES; PLATE COOLED TO 70°F BETWEEN EACH PASS

FIG. 31 MULTIPASS SPECIMEN

R-330-1



	NON-PREHEATED WELD	PREHEATED WELD (400°F.)
MAXIMUM HARDNESS	415	284
AVERAGE HARDNESS (WELD)	241	215
WIDTH-HEAT AFFECTED ZONE	2.30 mm.	3.65 mm.
WIDTH-ZONE OF LARGE PRIOR AUSTENITE* GRS.	0.80 mm.	1.40 mm.

FIG 32

TYPICAL MICROHARDNESS SURVEYS ACROSS PREHEATED AND NON-PREHEATED WELDS (E-6010 ELECTRODE)

JWH-4/15/46

R-332

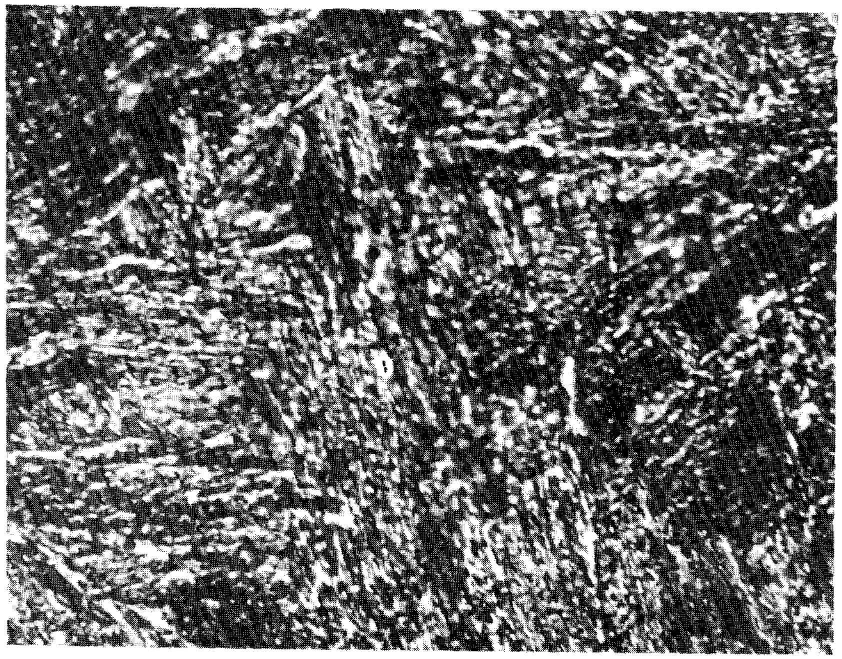


FIG. 33: HEAT AFFECTED ZONE, NON-PREHEATED WELD, E-6020 ELECTRODE, KNOOP HARDNESS 320, X1500

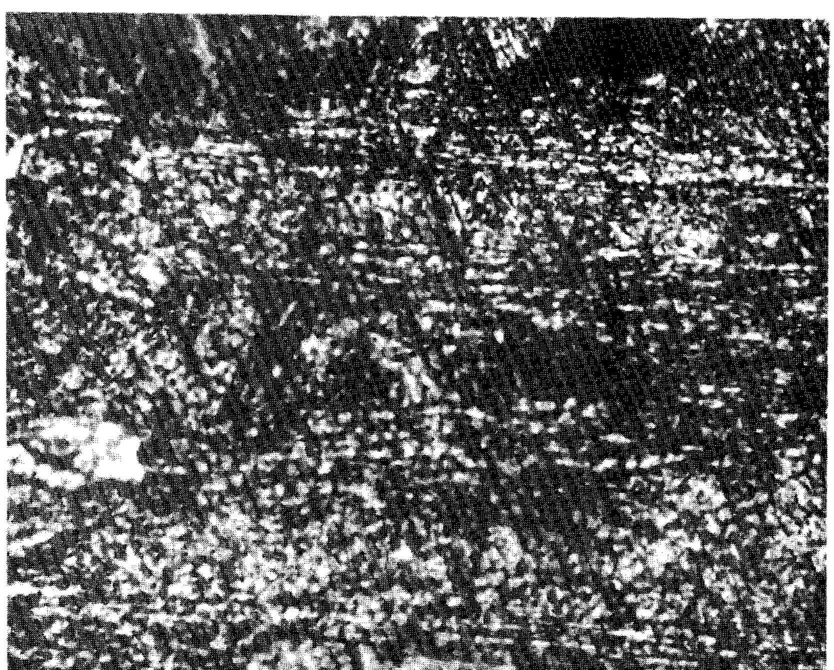


FIG. 34: HEAT AFFECTED ZONE, PREHEATED WELD, E-6020 ELECTRODE, HATCH CORNER SPECIMEN 15, KNOOP HARDNESS 300, X1500.

FIG. 35: HEAT AFFECTED ZONE, NON-PREHEATED WELD, E-6010 ELECTRODE, X500.

FIG. 36: HEAT AFFECTED ZONE, PREHEATED WELD, E-6010 ELECTRODE, X500.

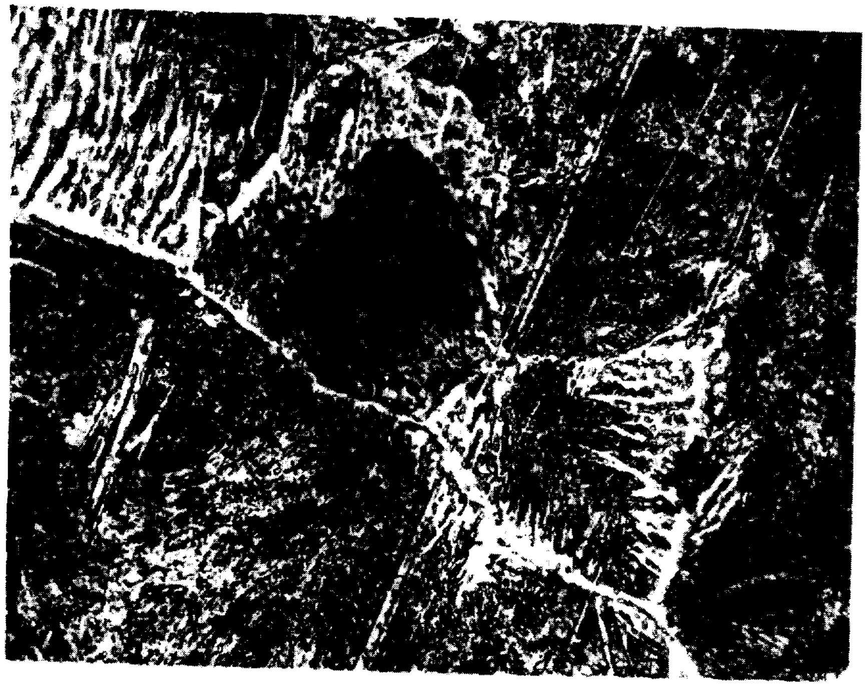


FIG. 37: HEAT AFFECTED ZONE, NON-PREHEATED WELD, E-6020 ELECTRODE, X500.

FIG. 38: HEAT AFFECTED ZONE, PREHEATED WELD. E-6020 ELECTRODE, X500.

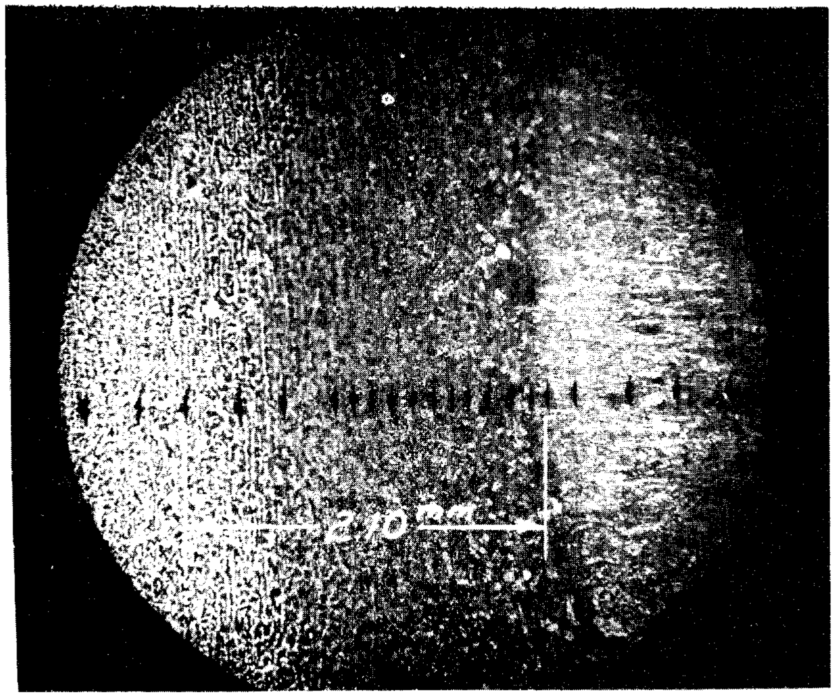


FIG. 39: HEAT AFFECTED ZONE, NON-PREHEATED WELD, E-6010 ELECTRODE, X25.

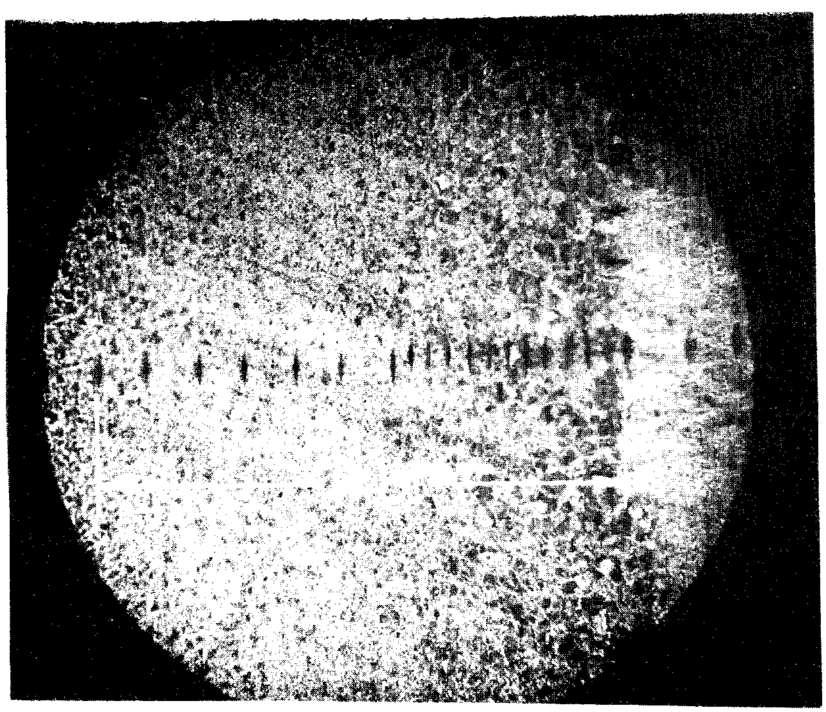


FIG. 40: HEAT AFFECTED ZONE, PREHEATED WELD, E-6010 ELECTRODE, X25.

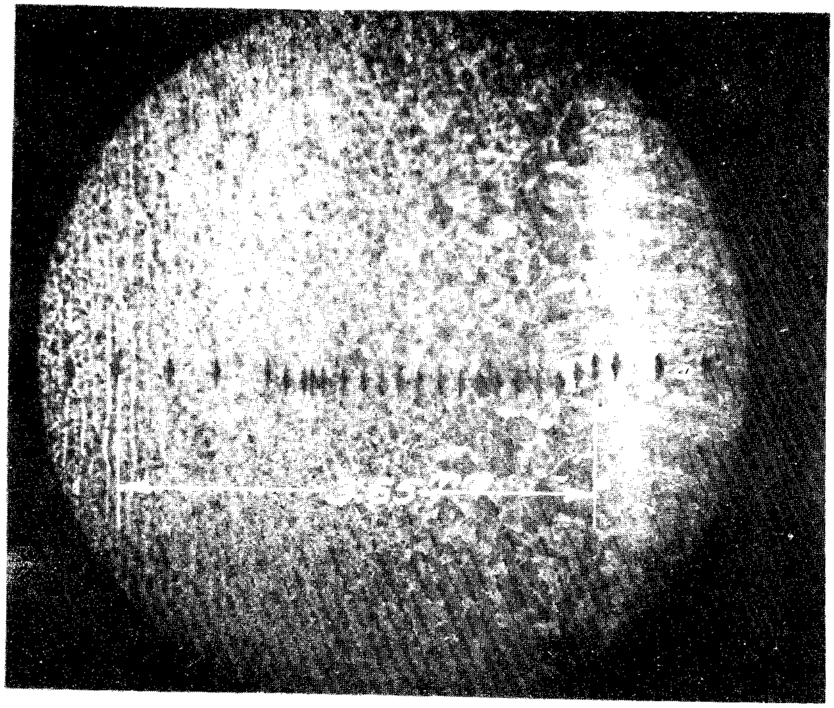


FIG. 41: HEAT AFFECTED ZONE, NON-PREHEATED WELD, E-6020 ELECTRODE, X25.

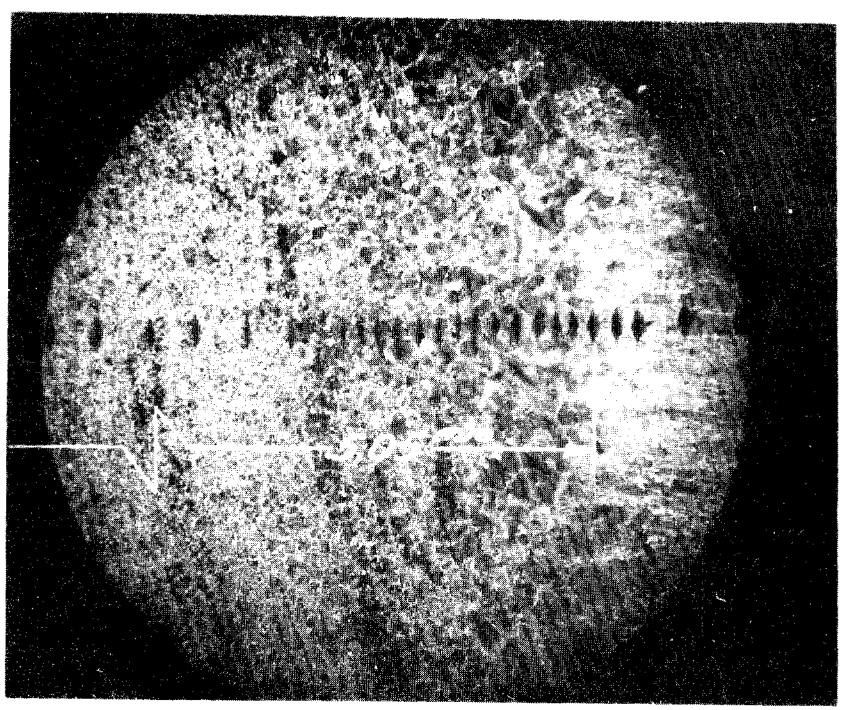


FIG. 42: HEAT AFFECTED ZONE, PREHEATED WELD, E-6020 ELECTRODE, X25.

FIG. 43: WELD METAL, NON-POSTHEATED WELD, E-6010 ELECTRODE, X500.

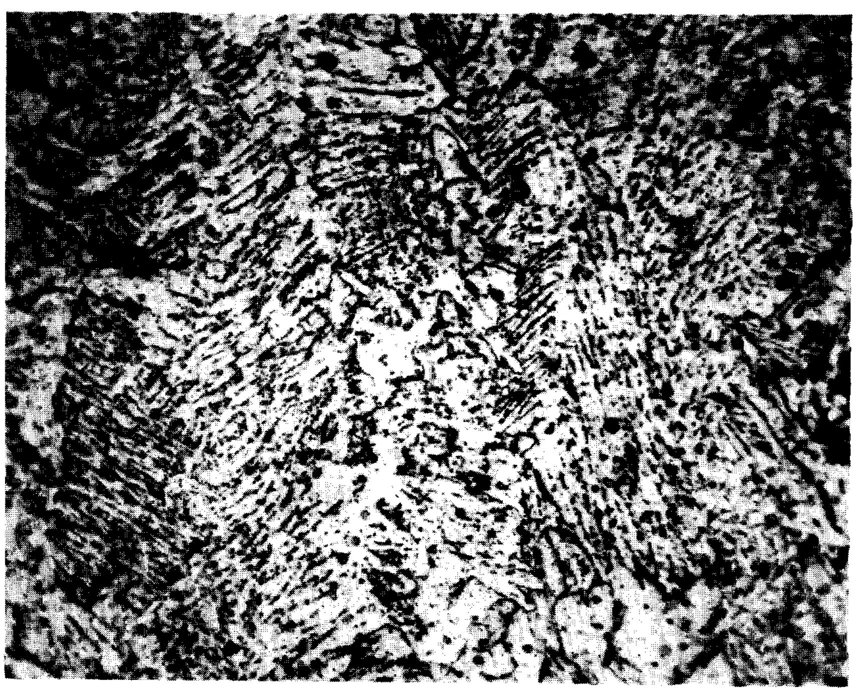


FIG. 44: WELD METAL, POSTHEATED WELD, E-6010 ELECTRODE, X500.

FIG. 45: WELD METAL, NON-POSTHEATED WELD, E-6020 ELECTRODE, X500.

FIG. 46: WELD METAL, POSTHEATED WELD, E-6020 ELECTRODE, X500.

FIG. 47: HEAT AFFECTED ZONE, NON-POSTHEATED WELD, E-6010 ELECTRODE, X500.

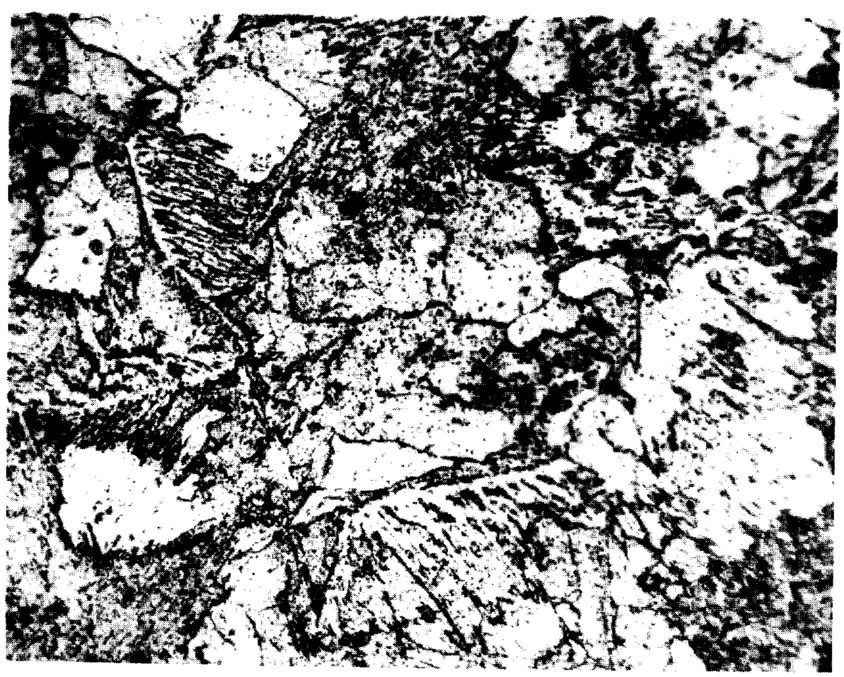
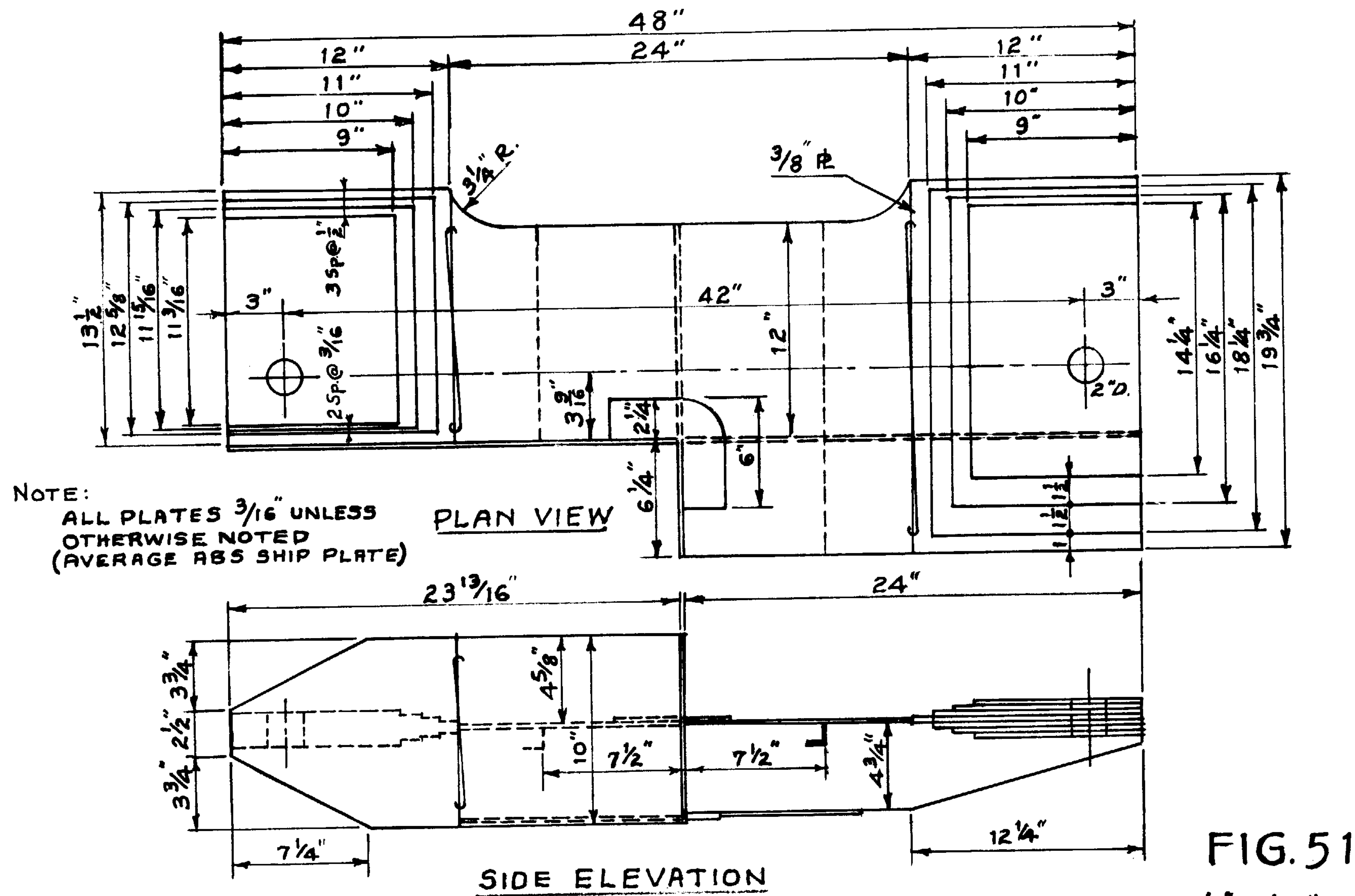


FIG. 48: HEAT AFFECTED ZONE, POSTHEATED WELD, E-6010 ELECTRODE, X500.

FIG. 49: HEAT AFFECTED ZONE, NON-POSTHEATED WELD, E-6020 ELECTRODE, X500

FIG. 50: HEAT AFFECTED ZONE, POSTHEATED WELD, E-6020 ELECTRODE, X500.



NOTE:
ALL PLATES 3/16" UNLESS
OTHERWISE NOTED
(AVERAGE ABS SHIP PLATE)

FIG. 51

SCALE 1 1/2" = 1'-0"

UNIVERSITY OF CALIFORNIA WELDING RESEARCH ENGINEERING BLDG. BERKELEY	DESIGN OF 1/4 SCALE ASYMMETRICAL HATCH CORNER MODEL	DR. BY R. Sisson CH. BY MMY APP'V'D EPO	DWG. R-351

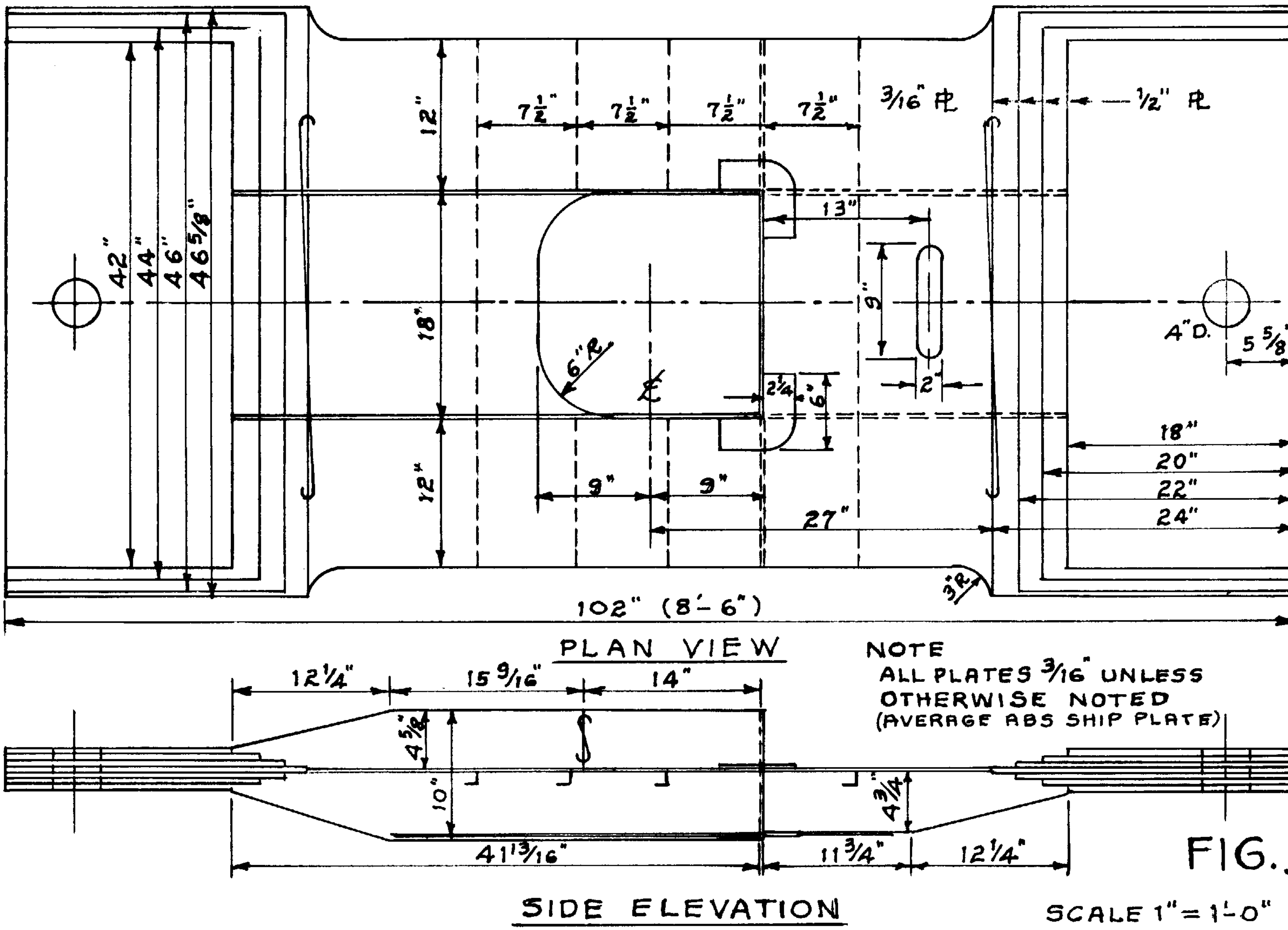


FIG. 52

UNIVERSITY OF CALIFORNIA WELDING RESEARCH ENGINEERING BLDG. BERKELEY	DESIGN OF 1/4 SCALE SYMMETRICAL HATCH CORNER MODEL	DR. BY R. Sisson CH. BY MJ APP'VD EPD	DWG R-352

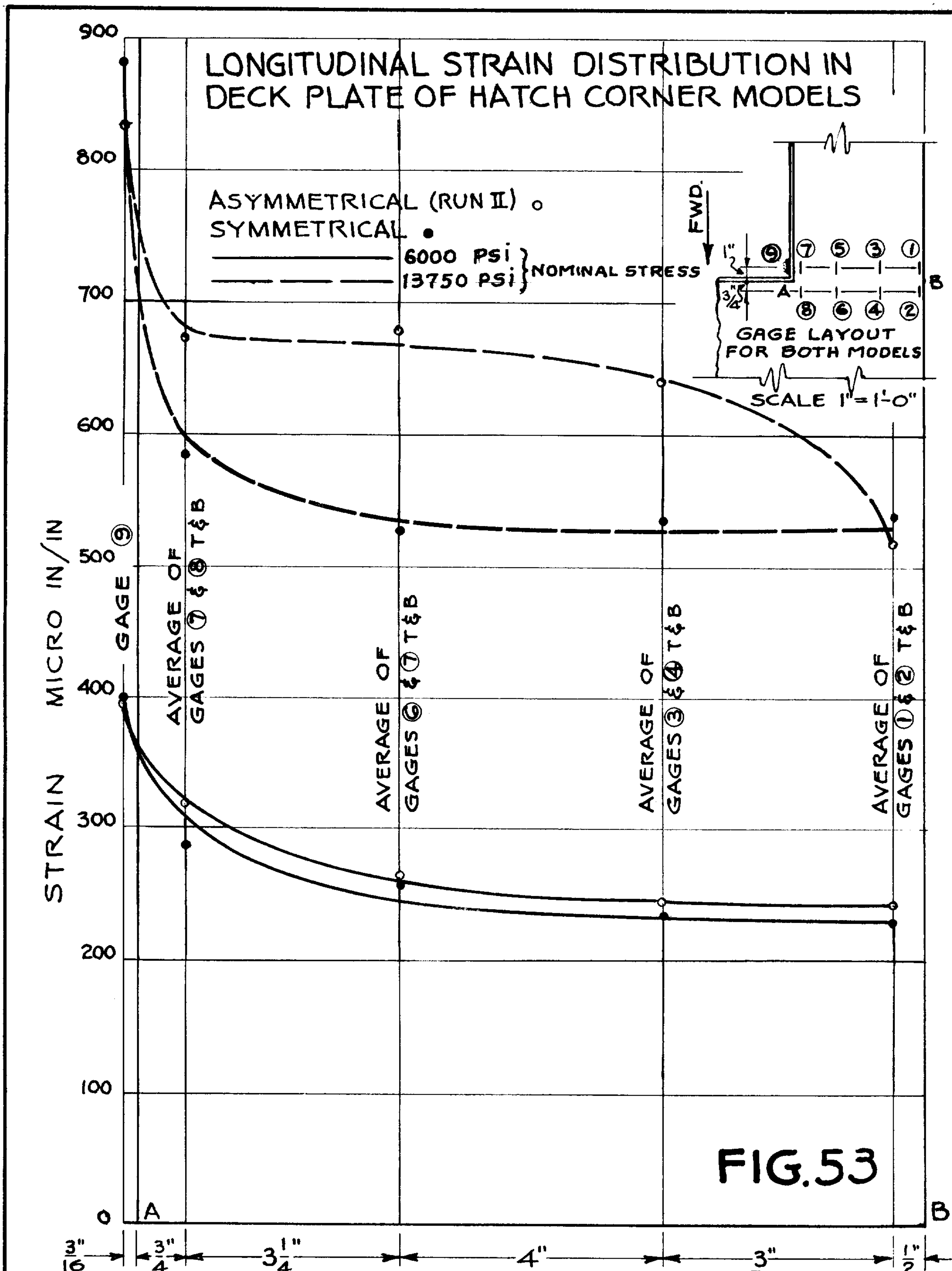


FIG.53

UNIVERSITY OF CALIFORNIA WELDING RESEARCH 310 ENGINEERING BLDG. BERKELEY	DR. BY	R. Sisson 1/21/46	DWG. R-353
	CH. BY	MJ	
	APPVD.	EPD.	

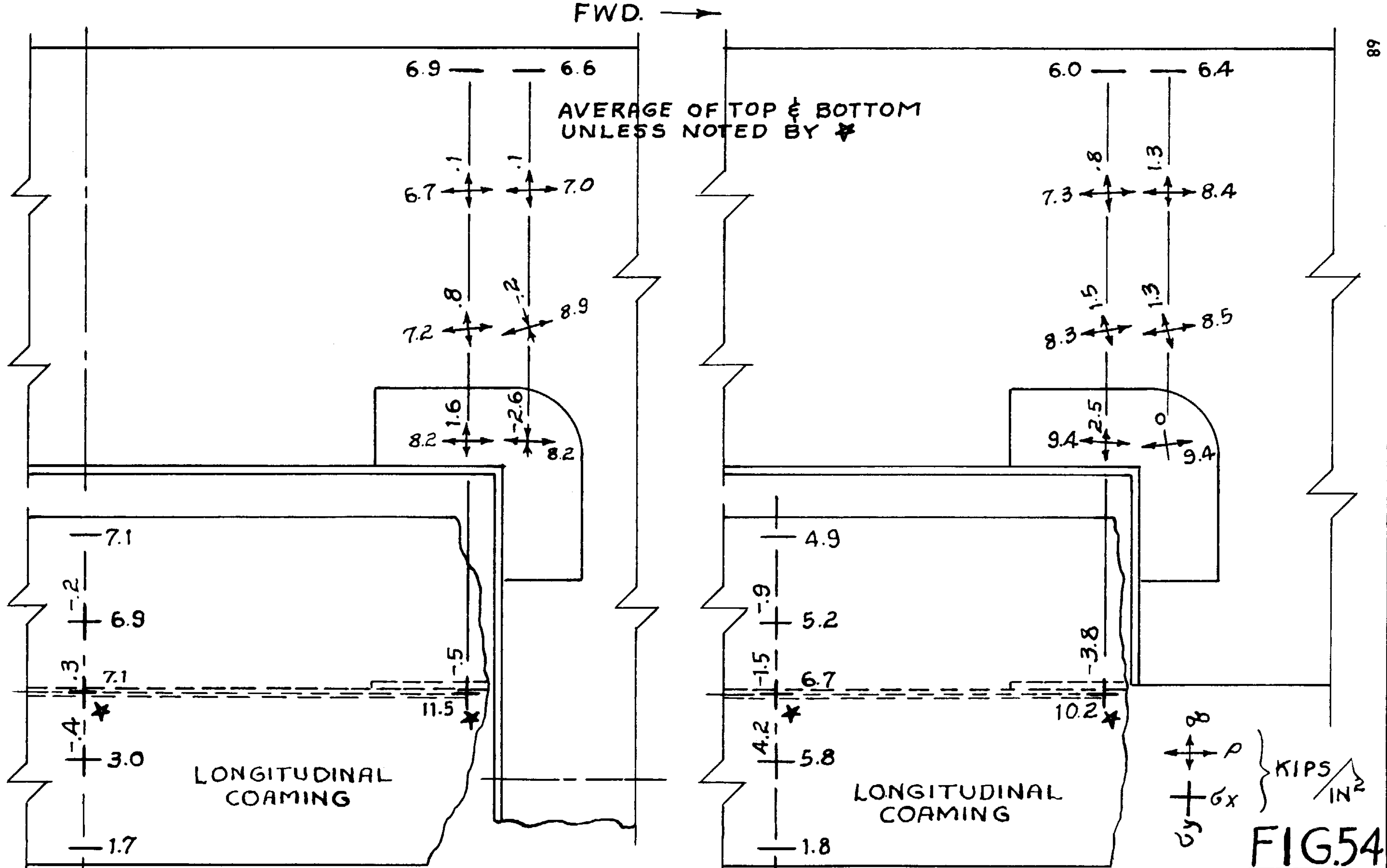
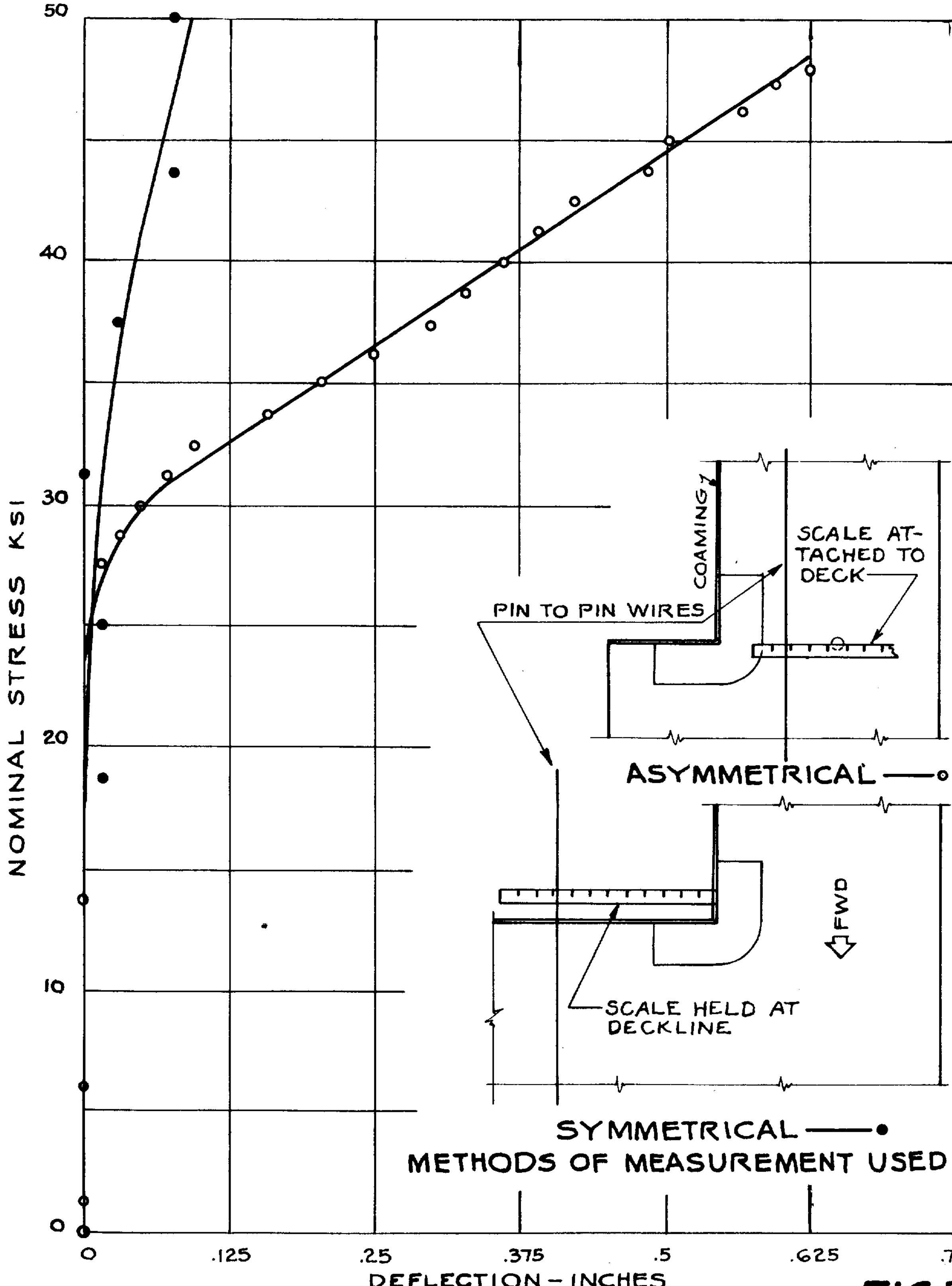


FIG.54

SYMMETRICAL NOMINAL STRESS 6.0 KIPS/IN² ASYMMETRICAL (RUN I)

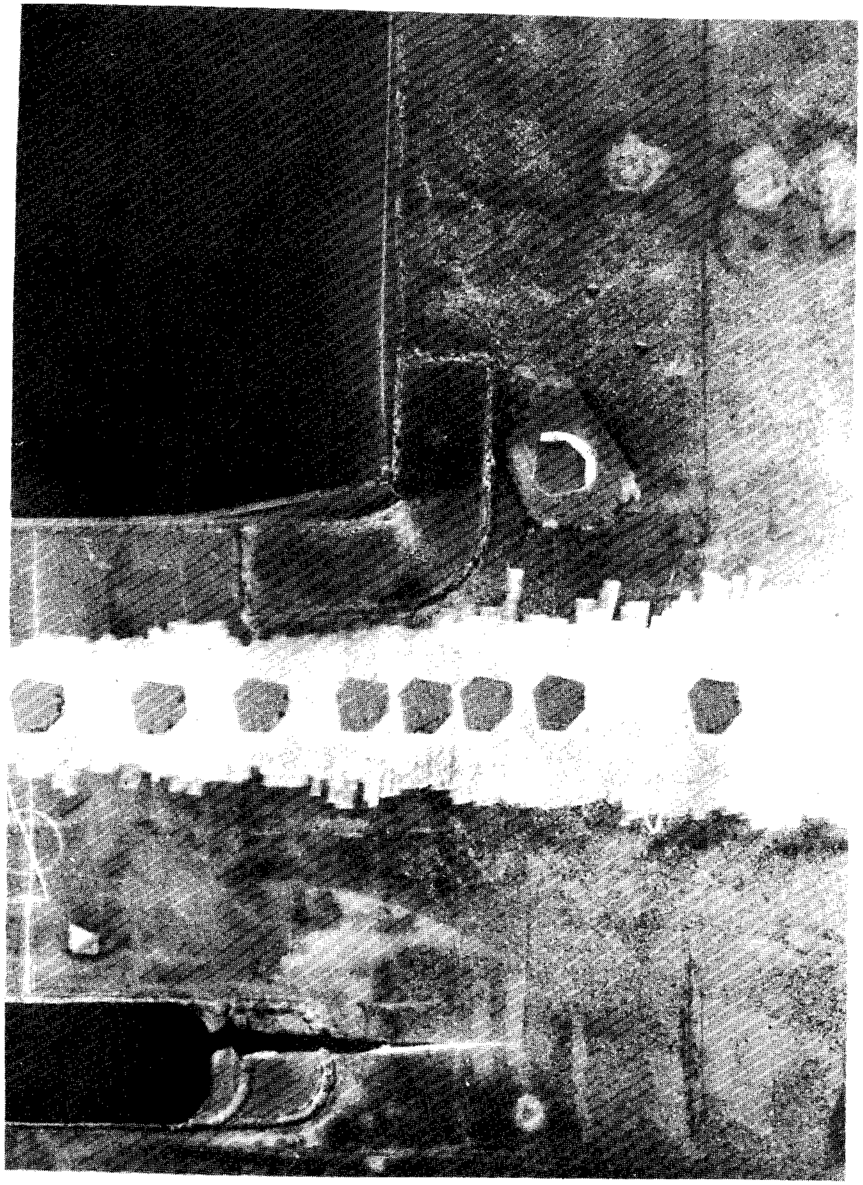
UNIVERSITY OF CALIFORNIA WELDING RESEARCH ENGINEERING BLDG. BERKELEY	STRESSES 1/4 SCALE MODELS	DR. BY	R.S.-M.J. 1-22-46	DWG. 354 R
		CHK. BY	MMF	
		APP'VD	EPD	



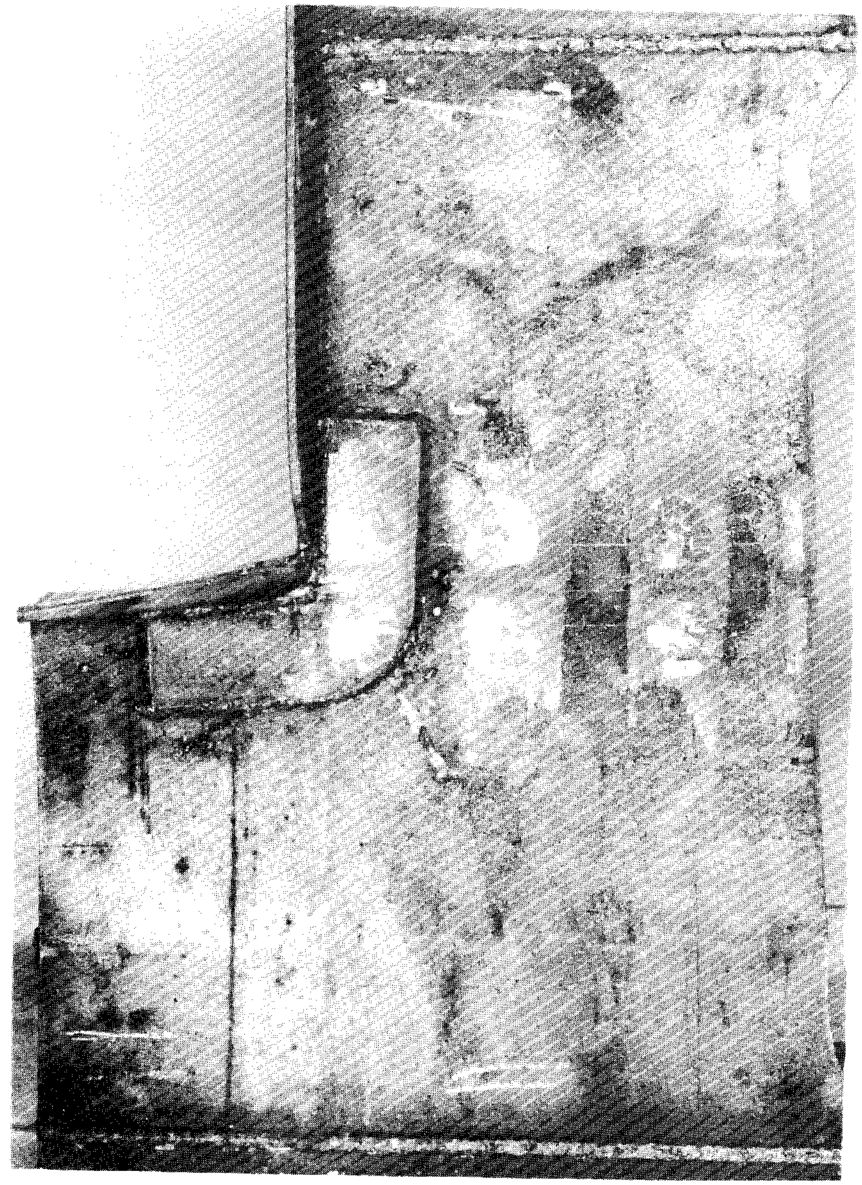
DEFLECTION MEASUREMENTS

FIG. 55

UNIVERSITY OF CALIFORNIA	DR. BY	R. Sisson 1-21-46	DWG. R-355
WELDING RESEARCH	CHK. BY	[illegible]	
310 ENGINEERING BLDG. BERKELEY	APPVD.	[illegible]	

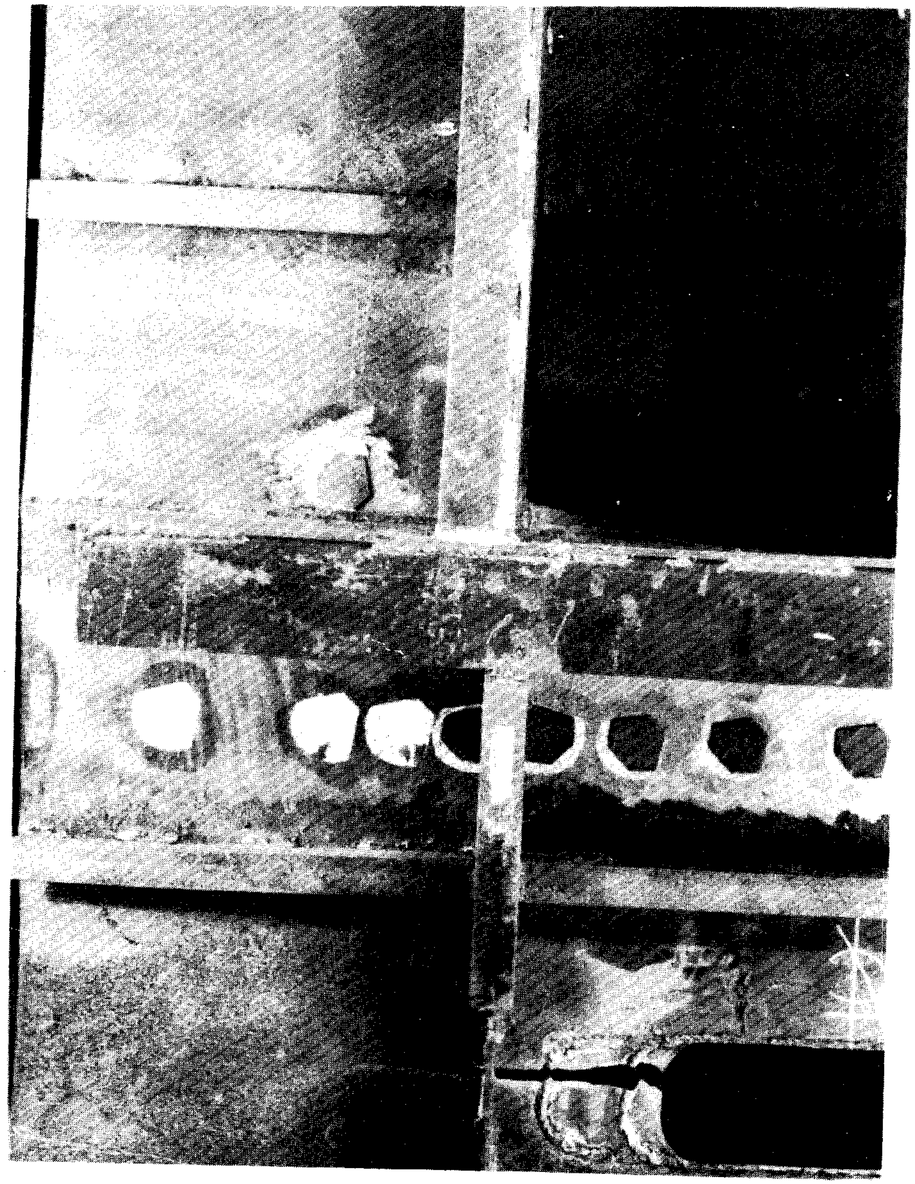


SYMMETRICAL



ASYMMETRICAL

FIGURE 56: QUARTER SCALE MODELS AFTER FAILURE (ABOVE DECK)



SYMMETRICAL

ASYMMETRICAL

FIGURE 57: QUARTER SCALE MODELS AFTER FAILURE (BELOW DECK)