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378' WHEC EXPANSION JOINT INSTALLATION AND PERFORMANCE EVALUATION

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Coast Guard Research and Development Center

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16. Abstract

This report presents the results of the installation and performance evaluation of a new expansion joint installed in the USCGC CHASE (WHEC-718) during the YARD availability of January 1973. Included is some design history and observations during the installation of the expansion joint. Data on performance evaluation were obtained on various portions of Atlantic Ocean station patrols during December 1973, January and February 1974. The data included strain readings to determine stress concentrations at the hinge of the expansion joint, the transverse structure directly under the expansion joint and the remaining length of aluminum superstructure at Frame 184. Strain readings were also taken on the new shear plates or side curtains installed between the main deck and 01 deck near the after end of the main deckhouse, which structure was installed concurrently with the expansion joint for the purpose of alleviating the longitudinal shear stresses presently imposed on the main deckhouse side.

17. Key Words

Ship structures
Expansion joint
Deckhouse cracking

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1.0 HISTORY

The original structural design concept of the 378' WHEC HAMILTON class cutters (Figure 1) assumed that the depth of the hull girder included the 01 deck; that is, the main deckhouse sides as well as the 01 deck proper were structurally considered to be part of the hull girder. Expansion joints in the superstructure above the 01 deck were not incorporated into the design primarily due to a history of conventional expansion joint failures and not because the contribution of the superstructure above the 01 deck was necessary for vessel strength.

A conventional expansion joint failure (WHEC 327' class) is illustrated in Figures 2 and 3. As might be expected, the sharp radius at the base of the expansion joint concentrated the longitudinal and shear strains in the deckhouse side resulting in a crack at the "hinge" of the joint.

Despite the attempt to design a vessel having a long deckhouse that would experience no superstructure failure, the 378' WHEC in service experienced many forms of minor cracking. The aluminum superstructure above the 01 deck was particularly affected; however, the extremities of the main deckhouse (steel) as well as the main deckhouse sides in the vicinity of the square window corners were also subject to failure.

To alleviate these problems full-scale studies were made by the Naval Ship Research and Development Center as well as other private design organizations, all of which concluded that no expansion joints were necessary but rather improvements in the details of construction and an increase in aluminum structure plating thickness were recommended. It was expected that such a structure would either eliminate entirely or reduce the incidences of cracks to an acceptable level. Several vessels received what was then called the "structural fix," which consisted of increasing the thickness of some of the topside aluminum plating. This proved disappointing as minor cracking occurred soon after ships were put back in service. The need for the expansion joints was now obvious. Weight considerations ruled out any further increase in topside plating thicknesses; and the main deckhouse sides, already suffering from excessive shear stress loading, could not be expected to absorb the additional shear stress resulting from an increase in thickness of topside plating.

The Hull Section of the Naval Engineering Division at Headquarters then undertook the design of a new expansion joint to solve the aforementioned structural problems and at the same time eliminate some of the shortcomings of the conventional expansion joints in use at the time. The result was an expansion joint design in which the cut through the deckhouse was made across the top of two newly installed high coaming doors, the high coaming thus becoming the expansion joint hinge plate. In this manner a door cut presented a very mild radius cut when compared to the 2-inch radius cuts utilized in conventional expansion joints (Figures 2 and 3 as compared with Figures 5, 6 and 7). A side plate of HY-80 was welded to the deck and in turn riveted to the aluminum superstructure to strengthen the area of the hinge (Figures 5, 6 and 7). The door frame was bolted and elastically bonded onto a 1 1/2-inch square rubber gasket permitting it to float on the side plate.

Originally two expansion joints were considered, one directly behind the foremast and one at Frame 184 directly in front of the turbine air intake. Cost considerations and the fact that the installation of the expansion joint directly behind the foremast would be difficult due to the electronic cabling in the control spaces below resulted in only one expansion joint being installed aboard the CHASE (WHEC-718). Although it was felt that this one expansion joint at Frame 184 would certainly eliminate the cracking in the immediate area around the turbine air intakes, it was expected that it would also reduce some of the stress on the 02 and 03 decks in the area directly behind the foremast. Depending on the extent of this stress reduction it was felt that one single expansion joint at Frame 184 might reduce the incidences of cracks on the remaining length of superstructure, and in particular the area directly behind the foremast. This was the installation that was accomplished on the CHASE in January 1973.

To reduce the incidence of crack formation on the main deckhouse side in the vicinity of the square windows, side curtains or shear plates were installed on CHASE between the main deck and the 01 deck near the after end of the main deckhouse at the same time the expansion joint was installed. These shear plates were later instrumented to determine if they were in fact being stressed in the manner envisioned. The stressing of these shear plates would relieve the main deckhouse side of some of its 01 deck "stretching" responsibilities. Shear stress on the main deckhouse side would thereby be reduced and crack tendency would be decreased.

Budgetary considerations prohibited structural restoration (complete repair of all existing cracks) of CHASE to the point of being a model ship. To record the condition of the vessel, CHASE was initially inspected by Headquarters (G-ENE) personnel immediately following the installation of the expansion joint and shear plates to record all cracks present, however small. Throughout the evaluation period these recorded cracks were inspected by the same Headquarters personnel to determine if they had elongated or propagated into the adjacent structure. The cracks on the deckhouse did not elongate or propagate, and no new cracks have been reported in the aluminum structure in the vicinity of the turbine air intakes.

2.0 OBSERVATIONS DURING EXPANSION JOINT INSTALLATION

The expansion joint cut on the 02 deck at Frame 184 was accomplished while the ship was in dry dock, with only 30 percent of liquids aboard. During the cutting process (starboard to port) the 02 deck split open through the remaining deck plating after the deck had been cut about two-thirds of the way. The entire cut separated 1/2 inch after splitting. It was theorized at the time that the separation or opening of cut was due to the lightly loaded condition of the ship as docked and that it was likely the separation would close upon undocking the ship. After the installation of the expansion joint when CHASE was undocked the separation did not close but instead opened up an additional 1/8 inch. It was then speculated that the separation would close up upon refueling the ship. Prior to refueling a dial indicator was installed directly across the expansion joint, but no change in the separation at the expansion joint was noted over the four-hour refueling period. The only change in the separation was a cycling of 1/8 inch due to the temperature changes between daylight and darkness hours.

3.0 PURPOSE

The primary purpose of the expansion joint was to isolate the 02 deckhouse aft of Frame 184 from the remaining forward portions of the 02 and 03 deckhouses, thereby reducing the shear stress required to be transmitted by the main deckhouse side. If the 02 deck is permitted to contribute to hull girder strength, it directly affects the longitudinal shear stress level present in the main deck house side. A high level of longitudinal shear stress could cause structural cracking, especially in areas of stress concentration such as square window corners, notches or areas of initially poor fabrication. Although designed primarily to reduce problems aft of Frame 184, it was anticipated that the expansion joint would also be beneficial to some degree forward of Frame 184. Elimination of any contribution to hull strength was of no real concern since the vessel had been designed without the aluminum superstructure being considered a structural member. It was, however, imperative to determine if as a result of the expansion joint there was any increase in the general level of stress in the hinge plate or directly below the expansion joint on the 01 deck plating as compared with the general level of stress immediately forward and aft of the expansion joint area.

Specifically this evaluation project was undertaken to:

1) Determine the degree of stress concentration at the hinge of the expansion joint.

2) Determine the magnitude of the vertical reactions imposed on the transverse structure directly below the expansion joint.

3) Determine the magnitude of the shear stress transmitted by the new main to 01 deck shear plates (side curtains).

4) To reaffirm the effectiveness of the main deckhouse as part of the hull girder in vertical bending as determined by the Naval Ship Research and Develcpment Center on CGC HAMILTON in 1968 (reference (1)).

5) Attempt to arrive at a qualitative correlation between the stress levels at the 02 and 03 decks and those previously recorded by NSRDC (reference (1)).

4.0 INSTRUMENTATION

4.1 Location of Gauges

The location of the gauges was determined from both the list of desired results, the ease of installation and with the limitation of the available equipment, i.e., being able to monitor 12 channels simultaneously. Since it was established from the first data collection effort in December 1973 that there were no severe stress concentrations existing in either the vicinity of the hinge of the expansion joint or in the shear plates, the latter half of the project utilized new gauges in a slightly different arrangement to concentrate on the determination of the effectiveness of the 01 deck as part of the hull girder. Figures 7 and 8 illustrate the initial location of the gauges for Phase I (the December 1973 data collection phase), and Figure 9 illustrates the location of the gauges for Phase II (January-February 1974).

In the initial phase for the stress at the hinge, three rosettes (Figure 8, gauges #1 - #9) were mounted on the HY-80 side on the hinge plate as shown in Figure 7. Two of these rosettes were on the starboard side and one on the port side. For the stress in the shear curtain a single 45° rosette was installed at Frame 288 (Figure 8, gauges #19 - #21). A single strain gauge (Figure 8, gauge #10) was mounted on the transverse beam directly below the expansion joint to ascertain the magnitude of vertical reactions generated by the expansion joint. The remainder of the gauges in Figure 8 were to provide sufficient information to reaffirm the effectiveness of the 01 deck as previously ascertained by NSRDC (reference (1)) on the same class of vessel without the expansion joint. Due to the failure of weather deck gauges #13 and #14 this was not possible during Phase I.

For Phase II (see Figure 9) gauges #3 - #8 all measured the strain on the 01 deck. This was to prevent a "data-gap" as was experienced by the previous failures of the 01 deck weather deck gauges (Figure 8, gauges #13 and #14). In addition, it was hoped that by installing gauges #5 and #6 at Frame 134 directly below gauges #1 and #2, some correlation between the superstructure strains at Frame 134 and the main hull girder strains at Frame 184 could be achieved.

4.2 Electronic Equipment

The strain gauge electronics system was designed by the Naval Underwater Systems Center, New London, Connecticut. The system consisted of 120 ohm strain gauges, 12 Tektronic 3C66 carrier amplifiers mounted in Tektronic Mod 129 power supply modules, 16 Hewlett-Packard low gain amplifiers and a Hewlett-Packard Series 4500 eighteen channel light-beam recorder. The system was limited to recording 12 channels at one time due to the number of carrier amplifiers.

The 3C66 Carrier Amplifier provided the necessary 25 kHz 5-volt RMS excitation for the strain gauge bridge and rectified the strain gauge bridge output to achieve a DC signal. It also contained the necessary resistance and capacitance adjustment to balance the bridge, and a 150K ohm calibration resistor for adjusting sensitivity. The Hewlett-Packard light-beam recorder with its low gain amplifiers recorded the signal from 3C66. Figure 10 illustrates the system in block diagram form.

5.0 TEST PROCEDURES AND RESULTS

Since the electronic recording system was only capable of monitoring 12 channels simultaneously, the test procedure during Phase I consisted of recording strain values from gauges #1 through #12 for the first half of the patrol and recording the remaining gauges plus gauge #12 during the latter half of the patrol. As Phase II instrumentation consisted of a total of 12 gauges, the entire installation could be monitored at one time.

Originally, in establishing the test procedure for Phase I, it was thought that some correlation of the data from gauges #1 through #12 with the data from gauges #13 through #21 could be achieved by using gauge #12 as a common trace of the output; however, this was not possible. Various failures of gauges, the random sea states and the error associated with full-scale strain gauge experiments prohibited accurate correlation.

During a data collection run the recorder was placed in the record mode and the vessel's speed, vessel heading relative to the seas, and the visually estimated wave height were noted. Preliminary data recording soon showed that the only significant recorded strains occurred when the vessel was negotiating head seas of over six feet and at speeds in excess of eight knots. Therefore, all further data collection was primarily in ahead seas at high speeds.

Occasionally several channels experienced temporary amplifier or gauge failures requiring some of the data to be discarded, thus not every test run conducted appears in the data tables. During the latter half of Phase II, three gauges (#5, #6 and #7) malfunctioned; thus no values are included for these gauges in Table 4, run number 2.

The data collected was in the form of recorder tracings as illustrated in Figure 11. To determine usable values from the recorder tracings, all gauge tracings were measured peak-to-peak and the mean or arithmetic average peak-to-peak value was calculated. The data for the first four areas of interest is presented in Tables 1 through 4. Data labelled as "peak" represents the highest individual peak-to-peak reading on a given run, while that labelled as "avg" represents the mean value of the peak-to-peak tracings.

Table 1 lists the principal stresses and shear stress calculated from the strains measured during Phase I on the three rosettes attached to the hinge plate of the expansion joint (gauges #1 through #9). Table 2 lists the local bending stress calculated from the strains recorded on the transverse beam at Frame 184 in the 01 deck directly below the expansion joint. Table 3 lists the principal stresses and shear stress calculated from strains measured on the rosette mounted on the side curtain (gauges #19 through #21). Finally, Table 4 lists the data taken during Phase II for all gauges shown in Figure 9 to reaffirm the effectiveness of the 01 deck. No correlation between the stress levels of the 02 and 03 decks and those previously recorded by NSRDC was obtained.

6.0 DISCUSSION OF TEST RESULTS

6.1 Stress Concentrations at the Hinge of Expansion Joint

Examination of the data presented in Table 1 reveals that the highest recorded peak-to-peak variation in principal stress at the hinge of the expansion joint is slightly in excess of 12,000 psi. It is important to note here that peak-to-peak readings include tensile stress imposed by hogging plus compressive stress imposed by sagging. Since the calculated hogging stress for this type vessel is approximately .55 of the peak-to-peak stress it follows that the maximum tensile stress experienced during the tests is of the order of 6600 psi. Considering the high yield strength (80,000 psi) and notch toughness of the HY-80 hinge plate, it is apparent that there is ample reserve to account for the higher strains that can be expected at the edge of the cut where the radius becomes finite. Ample safety margin exists even for the mild steel deck in the area.

Due to the failure of the 01 deck plate gauges (Figure 8, gauges #13 and #14) installed ten feet fore and aft of the expansion joint hinge, it was not possible to ascertain the 01 deck plating longitudinal stresses simultaneously with the principal stresses at the hinge; however, by correlation of the data obtained in Phase II (Figure 9, gauges #3, #4, #7 and #8), it is seen that the hogging and sagging-induced longitudinal stresses in the bottom portion of the hinge plate are of the same order of magnitude as the 01 deck plating stresses just forward and aft of the expansion joint.

Concerning the local bending stress in the transverse structure directly below the hinge, similar results are seen. The maximum vertical stress levels (1500-2000 psi) were experienced in head seas. The highest peak recorded (3000 psi) occurred in 15-foot head seas with a vessel speed of 14 knots. Obviously these local transverse stresses are not significant.

6.2 Side Curtain Shear Stress

The data presented in Table 3 concerning the shear stress carried by the side curtain reveals that the plates are being stressed in shear as intended, thus the main deckhouse sides should be relieved to some degree in performing this task. It is significant to note that the low strains existing in this newly installed plating are consistent with the strain measured throughout the hull. Consequently, the side curtain installation can be considered an effective improvement and should result in some reduction in the amount of cracking in the vicinity of the after portion of the main deckhouse.

6.3 Effectiveness of Deckhouse

Table 4 lists the data taken during Phase II used to determine the position of the neutral axis of the hull and hence the effectiveness of the 01 deck and main deckhouse sides (deckhouse), as shown in Figures 12 and 13. NSRDC in reference (1) determined the neutral axis of CGC HAMILTON to be 16.3 feet from the keel. Theoretically, the installation of the expansion joint should have lowered the position of the neutral axis due to the elimination of the after portion of the 02 deck's influence upon the inertia of the hull girder.

This can be seen in these results in both Figures 12 and 13 where the intersection of the stress distribution line and the ship's centerline is approximately 15 feet from the keel. This result is reasonable in comparison with the original design calculated position of the neutral axis (reference (2)). As can be seen in either Figure 12 or 13, the design position of the neutral axis considering the 01 deck as part of the hull girder is 14.2 feet from the keel and the position of the neutral access disregarding the 01 deck is a mere 9.3 feet. Since the forward portion of the 02 deck is influencing the hull girder, it can be expected that any measured neutral axis position would be higher than a design calculation disregarding the 02 deck.

By comparing experimental and design data, NSRDC determined (reference (1)) that the deckhouse at Frame 134 was 91 percent effective in contributing to hull strength. The limited data gathered and the data scatter experienced prohibit a new effectiveness to be determined; however, similar order of magnitude calculations indicate that the "effectiveness" of the deckhouse has increased with the installation of the expansion joint and the shear plates. This is logical as the reduction in 02 and 03 deck contribution to hull inertia plus the installation of the side curtains both result in a relative increase in main deckhouse side stiffness with respect to the 01 deck.

7.0 CONCLUSIONS

1. The "novel" design of the 378' WHEC expansion joint is an improvement over conventional expansion joints. No serious stress concentration exists (a) at the hinge of the expansion joint, (b) on the 01 deck, or (c) in the transverse structure directly below the expansion joint.

2. The new shear plates are effective in carrying shear stress, thereby unloading the main deck house sides to some degree.

3. The 01 deck is more effective in contributing to hull girder strength with the installation of the expansion joint and shear plate.

4. Less structural cracking should result on the 378' WHEC class vessel if both the expansion joint and shear plates are installed. An even greater reduction in cracking tendency should be realized if areas of stress concentration, such as the square corners on windows, were eliminated.

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(1) Birmingham, J.T. and F.W. Palmer, "Structural Seaworthiness and Hull Deckhouse Interaction of USCGC HAMILTON (WHEC-715)," Naval Ship Research and Development Center Report 139, June 1969.

(2) Avondale Shipyards, Incorporated, "Longitudinal Strength Calculations for U.S. Coast Guard 378-Foot High Endurance Cutter - WPG-715," revised 12 March 1965.

(3) Gibbs & Cox, Inc., "Proposed Structural Modifications to HAMILTON Class Cutters," June 1968.

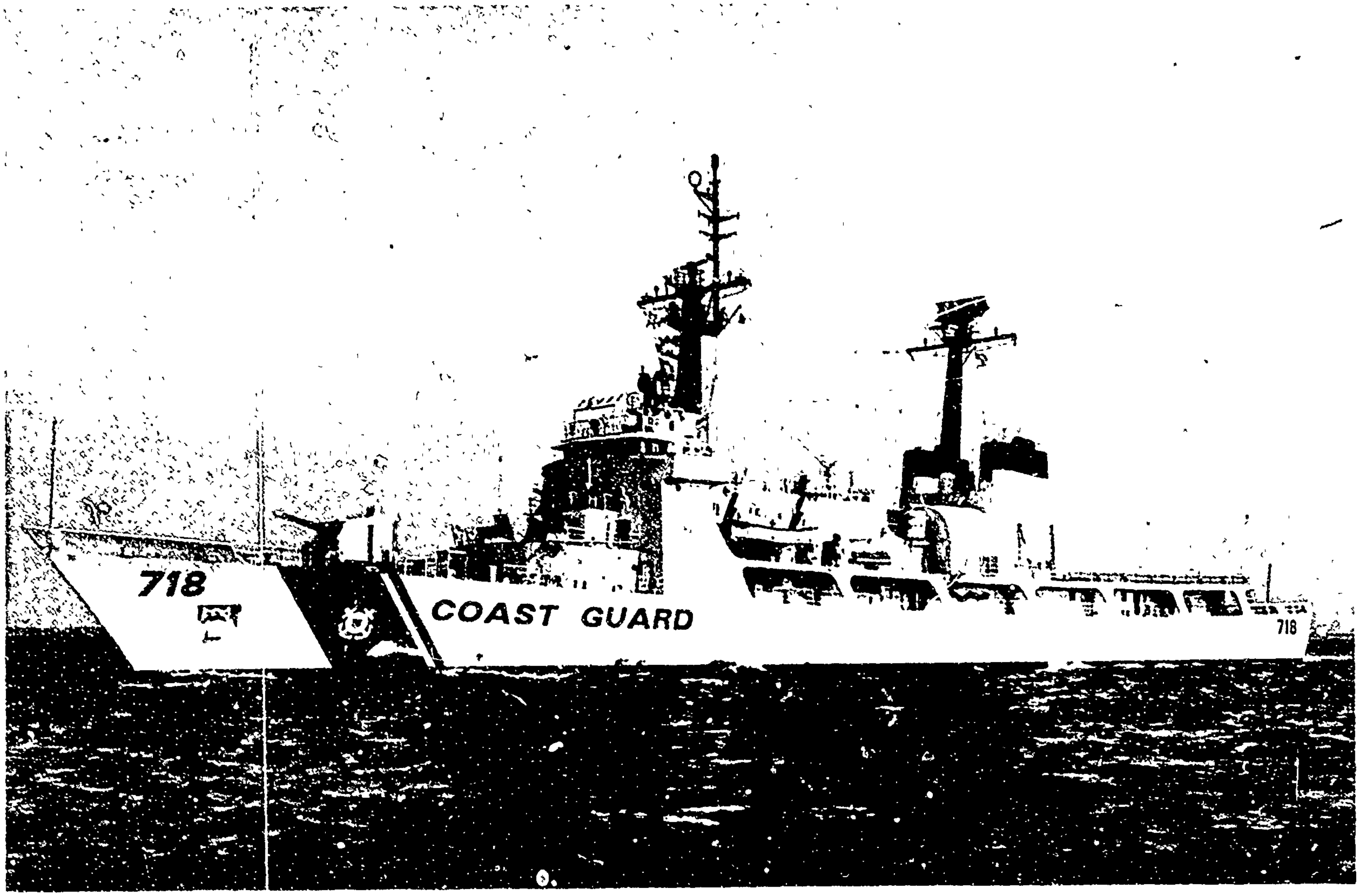


Figure 1. USCGC CHASE (WHEC-718) prior to installation of expansion joint and side curtain.

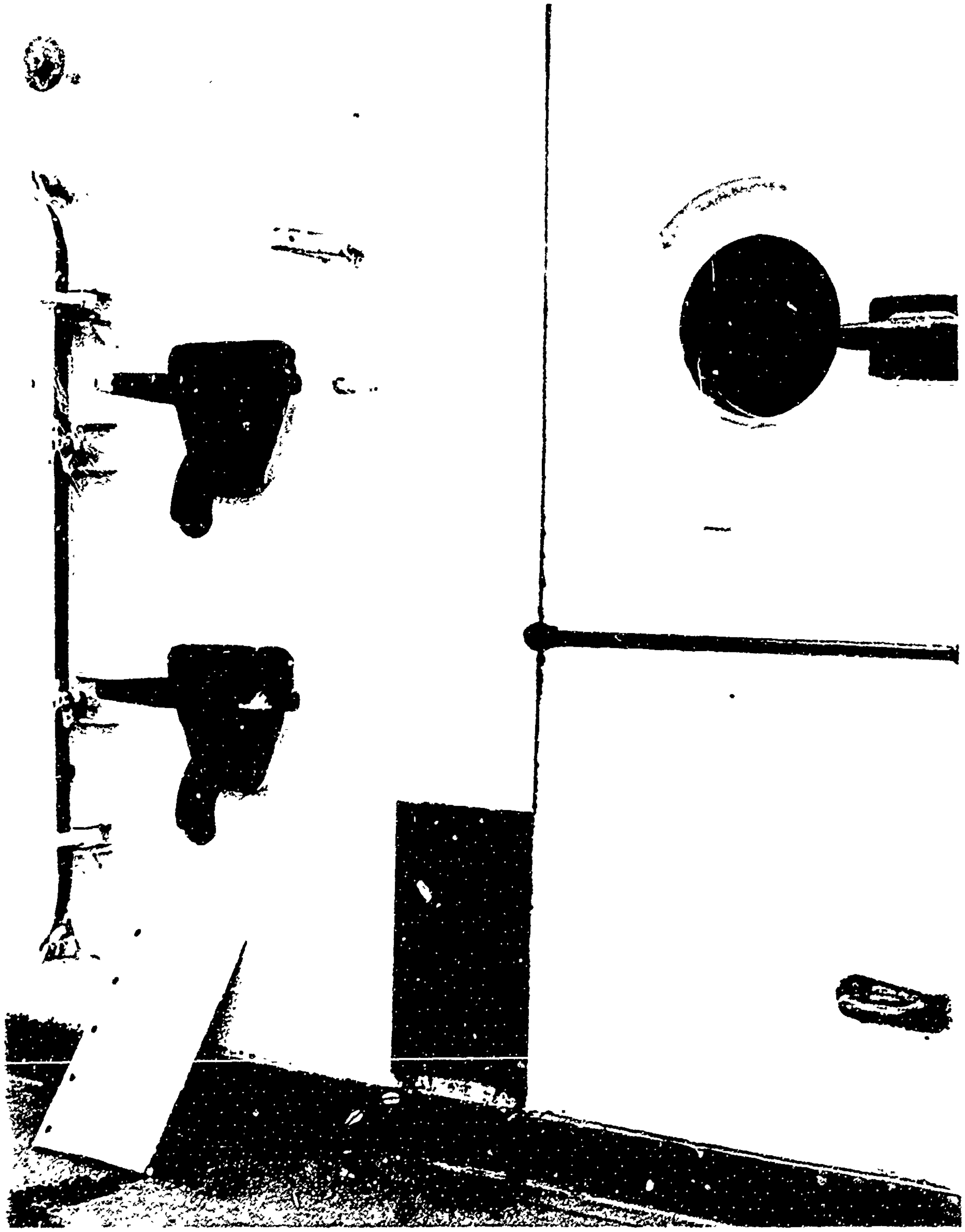
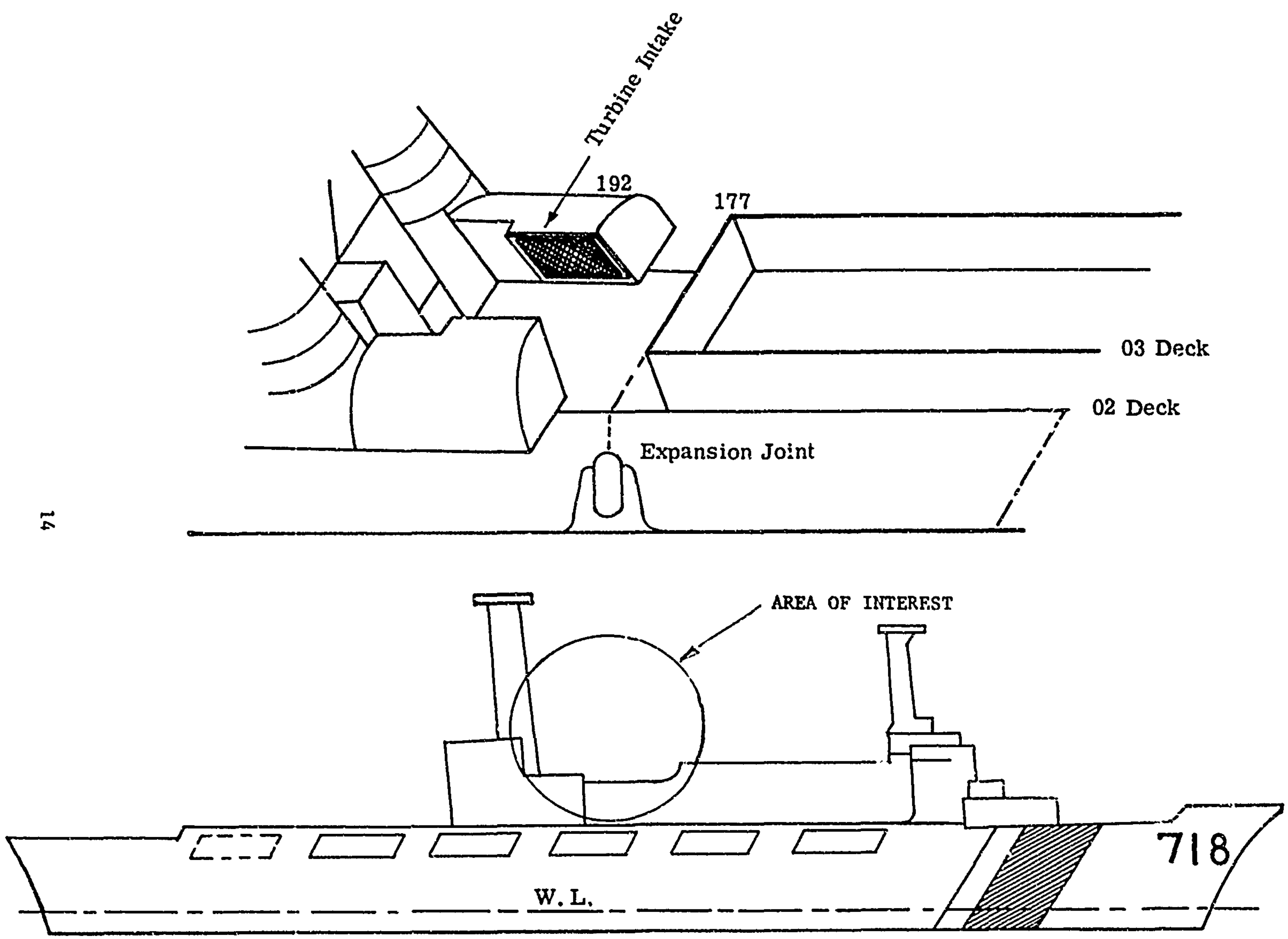


Figure 2. Main deckhouse side of 327' WHEC vessel showing expansion joint.

Figure 3. Detail of expansion joint notch and stress crack in 327' WHEC class vessel.



DETAILED VIEW OF EXPANSION JOINT AREA
Figure 4

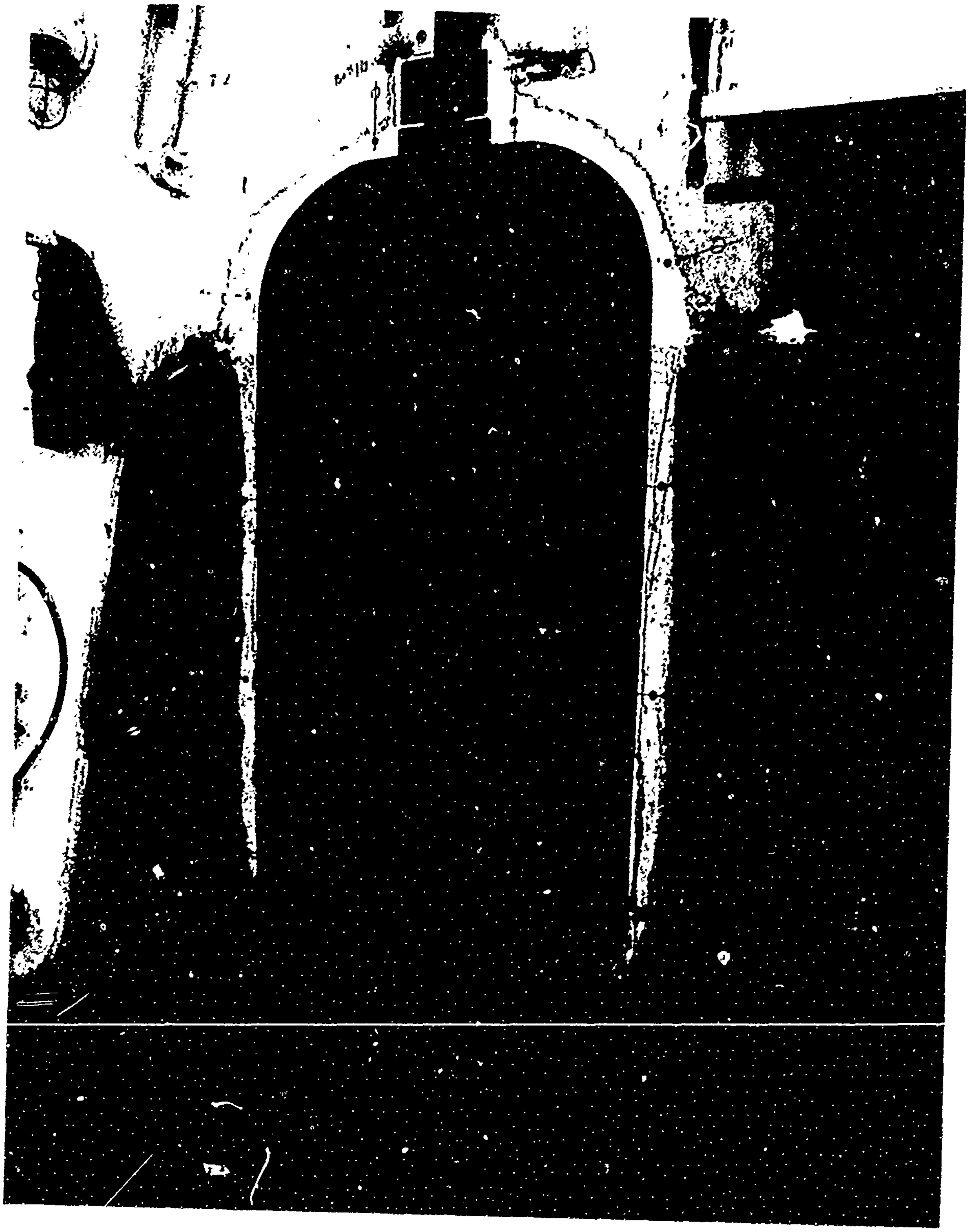


Figure 5. 378' expansion joint during installation showing "special radius cut" at hinge of joint.

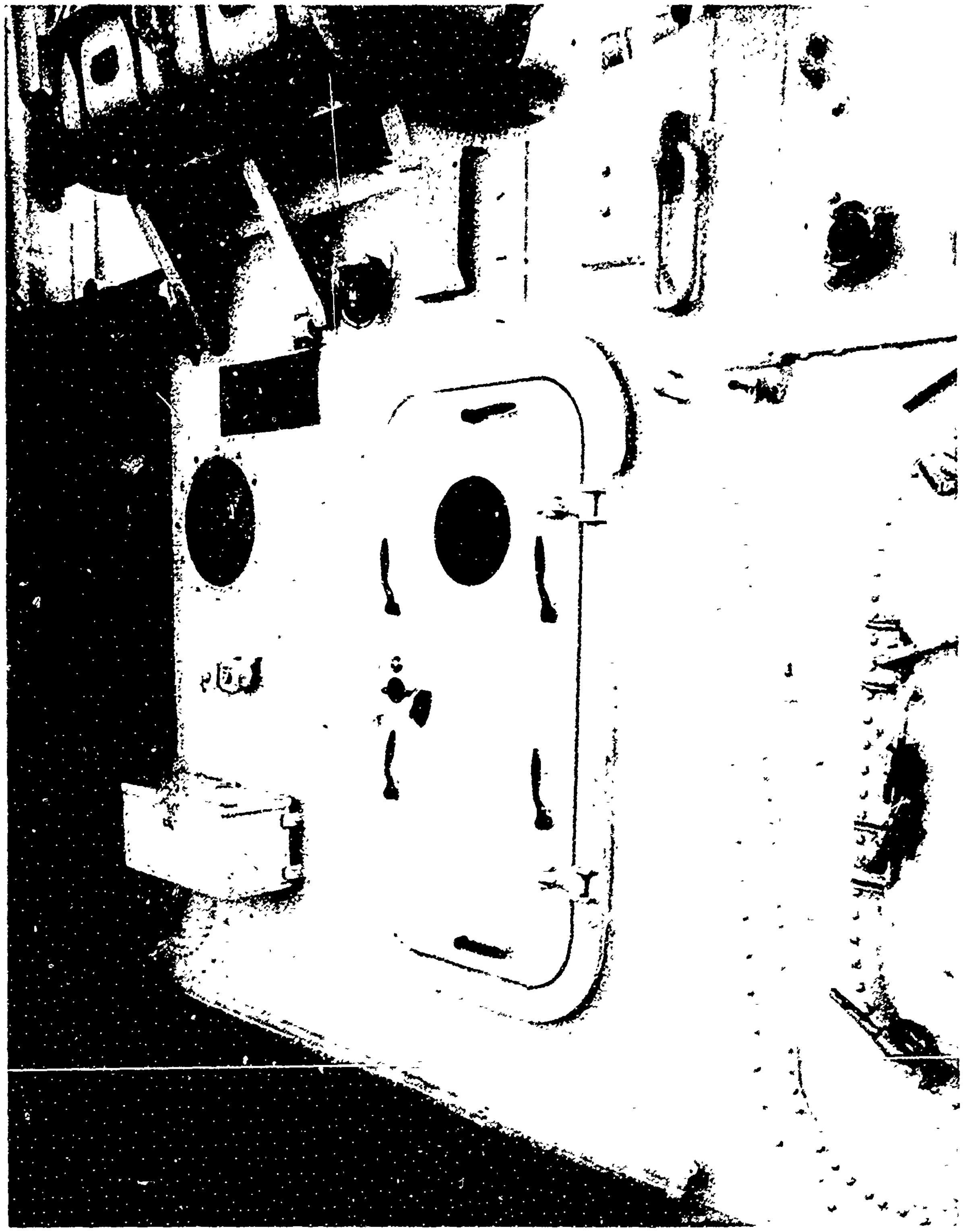
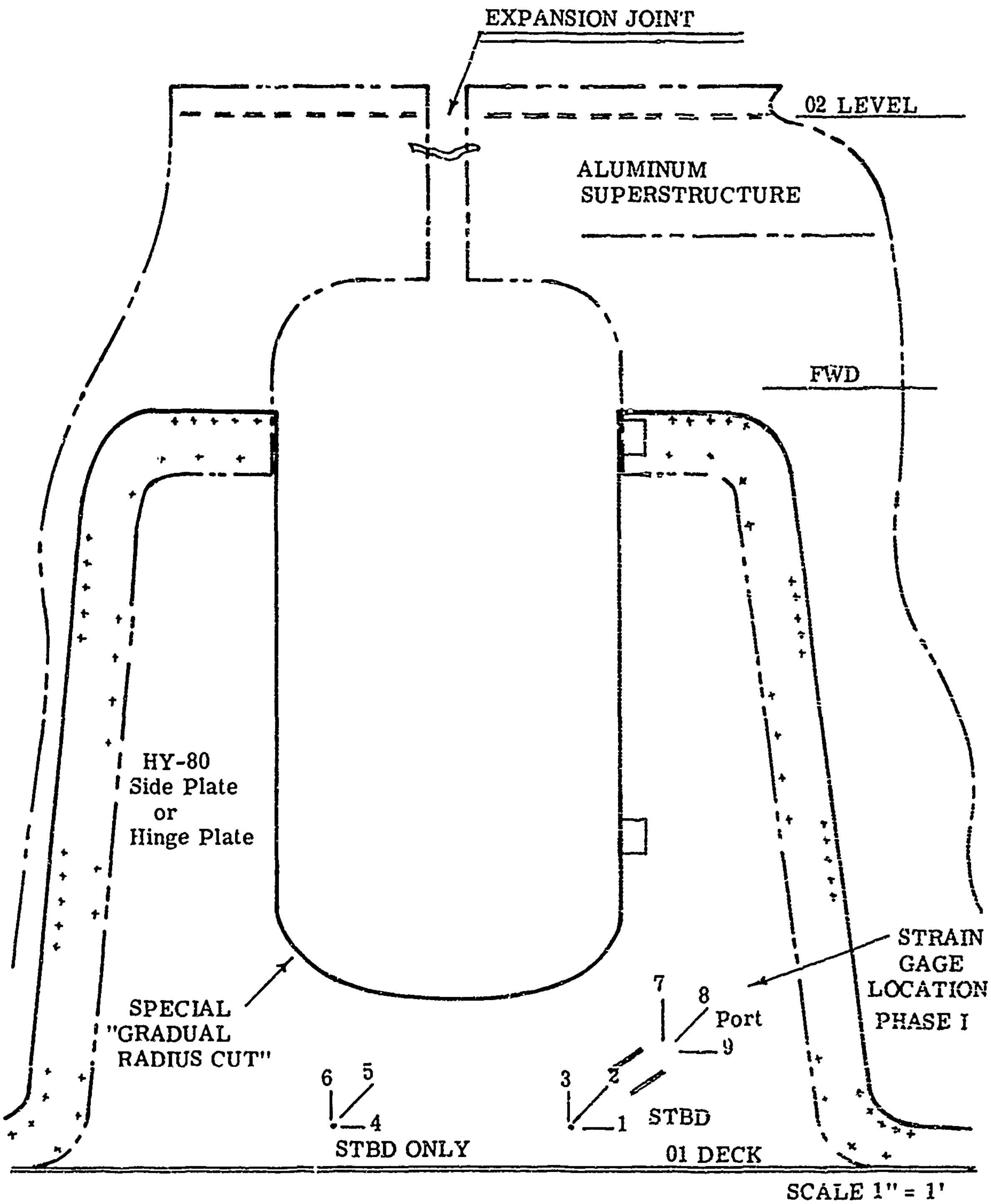


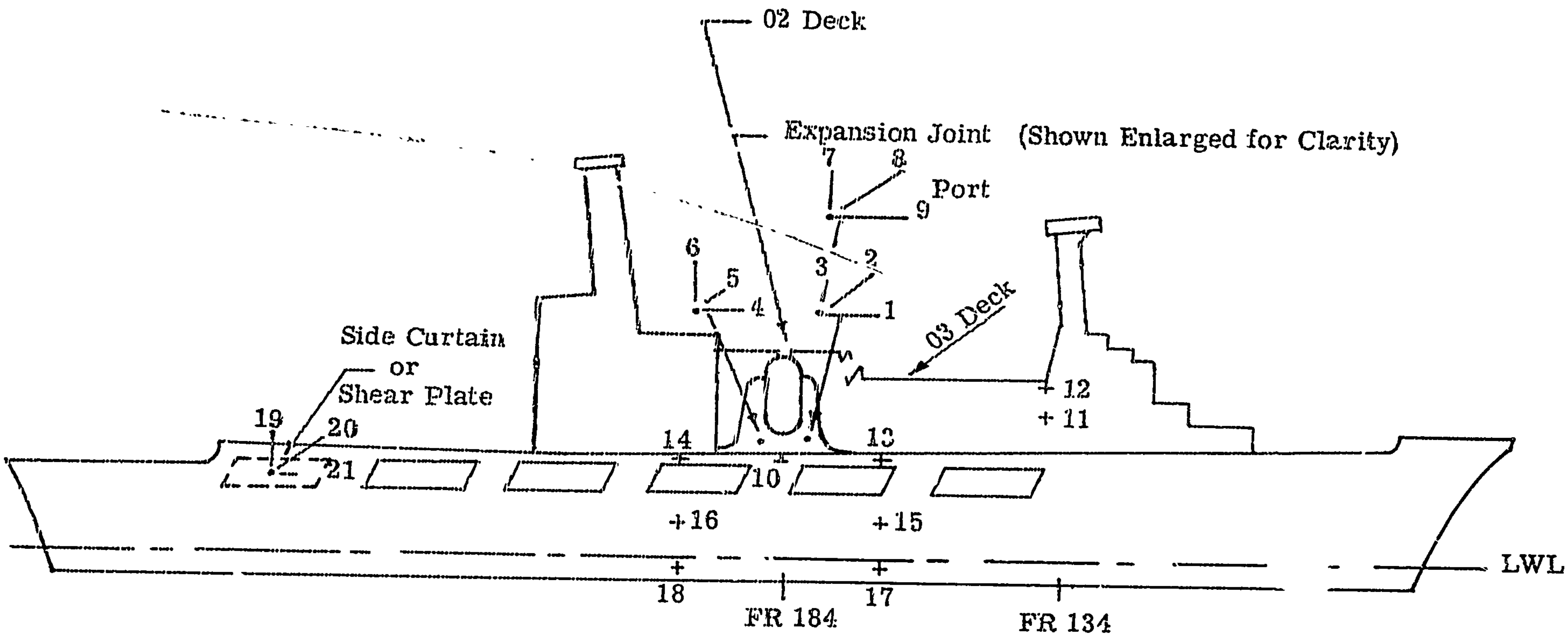
Figure 6. Completed 378' expansion joint
as seen from stbd side of 01 deck.



EXPANSION JOINT SIDE PLATE

USCGC CHASE WHEC-718

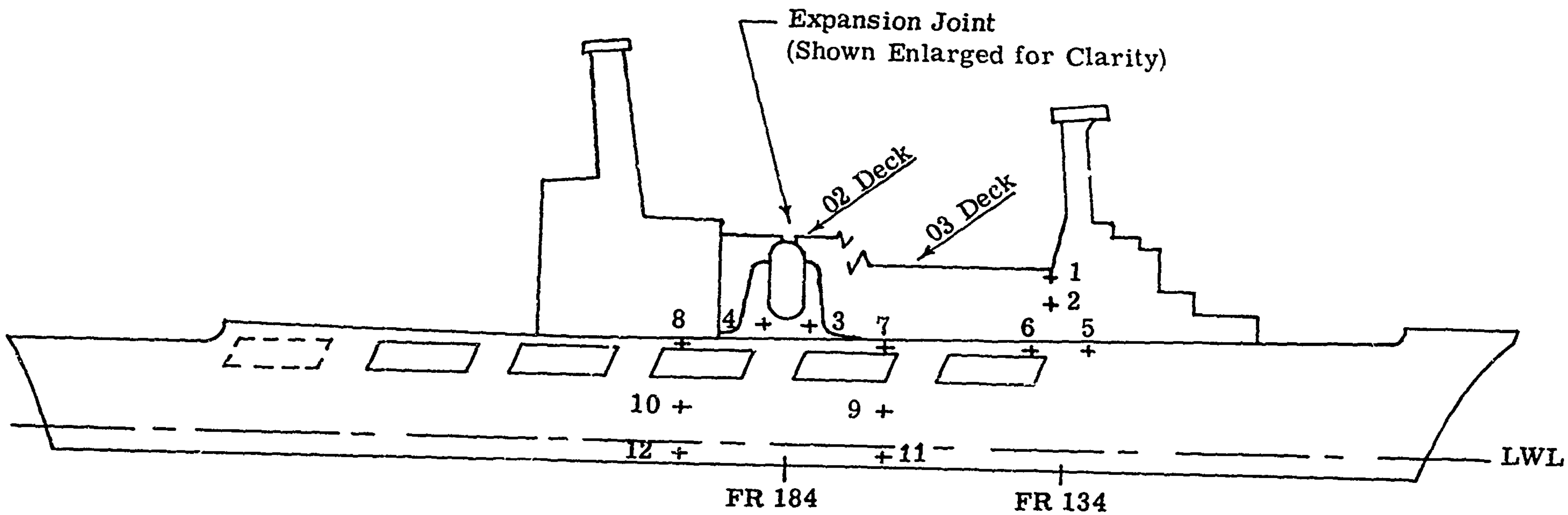
Figure 7. Diagram of hinge plate showing strain gauge locations.



STRAIN GAGE LOCATIONS PHASE I

USCGC CHASE WHEC-718

Figure 8



STRAIN GAGE LOCATIONS PHASE II

USCGC CHASE WHEC-718

Figure 9

ELECTRONICS SYSTEM BLOCK DIAGRAM

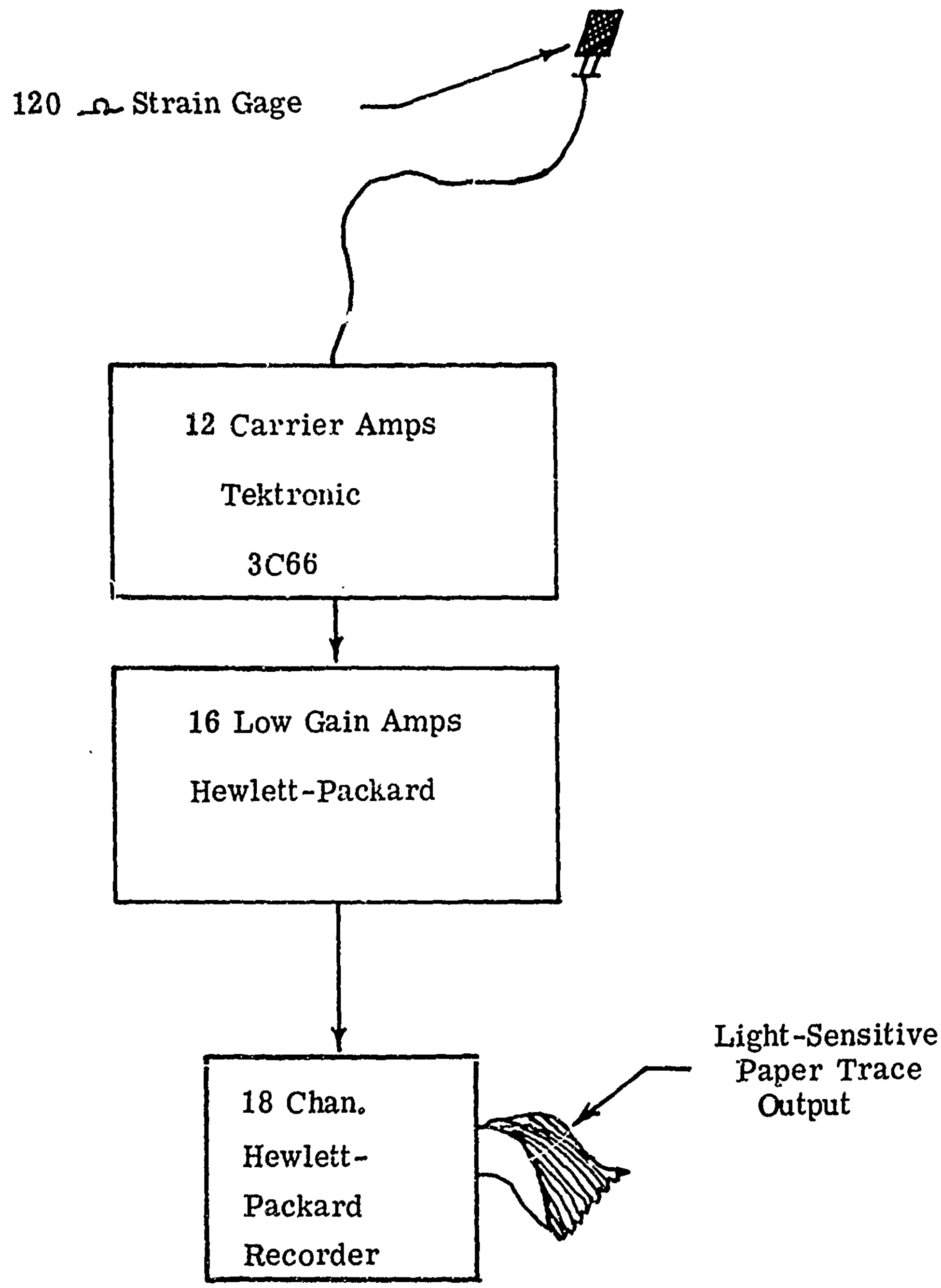


Figure 10

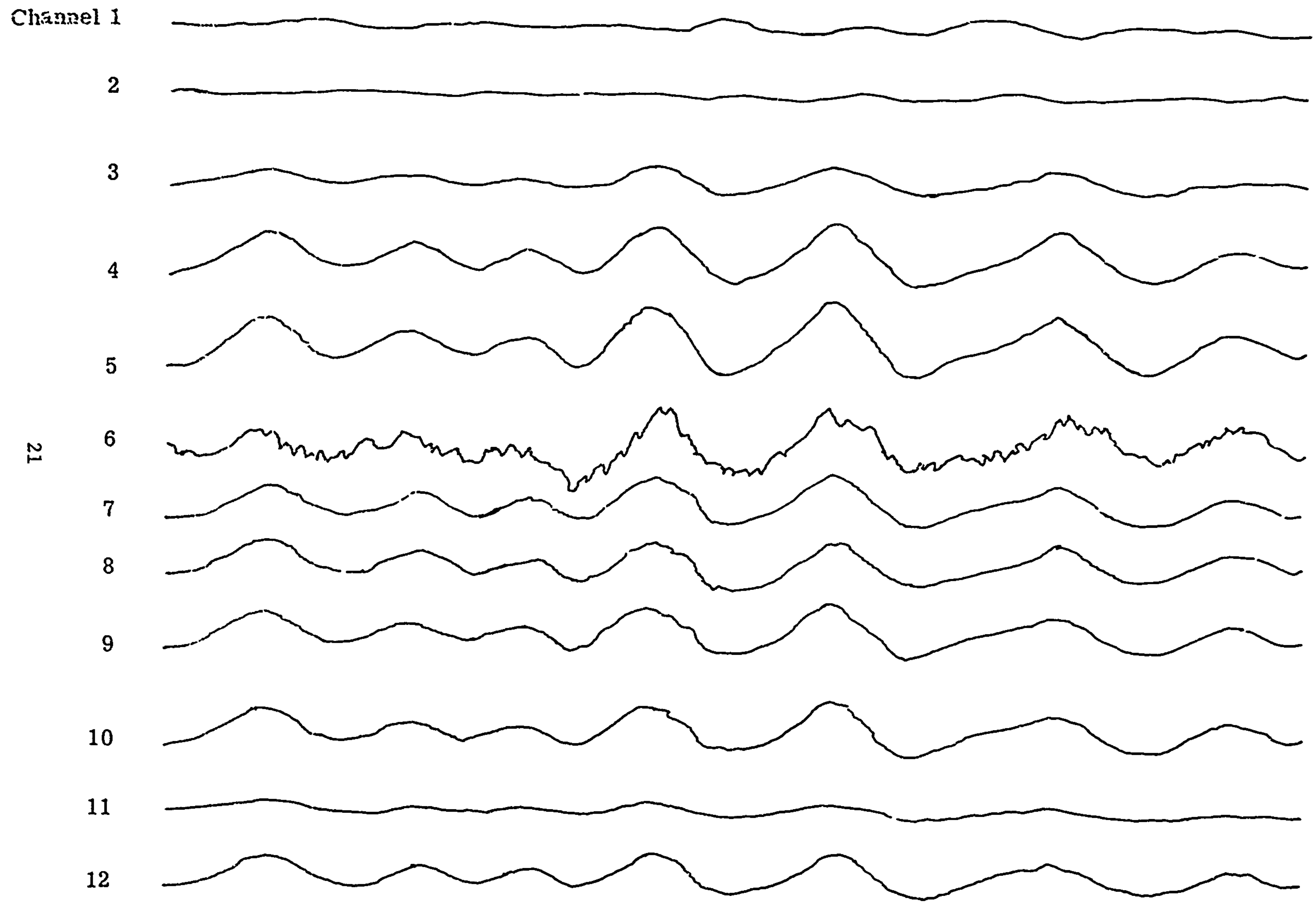


Figure 11
TYPICAL RECORDING TRACE OF STRAINS

Figure 12

Determination of Deckhouse Effectiveness

USCGC Chase (WHEC-718) Feb. 1974

Phase II Test Run No. 1

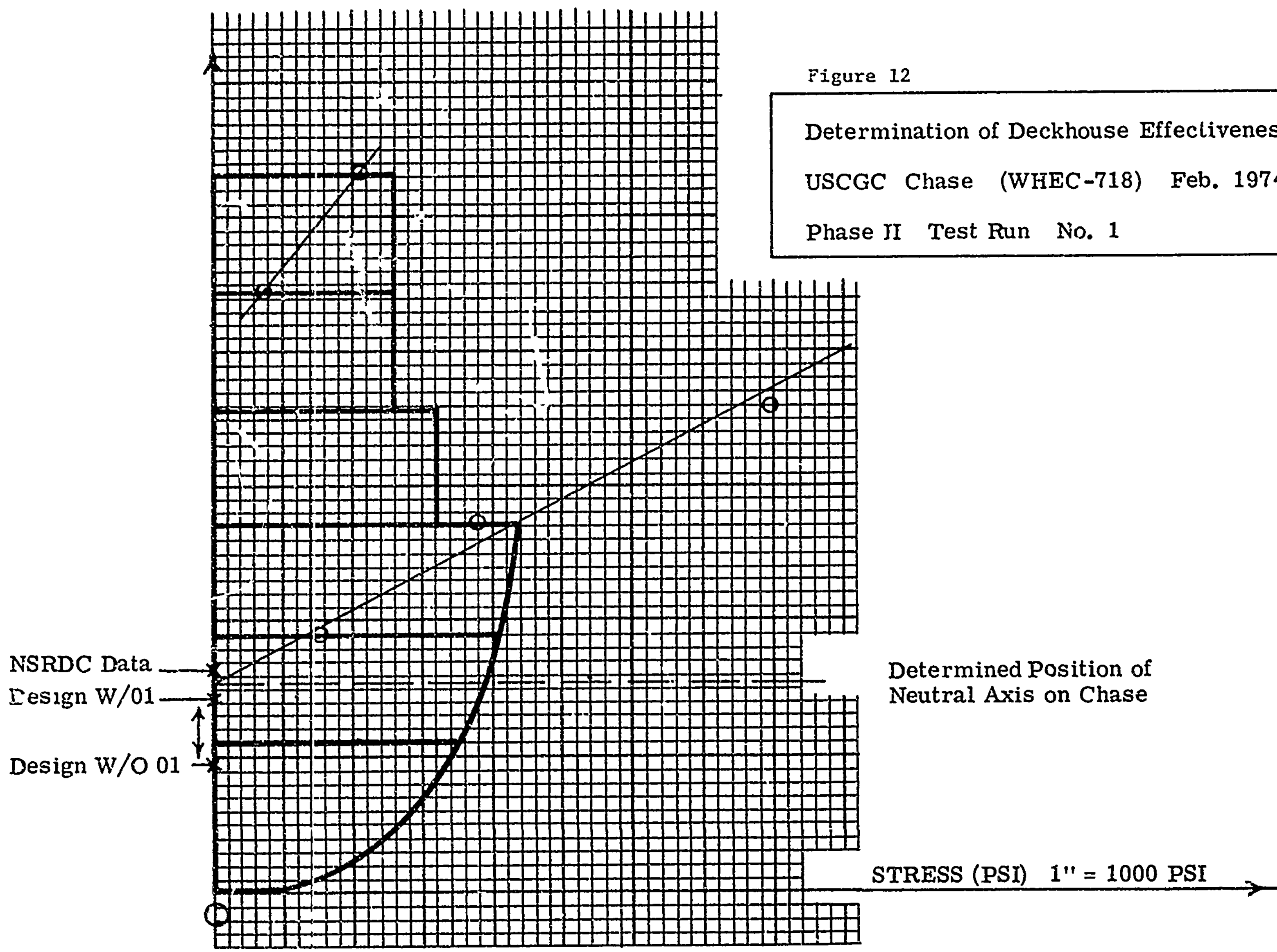
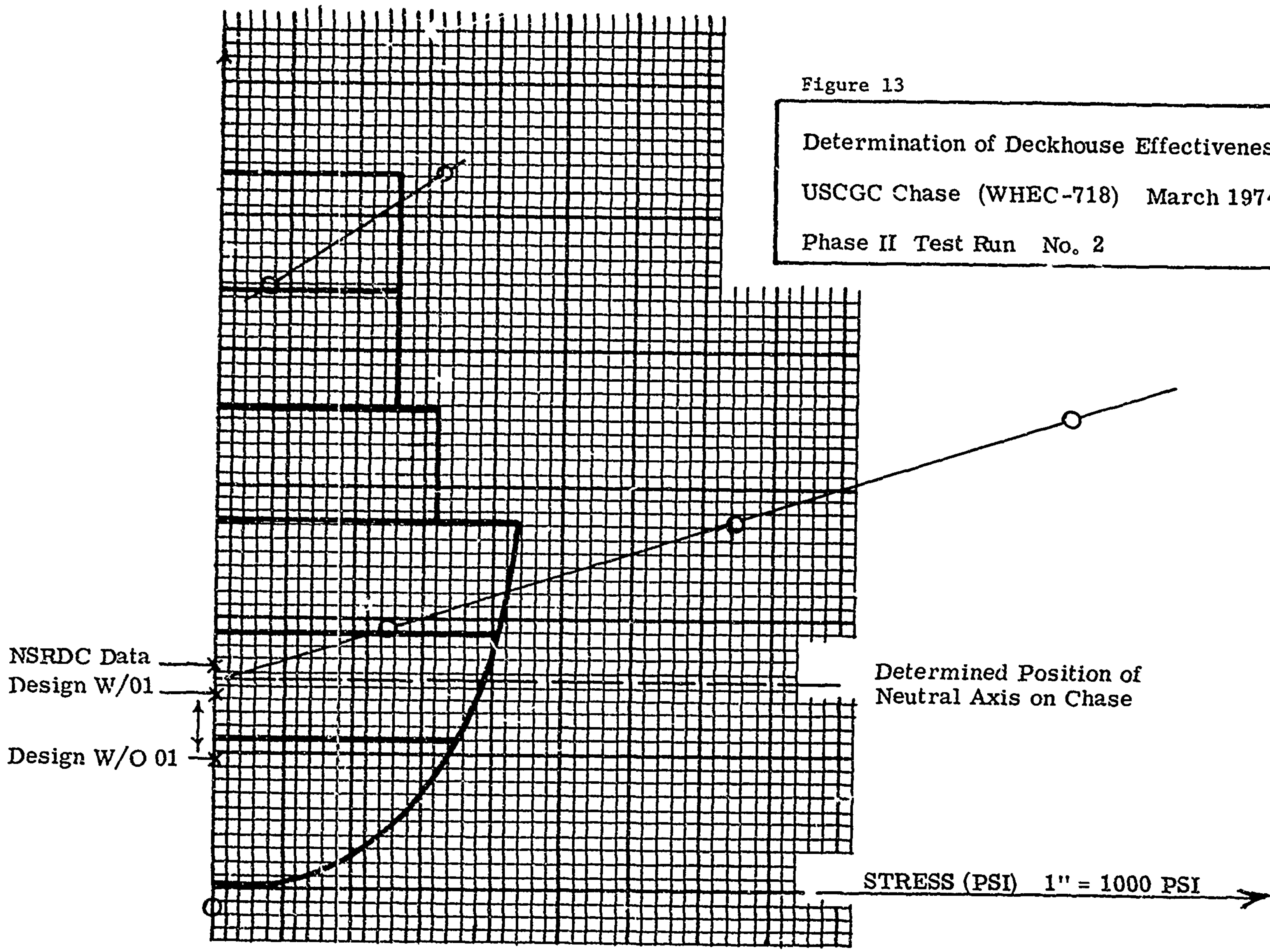


Figure 13



Determination of Deckhouse Effectiveness

USCGC Chase (WHEC-718) March 1974

Phase II Test Run No. 2

Table 1. Phase I data concerning stress concentrations at hinge.

Run Number	Ship's Speed	Sea Height/Rel Dir	Gauge Numbers	Principal Stress $\sigma+$	Principal Stress $\sigma-$	Shear Stress τ
1-1	22 knots	6'/000°	1-3 peak	10,051	5172	2439
			4-6 peak	5,627	3327	1150
			7-9 peak	8,982	5345	1818
1-1	22 knots	6'/000°	1-3 avg	6,026	3063	1481
			4-6 avg	3,597	2156	720
			7-9 avg	5,431	3254	1088
1-2	22 knots	6'/000°	1-3 peak	11,482	5756	2863
			4-6 peak	6,954	4687	1133
			7-9 peak	10,739	6723	2008
1-2	22 knots	6'/000°	1-3 avg	4,713	2602	1055
			4-6 avg	3,021	2262	379
			7-9 avg	3,950	3016	466
2-1	8 knots	9'/000°	1-3 peak	8,682	4302	2189
			4-6 peak	5,387	4015	686
			7-9 peak	8,182	5250	1466
2-1	8 knots	9'/000°	1-3 avg	5,450	3137	1156
			4-6 avg	3,175	2197	489
			7-9 avg	5,920	3576	1172
2-3	17 knots	9'/000°	1-3 peak	12,460	7464	2497
			4-6 peak	7,678	5082	1298
			7-9 peak	11,179	6730	2224
2-3	17 knots	9'/000°	4-6 avg	9,863	5660	2101
			7-9 avg	9,342	5630	1856

Table 2. Phase I data - Local bending stress at
Frame 184, Gauge #10, directly below expansion joint.

Run Number	Ship's Speed	Sea Height/Rel Dir	Stress σ PSI
1-1	22 knots	6'/000°	1800 peak 1050 avg
1-2	22 knots	6'/000°	2250 peak 1038 avg
2-1	8 knots	9'/000°	1500 peak 840 avg
2-2	8 knots	9'/000°	1500 peak 1098 avg
2-3	8 knots	9'/330°	1800 peak 1146 avg
2-4	14 knots	9'/000°	1650 peak 1143 avg
2-5	14 knots	9'/315°	1500 avg
2-6	14 knots	9'/270°	699 avg
2-7	14 knots	9'/225°	1800 peak 807 avg
2-8	14 knots	9'/180°	1050 peak 750 avg
2-10	17 knots	9'/225°	1350 peak 864 avg
2-11	17 knots	9'/270°	1200 peak 750 avg
2-12	17 knots	9'/135°	2250 peak 1212 avg
2-13	17 knots	9'/000°	2100 peak 1434 avg
3-6	14 knots	15'	3000 peak 1671 avg
3-16	17 knots	15'	3000 peak 1125 avg

Table 3. Phase I data concerning shear stress transmitted at side curtain.

Run Number	Ship's Speed	Sea Height	Gauge Numbers	Principal Stress σ+	Principal Stress σ−	Shear Stress λ
4-1	8 knots	12'	19-21 avg	1279	534	372
4-2	14 knots	12'	19-21 avg	2046	371	837
4-3	21 knots	12'	19-21 peak	3690	1906	891
4-3	21 knots	12'	19-21 avg	2188	1393	397
6-1	8 knots	12'-15'	19-21 avg	3211	415	1398
6-2	14 knots	12'-15'	19-21 peak	6072	2882	1594
6-2	14 knots	12'-15'	19-21 avg	2413	886	763
6-4	17 knots	12'-15'	19-21 peak	9127	-172	4650
6-4	17 knots	12'-15'	19-21 avg	4929	41	2444

Table 4. Phase II strain gauge data for determination of neutral axis.

Run Number	Ship's Speed	Sea State	Stress Level from Avg of 1/3 Highest Peaks 1	2	3	4	5	6	7	8	9	10	11	12
1	16 knots	6'	1050	383	3924	3774	3123	3474	4125	5454	1773	1998	723	1125
2	17 knots	8'	1600	380	5010	5190	--	--	--	7830	4590	2820	900	1680

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