Report 1965

MODEL BASIN
WASHINGTON, D.C.

DEPARTMENT OF THE NAVY

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LABORATORY DETERMINATION OF STRESS CONCENTRATIONS IN THE DECKHOUSE OF AOE-CLASS CARGO SHIPS

by

Louis A. Becker

STRUCTURAL MECHANICS LABORATORY
RESEARCH AND DEVELOPMENT REPORT

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ABSTRACT

This report presents a model testing method from which relative stress concentration factors were determined. This method used steel and photoelastic models representing the side of a deckhouse with simulated cargo door openings with and without expansion joints. A high-speed cargo ship (AOE) was the prototype design from which the models were scaled. Loads causing pure bending produced stress concentrations in the order of 2.6 for the model without expansion joints and less than 1 when expansion joints were included. However, the stress gradient in the vicinity of the expansion joint is such that the magnitudes of stress concentration for this structure are still unknown. A much larger scale model would be required to study this detail. It was concluded from the model tests that deckhouse construction (of the AOE type) without expansion joints is superior to that with expansion joints.

ADMINISTRATIVE INFORMATION

By Bureau of Ships letter F013 03 01, Serial 442-39 of 4 May 1960, the David Taylor Model Basin was requested to investigate the stress fields near the large side opening in the deckhouse of a new fast cargo ship, AOE. The purpose of this investigation was to ascertain the need for expansion joints in the deckhouse of ships of this class. Following the completion and verbal reporting of these tests, the program was expanded to consider stress concentrations at the openings when shear loadings were applied (conference at BuShips between BuShips Code 442 and Model Basin Code 722 in April 1962). A final addition to the program, the determination of stresses in the top of the deckhouse, was requested by Bureau of Ships letter F013-03 01, Serial 442-194 of 22 October 1962.

INTRODUCTION

Today's modern naval warship is a heavily armed, well manned weapons system. As a consequence large amounts of supplies are consumed, particularly during combat when large quantities of ammunition are used. Since it is not possible to return frequently to a shore base, resupply at sea is mandatory. The only ships available in quantity to handle this supply mission are the World War II classes of supply ship. These ships are too slow to keep up with today's combat ships, and, furthermore, they are not equipped to handle today's armament supplies efficiently. Therefore, the design and construction of a new class of cargo ship was imperative. The Bureau of Ships now has such a design. This ship, designated an AOE, is a combat support ship with a large below-decks cargo capacity and is capable of speeds in excess of 30 knots. It has ten elevators all housed in a long deckhouse to aid in moving supplies from the below-decks storage areas to the waiting ships.

The deckhouse of the AOE covers more than 5/8 of the length of the ship. The length of the deckhouse and its isolation from the hull girder through the use of expansion joints have caused controversy from the beginning of the ship design. Early in the design of this ship, consideration was given to including the superstructure as part of the hull girder strength member. However, the five larger doors in each side of the deckhouse in way of the cargo elevators introduce stress conditions which the designer can not completely define. The state-of-the-art for analysis of such stress risers had not progressed sufficiently to guide the designer. Therefore, the first AOE was designed with expansion joints in the deckhouse. These were located on both sides of the cargo door openings to isolate each door from the remainder of the deckhouse. This technique not only eliminated the stress risers but it also isolated the deckhouse from the hull, structurally. Unfortunately, expansion joints do not completely solve the design problem. They are costly to build and maintain, and they introduce additional stress concentrations in the hull just below the expansion joints.

The current shipbuilding program includes the construction of a number of ships of the AOE class. Elimination of the deckhouse expansion joints would significantly reduce the cost of deckhouse construction. Therefore the Bureau of Ships authorized the Taylor Model Basin to conduct a study to determine whether the deckhouse joints should be eliminated and to verify the adequacy of the spacing between openings and the stress condition around these openings.

The initial program was oriented to measure stress concentration factors in way of simulated cargo doors and at the end of the simulated deckhouse when loads which caused pure moment at the test section were applied to photoelastic beam. The program was later expanded to consider stress concentrations at the openings when shear loadings were applied. This program required the use of steel models. A final addition to the program was the determination of stresses in the top of the deckhouse.

The test program described in this report was conducted prior to the design of AOE 2. The report not only describes that program but also draws conclusions concerning the need for expansion joints in the deckhouse of future ships of the AOE Class.

DESCRIPTION OF PERTINENT SHIP STRUCTURE

The hull of AOE is essentially a box girder with two internal longitudinal bulkheads as shown in Figure 1. This figure also shows the openings in the deckhouse and the construction details of AOE 1 and AOE 2 that are important to this program. The major difference in the ships is that AOE 1 has a heavy deck running continuously over the bulkhead and has light deckhouse sides and top. In the vicinity of the large door openings, the deckhouse sides are attached to the deck by means of wobble plates. (Wobble plates are thin plates riveted to the deck and welded to the side of the deckhouse. They can deflect upward slightly, thus relieving some stress concentration at the connection.) AOE 2 has the decks framing into the longitudinal bulkhead and has a heavier bulkhead than AOE 1. On AOE 2, the 01 level deck is considerably lighter inboard of the longitudinal bulkhead than it is on AOE 1 (1 in. on AOE 1 and 5/8 in. on AOE 2). The top of the deckhouse on AOE 2 is of 1/2-in. plate compared to 3/16-in. plate on AOE 1.

THE TEST PROGRAM

The test program was divided into two different model studies. For the first part of the program, simple photoelastic models were subjected to loads which caused only moment at the test section. In the second part of the program, steel models were instrumented with strain gages and loaded to produce shear at the test section. The two different types of models were used primarily because of the different loadings being studied. Photoelastic tests are slightly more desirable because it is possible to measure point stresses rather than average stresses over the length of the

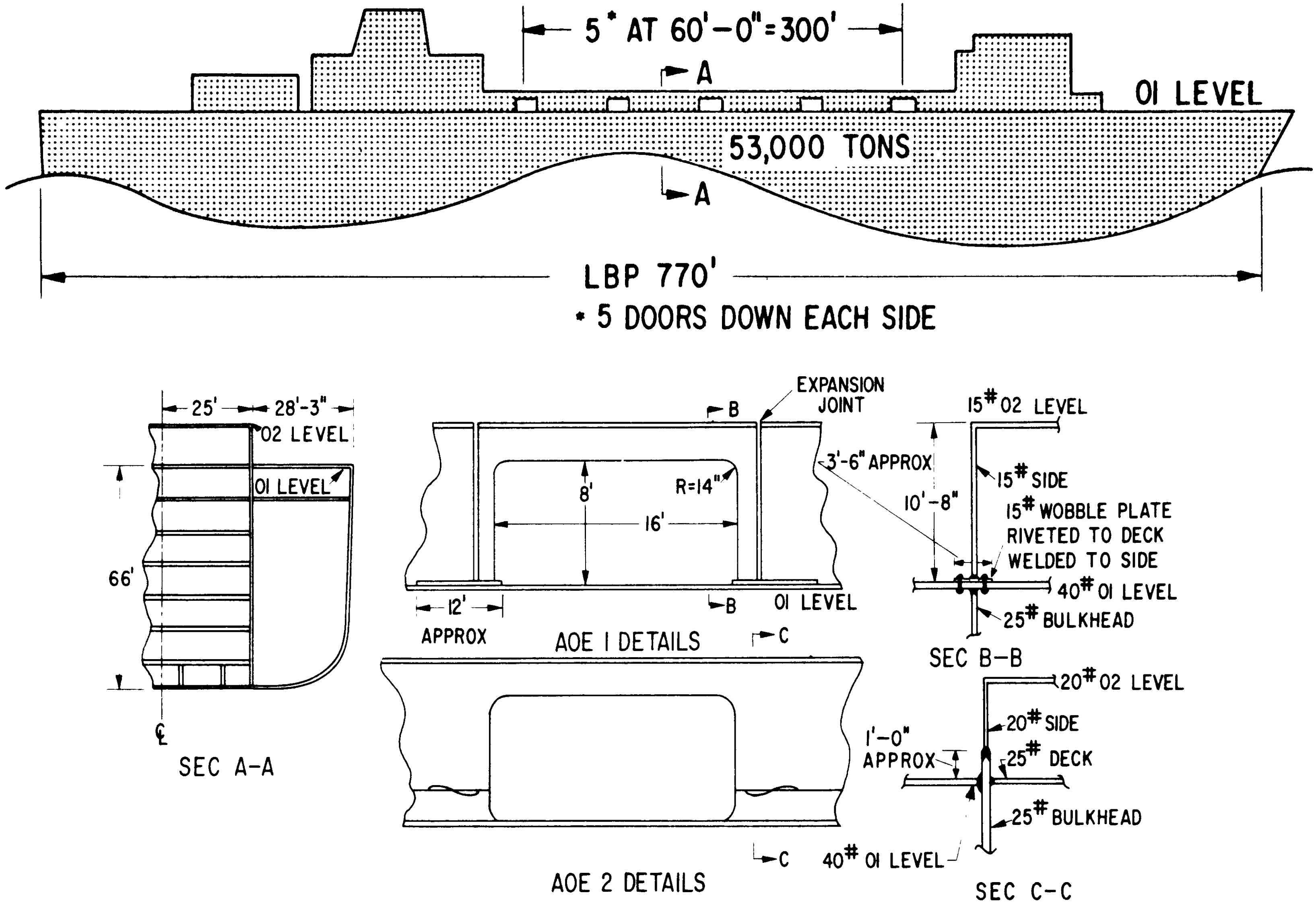


Figure 1 - Pertinent Construction Details of AOE

strain gage (1/64 in.), but it is difficult to use a photoelastic model in a compressive stress field, such as exists in the shear test, because the model will buckle locally and give erroneous results. The test program developed from these considerations is described in the following sections.

THE PHOTOELASTIC MODEL STUDY

This part of the program considered loads which caused only pure moment (no shear) at the test section. Specific objectives were to determine:

1. The adequacy of spacing between openings to avoid amplification of stress disturbances created by each opening,
2. The magnitude and locations of the stress concentrations introduced by the simulated deckhouse openings.

Tests were performed on simplified photoelastic models made of Columbia Resin, a plastic with good stress-optic properties. Before designing the models, several important scaling factors had to be determined. First, the openings on the ship were spaced 60 ft apart which means that the model used to study spacing must represent at least 100 ft of the prototype deckhouse. Second, the plate thickness of the prototype was only 5/8 in. The standard size of Columbia Resin sheets is 2 ft x 3 ft and, therefore, a 3/100-scale model is indicated. The 5/8-in. plate scales to 0.02 in. thick, which makes it virtually impossible to construct a true scaled model. Fortunately, the desired test objective was stress concentration rather than stress distribution and thus it was possible to use a double scale, i.e., one scale for the major dimensions and a second for thickness. This double-scaled model was adequate for determining stress concentration factors even though it did not exactly reproduce the prototype hull and superstructure. To study opening spacing, a single sheet of plastic scaled to represent the longitudinal bulkhead from the neutral axis to the 02 level was used as a model. Initially, this model had a single opening at the third point as shown by Figure 2. The model was put in the TMB Polariscope, as shown by Figure 3, and loaded in pure tension, off center, as shown in Figure 4. This loading produces the same stress distribution in the model as pure bending would produce in the top half of

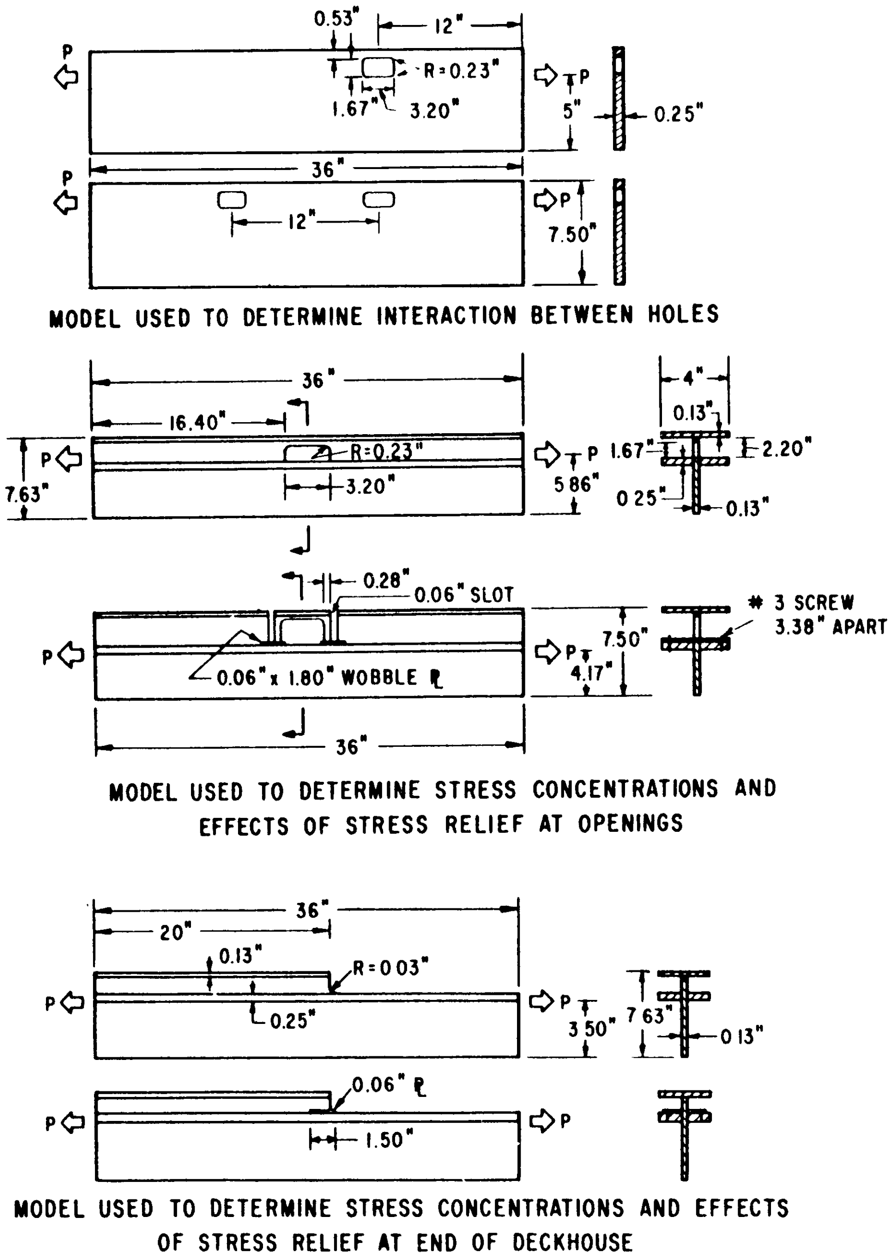


Figure 2 - Photoelastic Models

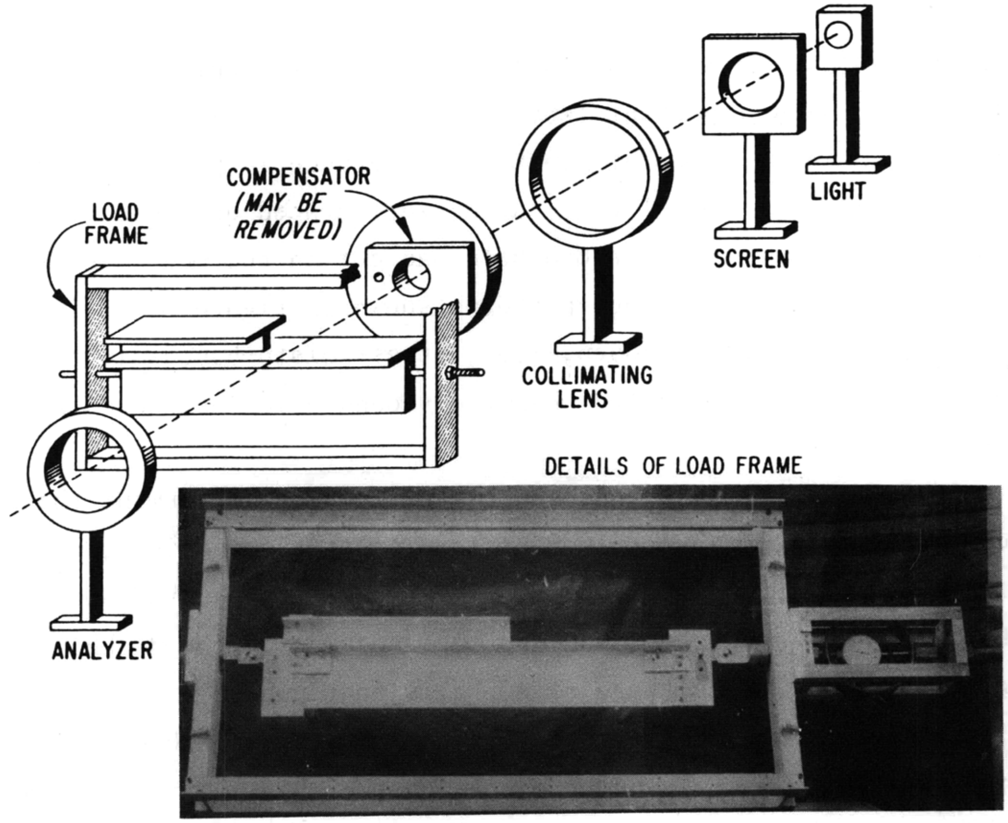


Figure 3 - TMB Polariscope

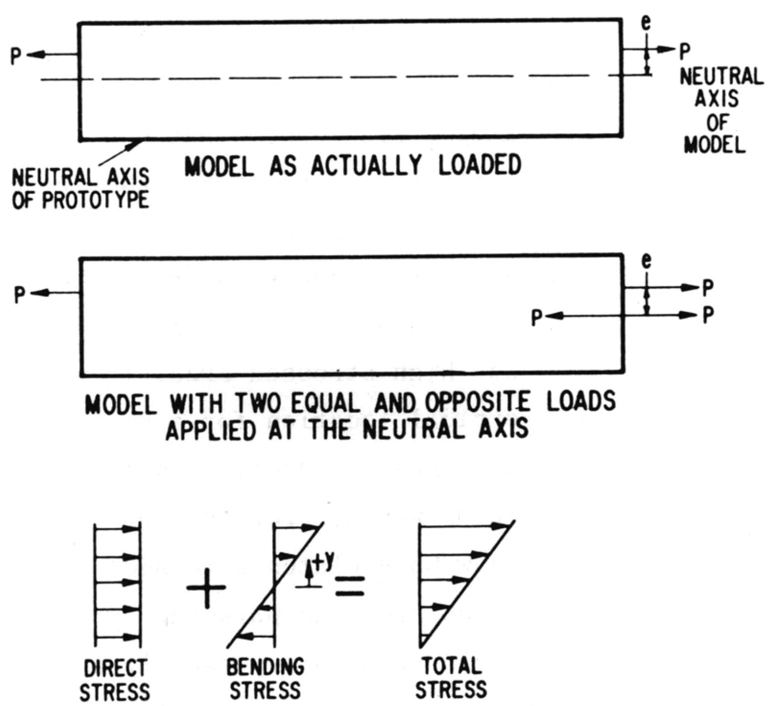


Figure 4 - Simplified Diagram of Loading Configuration
Used for the Photoelastic Tests

the prototype and tension loadings are easy to apply in the polariscope. This was a very important feature since buckling was not desired. The fringe patterns (lines of constant difference in principal stress), which appeared when the model was loaded, were traced on a piece of ground glass taped to the model. A second hole was cut in the model and the test was repeated. From the fringe patterns shown in Figure 5, it is apparent that the spacing was well chosen, i.e., stress disturbances in the vicinity of one hole were not affected when the second hole was added in the location shown.

To reach the second objective, i.e., to determine the stress concentration factors due to moment loading at the openings, a second model was built as shown in Figure 2. This model represented the longitudinal bulkhead, the main deck, and the top and side of the deckhouse modeled after AOE 2. The bulkhead of AOE 2 is continuous, with the decks framing into it. The top of the model or the simulated deckhouse is symmetric with the bulkhead, which is not the case on the ship. This was done because there would be no dissymmetry if the entire cross section of the prototypes were considered.

The photoelastic model was set up in a load frame and put into the polariscope as shown in Figure 3. The model was loaded using the technique described for the previous model (see Figure 4). Examination of the fringe patterns (Figure 6a) indicates stress concentrations at the corners of the openings. However, it is difficult to tell what the fringe values are from these photographs. Therefore, after areas of high stress were located, they were marked and examined more closely using a compensator, a device used to measure fractional fringe orders at a given point. Once the fringe order was determined for each high stressed area, it was compared to the fringe order at the same vertical location for a section not influenced by the opening to determine the stress concentration factor; see Figure 7. The stress concentration factor was 2.6 for this opening.

Expansion joints and wobble plates were added to the model and the test procedure described in the previous paragraph was repeated. As shown in Figure 6b, the stress levels reduce very rapidly around the deckhouse opening and the stress concentrations are virtually eliminated in the upper corners of the opening. However, further examination of Figure 6b reveals

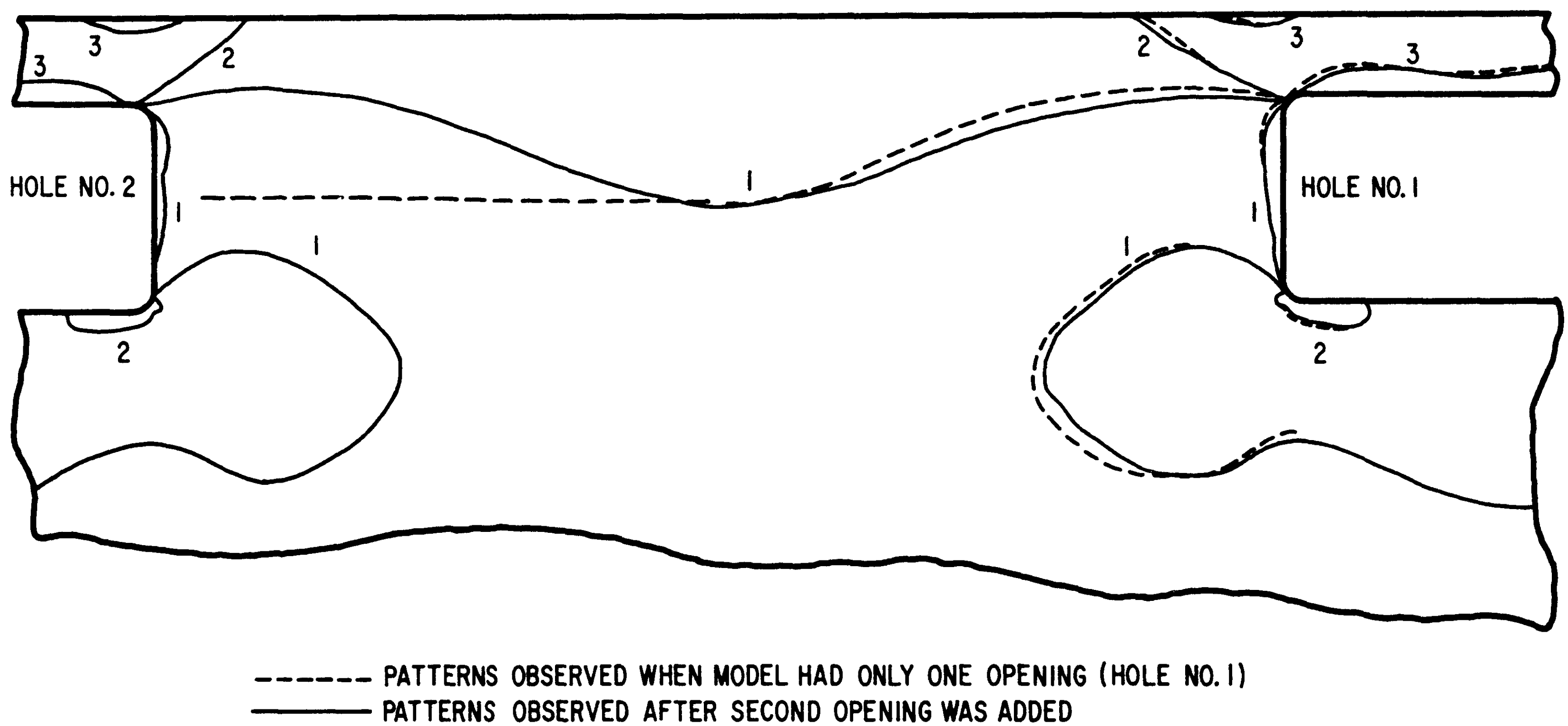


Figure 5 - Fringe Patterns Observed during Tests to Investigate the Stress Field Interaction due to the Openings

Model Representing Area near Opening

Model Representing Area near end of Deckhouse

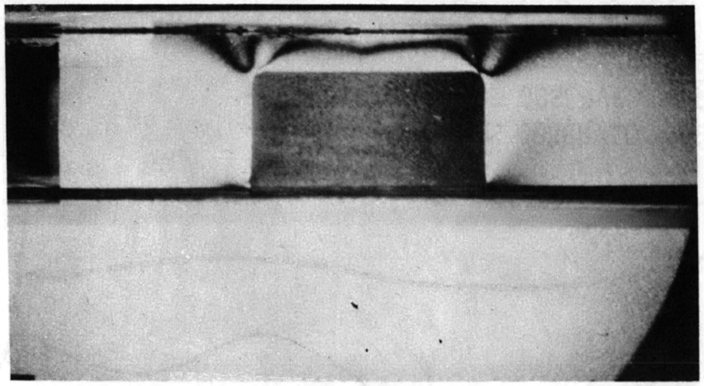


Figure 6a

Figure 6c

No Stress Relief

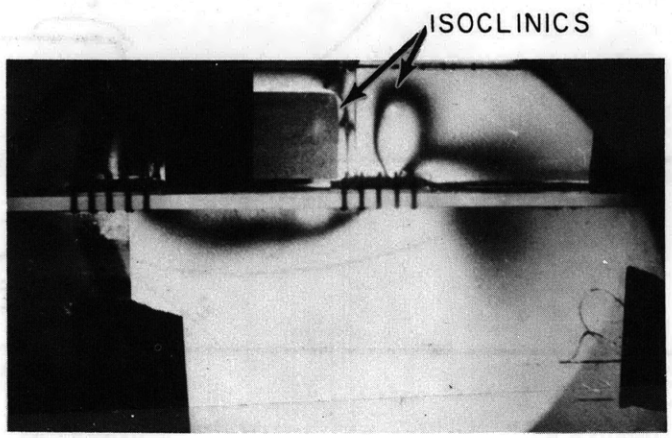


Figure 6b

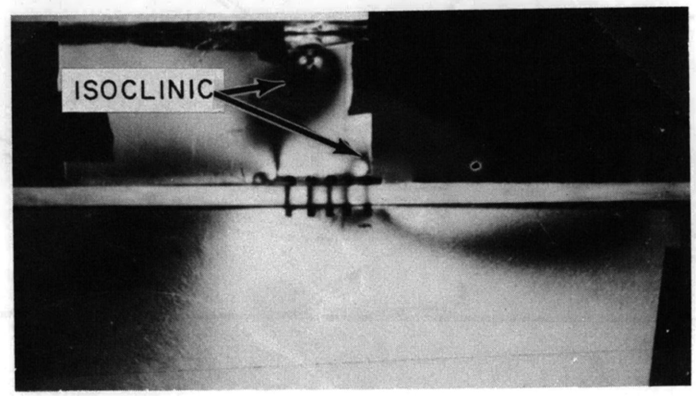


Figure 6d

Stress Relief

Figure 6 - Fringe Patterns from Photoelastic Models

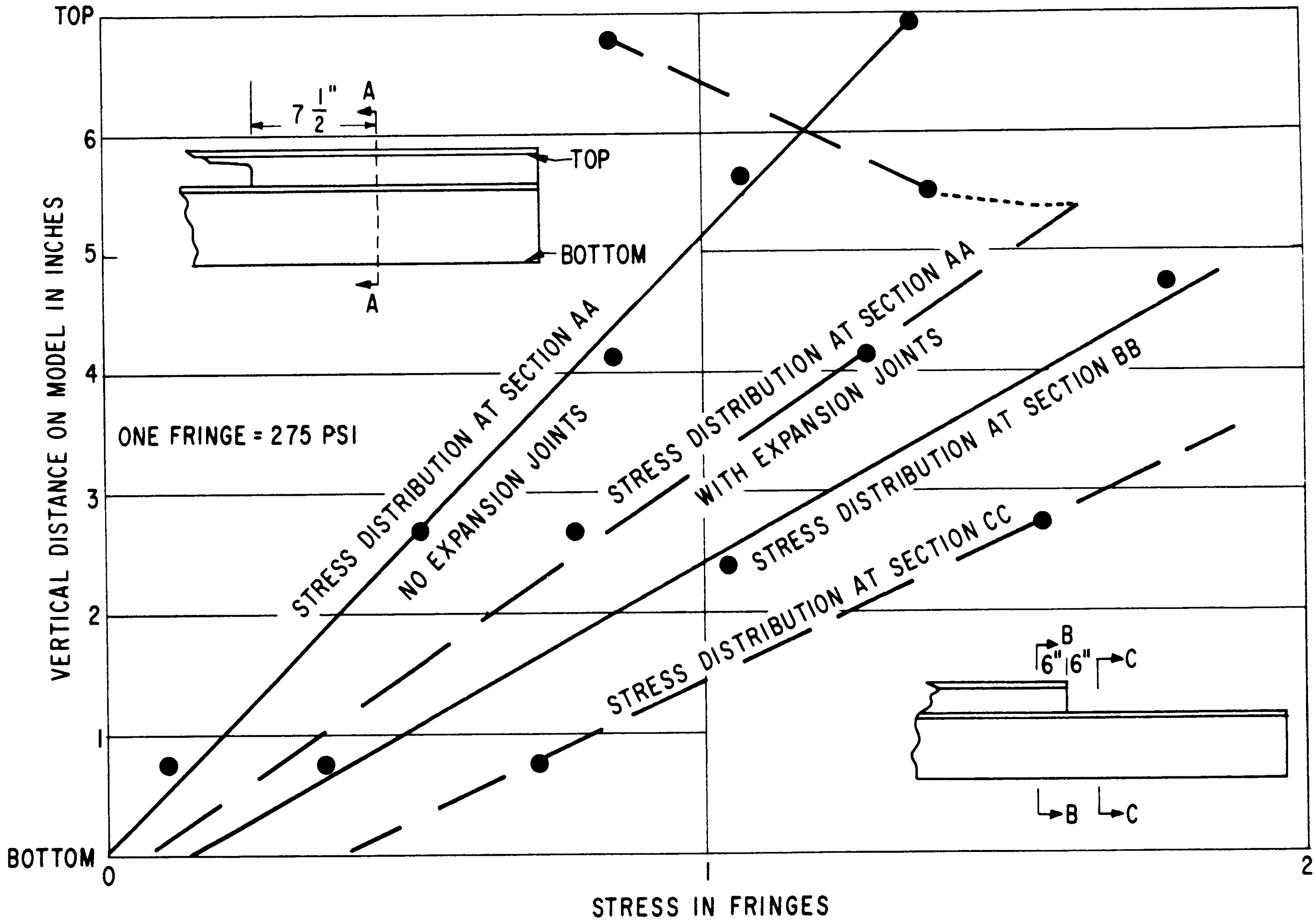


Figure 7 - Stress Distribution at Undisturbed Cross Section of the Photoelastic Models

the presence of a new point of stress concentration just below the expansion joint, which is apparently caused by that joint. No stress concentration values are given since scaling does not permit the construction of a structural model to represent this area. The presence of the stress concentration, however, indicates that the designer must exercise care when he considers the use of expansion joints.

A test was also performed on a model simulating the end of the deckhouse as shown in Figure 2. This test produced stress concentrations of 2.7 without wobble plates. These values were reduced by the addition of wobble plates; see Figures 6c and 6d.

THE STRAIN-GAGED STEEL MODEL STUDY

After completion of the photoelastic tests, the study was extended to examine shear effects. The loads necessary to produce shear cause compressive stresses in the model and, therefore, the tests were conducted on a model fabricated from a 14-in. wide flange, 30-lb/ft steel beam. This beam was chosen because it had the proper scaled flange to web inertia ratio. This first steel model (see Figure 8) was instrumented with strain gages and loaded as shown in Figure 9. Strain was measured at the locations shown in Figure 10 at each load increment before and after expansion joints were cut and strain sensitivities were determined. These sensitivities were compared to strain sensitivities calculated for this beam without openings. Figure 10 lists the results of these tests.

The test program just described considers stresses in the sides of the deckhouse model. Tests were also conducted to determine the stress distribution in the top of the deckhouse. These tests were performed on a steel beam modified as shown in Figure 11. Prior to testing, the beam was instrumented extensively with strain gages; see Figure 12. Strain sensitivities were determined for both pure moment and pure shear at the center opening. The tests were repeated six times to determine the changes in strain sensitivity as expansion joints were added. The results of this series of tests are shown in the Appendix and are summarized in Figure 13. As shown in this figure, the average strain before adding expansion joints is very close to the value calculated from the flexure formula.

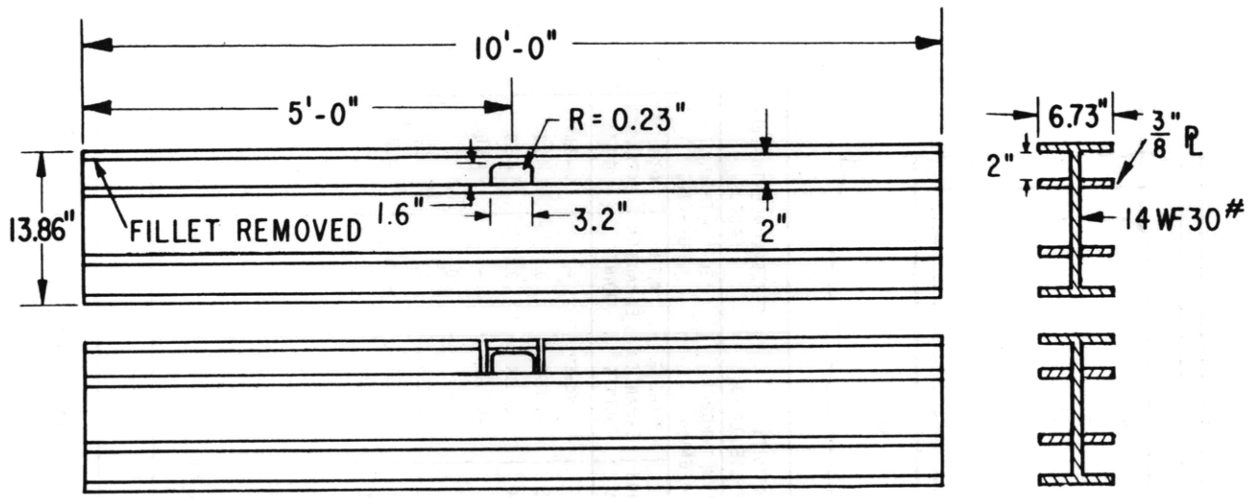


Figure 8 - First Steel Model

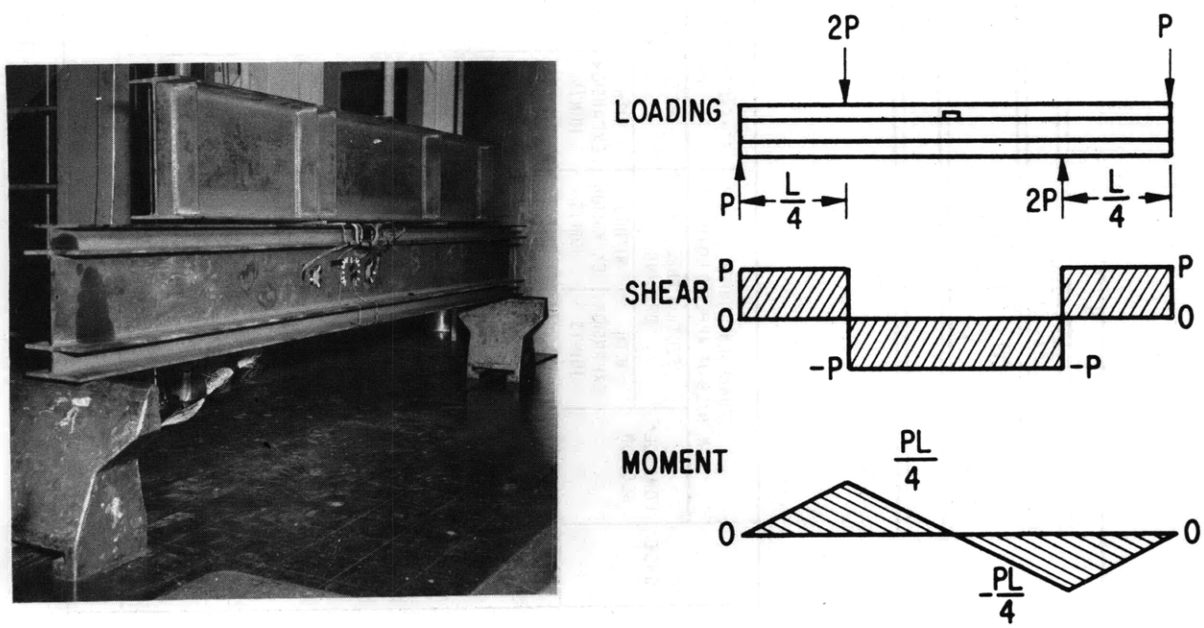
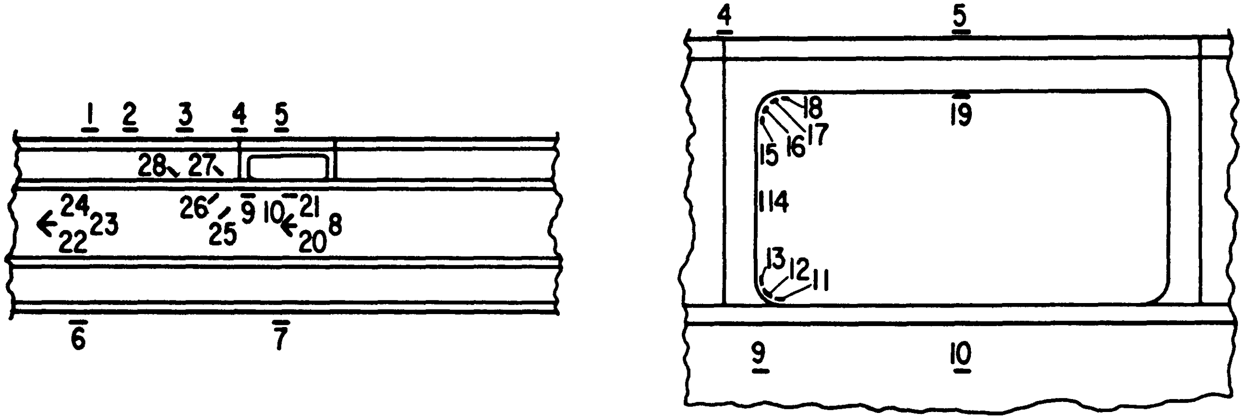


Figure 9 - Loading of First Steel Model in TMB
600,000-Pound Testing Machine



GAGE	STRAIN SENSITIVITY µIN/IN/LB OF APPLIED LOAD			STRESS CONCENTRATION FACTOR		GAGE	STRAIN SENSITIVITY µIN/IN/LB OF APPLIED LOAD			STRESS CONCENTRATION FACTOR	
	CONTROL* SECTION	SECTION THROUGH OPENING		SECTION THROUGH OPENING			CONTROL SECTION	SECTION THROUGH OPENING		SECTION THROUGH OPENING	
		WITH EXPANSION JOINTS	WITHOUT EXPANSION JOINTS	WITH EXPANSION JOINTS	WITHOUT EXPANSION JOINTS			WITH EXPANSION JOINTS	WITHOUT EXPANSION JOINTS	WITH EXPANSION JOINTS	WITHOUT EXPANSION JOINTS
1	0	0.0019	0.0022	-	-	15	0.0019	-	-0.0068	-	-3.6
2	0	0.0007	0.0012	-	-	16	0.0019	0.0005	-0.0096	0.3	-5.0
3	0	0	0.0004	-	-	17	0.0019	0.0004	-0.0114	0.2	-6.0
4	0	-	0.0016	-	-	18	0.0019	-	-0.0096	-	-5.0
5	0	0	0	-	-	19	0.0019	0	0	0	0
6	0	-0.0021	-0.0021	-	-	20	0.0036	0.0060	0.0055	1.7	1.5
7	0	0	0	-	-	21	0.0036	-0.0056	-0.0053	-1.6	-1.5
8	0	0.0003	0	-	-	22	0.0036	0.0045	0.0040	1.3	1.1
9	0	0.0003	-0.0012	-	-	23	0	0	-0.0008	0	-
10	0	0	0	-	-	24	0.0036	-0.0046	-0.0054	-1.3	-1.5
11	0.0022	0.0031	0.0090	1.4	4.1	25	0.0038	-0.0048	-		-
12	0.0022	0.0009	0.0148	0.4	6.7	26	0.0038	0.0028	-		-
13	0.0022	-0.0011	0.0149	-0.5	6.8	27	0.0021	0.0048	-		-
14	0.0020	-	0.0008	-	0.4	28	0.0021	0.0039	-		-

*Calculated from similar beam with no opening.

Figure 10 - Results of Tests to Determine Shear Stress Concentration Factors

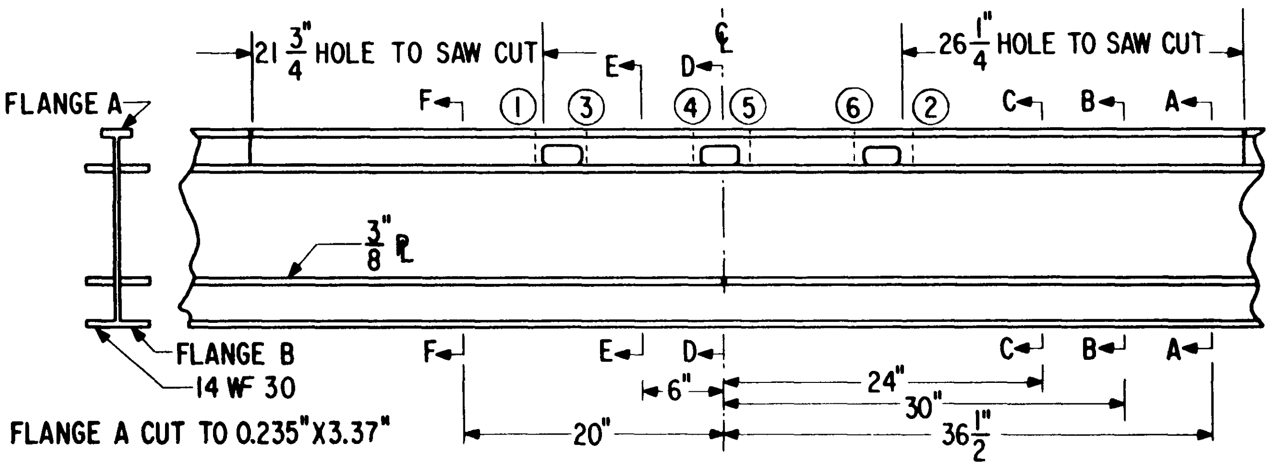


Figure 11 - Second Steel Model

Numbers in circles indicate order in which expansion joints were added.

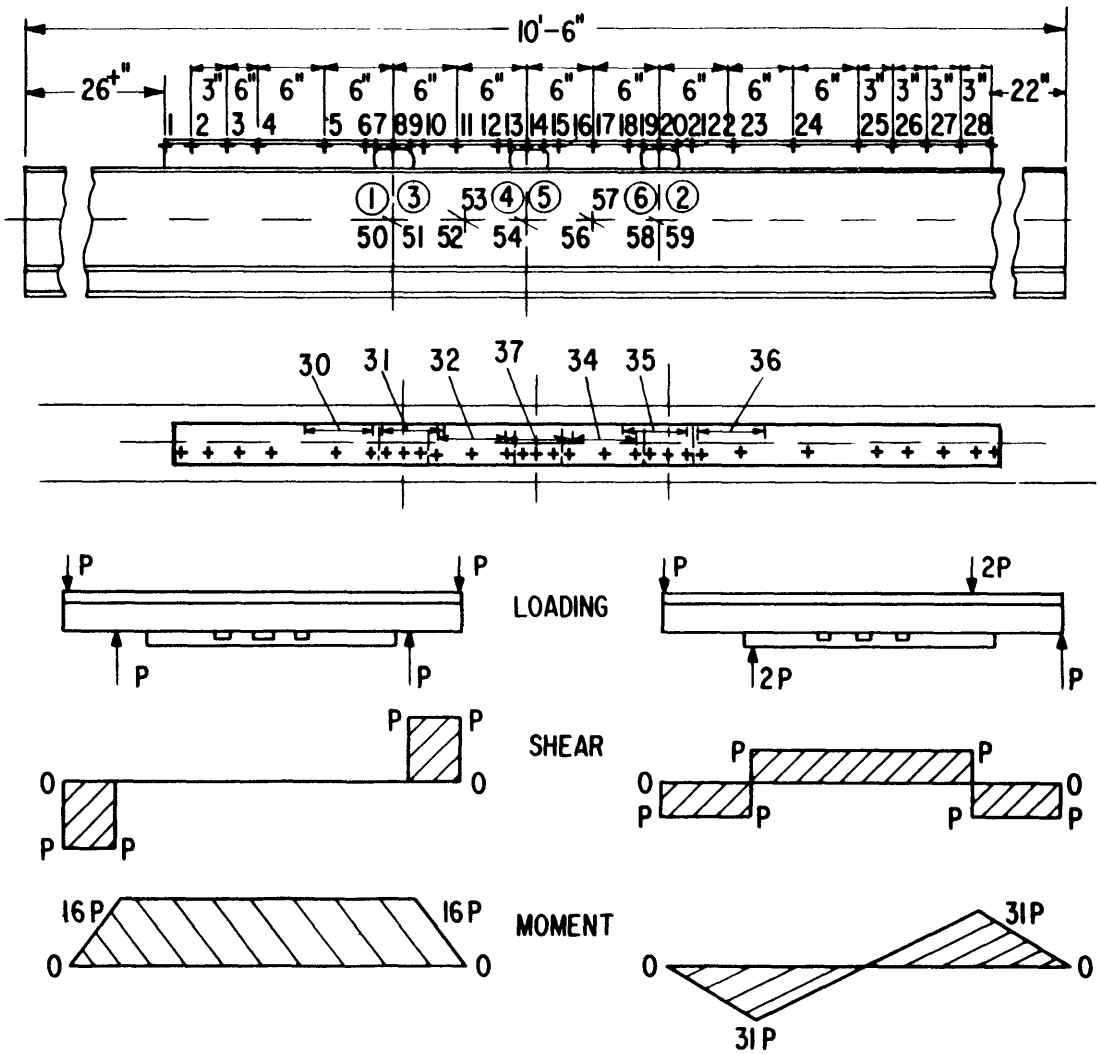


Figure 12 - Location of Strain Gages and Load Points
for Tests of Second Steel Model

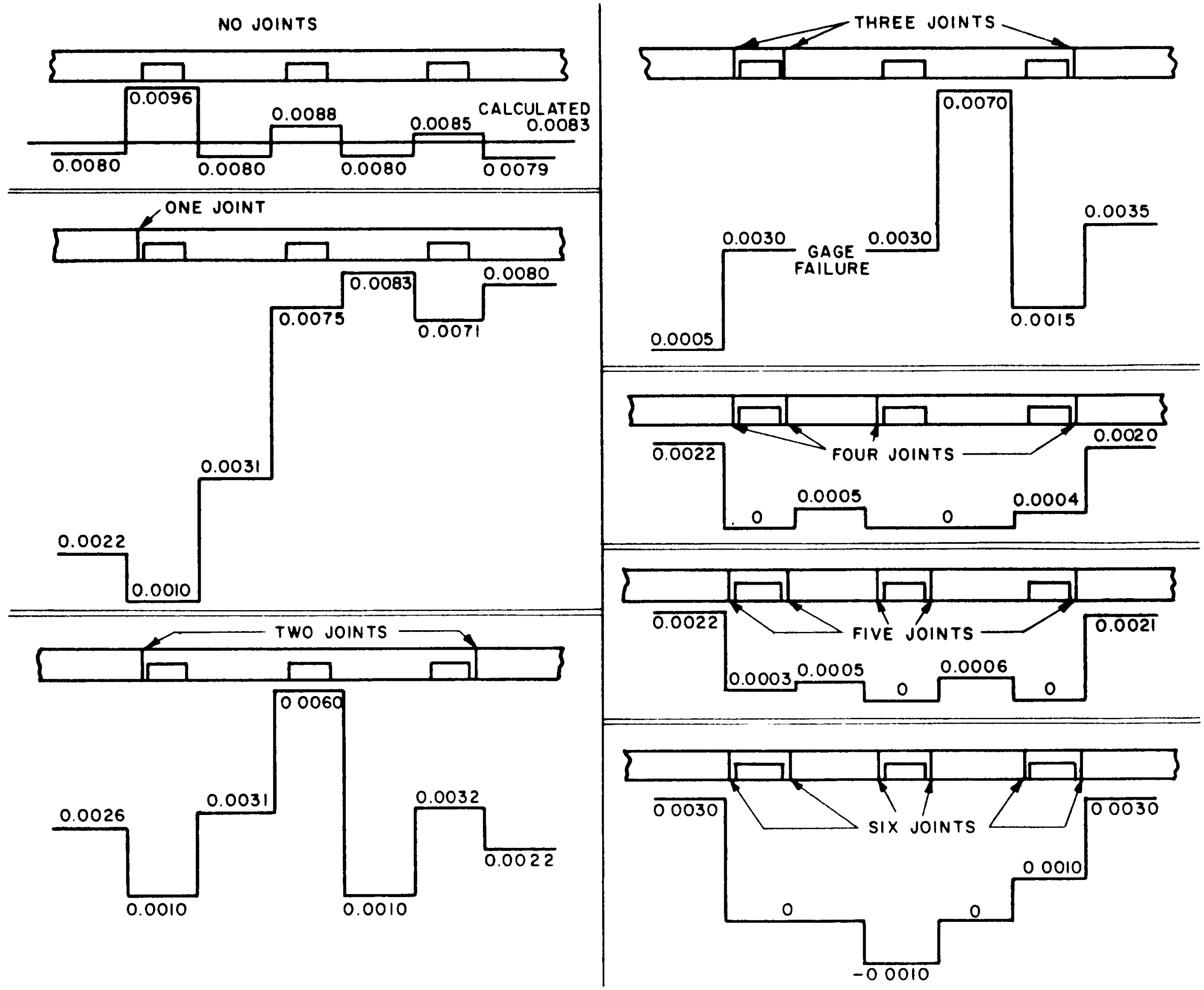


Figure 13 - Strain Sensitivities in Top Flange of Second Steel Model as Determined from 6-Inch Strain Gages

DISCUSSION OF PROGRAM

The tests indicate stress concentrations of 6.8 and 2.6 for shear and moment, respectively. The use of reinforcement such as insert plates and combing will reduce these values to 4.6 and 1.8,* which are still significant. The addition of expansion joints to isolate the deckhouse from the hull girder will eliminate the concentrations in the deckhouse openings completely, therefore, indicating that this design is superior. Expansion joints are very costly to install and maintain, however, and their presence introduces a new stress concentration of unknown magnitude. Therefore, the better design should be based on stress, safety, and economy, and may be determined by examining these factors for a structure with and without expansion joints as follows: The maximum hull bending stress for the AOE with the hull isolated from the deckhouse is 12,500 psi,** which increases locally at the expansion joints to about 19,000 psi or 57 percent of yield (assuming a stress concentration of 1.5 for the expansion joint and a yield of 35,000 psi for medium steel). The maximum combined stress at the same station for a structure without expansion joints is 14,000 psi. This basic value increases to a maximum of 26,000 psi at the maximum stress point. If insert plates are made of high tensile steel (47,000-psi yield strength), this local stress is 55 percent of the yield, which is the same order of magnitude as the stresses produced in the first structure. The maximum combined stress near the opening when the model is subjected to maximum shear loading is 27,600 psi or 59 percent of the HTS yield value. The above stress calculations indicate comparable factors of safety (percent yield) for the two designs. Therefore, the decision to use or omit expansion joints should be governed primarily by cost factors.

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*E. M. MacCutcheon, et al., "Effects of Contours, Face Plates, and Reinforced Insert Plates on the Stress Concentrations around Large Openings in Ship Sides as Determined from Tests on a 1/40-Scale Structural Model of an Aircraft Carrier," David Taylor Model Basin Report C-327 (Mar 1951) CONFIDENTIAL.

**Calculation based on data given on BuShips Plan AOE 800-1934456.

Throughout this report, loading configurations have been indicated but the magnitude of these loads has been omitted. As already stated, it was necessary to use two different scales for each model and as a result it is almost impossible to predict prototype stresses from model stresses; therefore, the loads applied to the model are not given. It is noted that these loads were low enough to ensure elastic response of the models.

SUMMARY AND CONCLUSIONS

Since facilities at the Model Basin are limited, only the overall aspects of this problem could be studied. However, within the limitations of the approach, the following qualified conclusions are drawn:

1. The stress concentration factors introduced by an opening scaled to represent the cargo door openings on AOE are 2.6 for loading causing pure moment at the test section and 6.8 for loading causing pure shear at the test section.

2. Cargo door spacing of four times the opening width are sufficient to isolate the stress concentration effects of one opening of this shape from the adjacent openings, i.e., to prevent opening interaction.

3. The use of expansion joints and wobble plates greatly reduces the stress concentrations but adds new concentrations which cannot be overlooked by the designer.

4. The use of inserts and opening reinforcement will reduce the stress concentration levels sufficiently so that expansion joints may be eliminated in future AOE's.

ACKNOWLEDGMENTS

The author wishes to thank all the Model Basin personnel who participated in these tests. In particular, the assistance of Mr. J. S. Brock in the photoelastic phase is gratefully acknowledged.

APPENDIX

STRAINS RECORDED ON SECOND STEEL MODEL

Strain Sensitivities Measured in the Top Flange of the Second Steel Model

All values in μin/in/lb of machine load

Gage	No Exp. Joints		One Exp. Joint		Two Exp. Joints		Three Exp. Joints		Four Exp. Joints		Five Exp. Joints		Six Exp. Joints	
No.	Moment	Shear	Moment	Shear	Moment	Shear	Moment	Shear	Moment	Shear	Moment	Shear	Moment	Shear
1	-0.0005	-0.0010	-0.0010	-0.0006	-0.0008	-0.0006	-0.0004	-0.0010	-0.0010	-0.0008	-0.0008	-0.0010	-0.0009	-0.0010
2	+0.0034	+0.0044	+0.0028	+0.0046	+0.0030	+0.0048	+0.0036	+0.0050	+0.0032	+0.0042	+0.0030	+0.0042	+0.0030	+0.0042
3	+0.0036	+0.0042	+0.0045	+0.0050	+0.0042	+0.0050	+0.0042	+0.0050	+0.0032	+0.0045	+0.0035	+0.0048	+0.0036	+0.0048
4	+0.0070	+0.0071	+0.0063	+0.0070	+0.0060	+0.0070	+0.0065	+0.0072	+0.0059	+0.0053	+0.0060	+0.0068	+0.0055	+0.0068
5	+0.0075	+0.0049	+0.0032	+0.0030	+0.0032	+0.0030	+0.0035	+0.0030	+0.0029	+0.0028	+0.0035	+0.0038	+0.0031	-0.0005
6	+0.0085	+0.0047	-0.0008	-0.0005	-0.0005	-0.0002	-0.0005	-0.0005	-0.0010	-0.0004	0.0000	-0.0005	-0.0009	0.0000
7	+0.0085	+0.0050	-0.0010	0.0000	-0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	+0.0080	+0.0036	+0.0010	0.0000	+0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	+0.0088	+0.0025	+0.0025	0.0000	+0.0022	+0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	+0.0100	+0.0042	0.0000	0.0000	0.0000	0.0000	-0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	+0.0075	+0.0014	+0.0038	0.0000	+0.0035	0.0000	+0.0040	+0.0005	+0.0008	0.0000	+0.0010	+0.0005	+0.0006	0.0000
12	+0.0100	0.0000	+0.0085	0.0000	+0.0075	0.0000	+0.0080	+0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	+0.0088	+0.0010	+0.0065	0.0000	+0.0062	0.0000	+0.0065	+0.0010	-0.0010	0.0000	0.0000	0.0000	0.0000	0.0000
14	+0.0080	-0.0004	+0.0070	0.0000	+0.0055	0.0000	+0.0070	+0.0005	0.0000	0.0000	-0.0004	0.0000	0.0000	0.0000
15	+0.0090	-0.0015	+0.0087	-0.0010	+0.0064	0.0000	+0.0070	0.0000	+0.0016	0.0000	0.0000	0.0000	0.0000	0.0000
16	+0.0095	-0.0008	+0.0083	0.0000	+0.0075	0.0000	+0.0080	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17	+0.0074	-0.0020	+0.0072	-0.0014	+0.0040	0.0000	+0.0042	0.0000	+0.0010	0.0000	+0.0010	-0.0005	0.0000	0.0000
18	+0.0100	-0.0042	+0.0096	-0.0036	0.0000	0.0000	+0.0005	0.0000	+0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
19	+0.0090	-0.0025	+0.0082	-0.0022	+0.0025	0.0000	+0.0030	0.0000	+0.0020	0.0000	+0.0020	-0.0008	0.0000	0.0000
20														
21	+0.0084	-0.0049	+0.0080	-0.0045	-0.0015	+0.0010	-0.0012	+0.0005	-0.0010	+0.0005	-0.0010	0.0000	-0.0003	0.0000
22	+0.0099	-0.0028	+0.0100	-0.0042	-0.0010	+0.0010	-0.0005	+0.0005	-0.0008	+0.0006	0.0000	+0.0004	-0.0010	0.0000
23	+0.0078	-0.0059	+0.0074	-0.0042	+0.0035	-0.0025	+0.0038	-0.0028	+0.0030	-0.0025	+0.0030	-0.0025	+0.0032	-0.0024
24	+0.0076	-0.0072	+0.0076	-0.0060	+0.0066	-0.0055	+0.0070	-0.0068	+0.0063	-0.0055	+0.0064	-0.0058	+0.0065	-0.0058
25	+0.0072	-0.0065	+0.0072	-0.0065	+0.0068	-0.0028	+0.0072	-0.0030	+0.0065	-0.0050	+0.0070	-0.0031	+0.0065	-0.0024
26	+0.0065	-0.0078	+0.0065	-0.0055	+0.0062	-0.0055	+0.0065	-0.0060	+0.0059	-0.0057	+0.0065	-0.0060	+0.0064	-0.0061
27	+0.0050	-0.0066	+0.0052	-0.0050	+0.0045	-0.0045	+0.0052	-0.0052	+0.0045	-0.0045	+0.0050	-0.0052	+0.0051	-0.0054
28	+0.0021	-0.0022	+0.0014	-0.0010	+0.0015	-0.0008	+0.0016	-0.0015	+0.0014	-0.0012	+0.0012	-0.0014	+0.0011	-0.0015
29	+0.0010	0.0000	-0.0005	0.0000	+0.0010	+0.0010	0.0000	+0.0010	-0.0009	+0.0006	-0.0005	+0.0005	-0.0010	+0.0006
50	+0.0007	+0.0062	+0.0020	+0.0070	+0.0015	+0.0075	+0.0028	+0.0068	+0.0023	+0.0057	+0.0020	+0.0068	+0.0010	+0.0068
51	+0.0006	+0.0035	+0.0010	+0.0045	+0.0008	+0.0050	+0.0026	+0.0048	+0.0003	+0.0050	+0.0010	+0.0048	0.0000	+0.0045
52	+0.0005	+0.0042	+0.0020	+0.0045	+0.0015	+0.0050	+0.0010	+0.0045	+0.0014	+0.0038	+0.0015	+0.0045	0.0000	+0.0042
53	+0.0005	+0.0034	+0.0010	+0.0045	+0.0008	+0.0050	+0.0022	+0.0048	0.0000	+0.0042	0.0000	+0.0040	0.0000	+0.0042
54	+0.0005	+0.0055	+0.0010	+0.0055	+0.0008	+0.0062	+0.0010	+0.0055	+0.0018	+0.0050	+0.0012	+0.0055	+0.0010	+0.0052
55	0.0000	+0.0040	0.0000	+0.0045	0.0000	+0.0050	+0.0015	+0.0050	0.0000	+0.0042	+0.0007	+0.0040	0.0000	+0.0045
56	+0.0005	+0.0045	+0.0010	+0.0045	0.0000	+0.0055	0.0000	+0.0048	+0.0015	+0.0046	+0.0012	+0.0050	+0.0008	+0.0048
57	+0.0005	+0.0038	0.0000	+0.0045	-0.0010	+0.0050	+0.0005	+0.0042	0.0000	+0.0045	+0.0006	+0.0044	0.0000	+0.0038
58	0.0000	+0.0042	+0.0010	+0.0045	+0.0012	+0.0045	-0.0010	+0.0048	+0.0015	+0.0041	+0.0014	+0.0044	+0.0010	+0.0040
59	+0.0002	+0.0032	0.0000	+0.0050	+0.0008	+0.0050	+0.0020	+0.0022	0.0000	+0.0041	+0.0010	+0.0044	0.0000	+0.0040
30	+0.0078	+0.0050	+0.0025	+0.0022	+0.0022	+0.0025	+0.0005	out	+0.0023	+0.0016	+0.0023	+0.0020	+0.0030	+0.0021
31	+0.0085	+0.0032	+0.0010	0.0000	+0.0010	0.0000	+0.0030	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
32	+0.0079	+0.0025	+0.0030	0.0000	+0.0025	0.0000	out	0.0000	+0.0005	0.0000	+0.0005	0.0000	0.0000	0.0000
33	+0.0088	0.0000	+0.0075	0.0000	+0.0060	0.0000	+0.0030	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0011	0.0000
34	+0.0080	-0.0035	+0.0082	-0.0026	+0.0010	0.0000	+0.0070	0.0000	0.0000	0.0000	+0.0005	0.0000	0.0000	0.0000
35	+0.0096	-0.0022	+0.0070	-0.0015	+0.0032	0.0000	+0.0015	0.0000	+0.0006	0.0000	+0.0004	0.0000	+0.0010	0.0000
36	+0.0080	-0.0035	+0.0080	-0.0040	+0.0022	-0.0018	+0.0035	-0.0020	+0.0020	-0.0017	+0.0020	-0.0015	+0.0029	-0.0020

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This report presents a model testing method from which relative stress concentration factors were determined. This method used steel and photoelastic models representing the side of a deckhouse with simulated cargo door openings with and without expansion joints. A high-speed cargo ship (AOE) was the prototype design from which the models were scaled. Loads causing pure bending produced stress concentrations in the order of 2.6 for the model without expansion joints and less than 1 when expansion joints were included. However, the stress gradient in the vicinity of the expansion joint is such that the magnitudes of stress concentration for this structure are still unknown. A much larger scale model would be required to study this detail. It was concluded from the model tests that deckhouse construction (of the AOE type) without expansion joints is superior to that with expansion joints

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