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STATIC TENSILE TEST OF A 3000-POUND LIGHTWEIGHT ANCHOR, TYPE (LWT), MARK II, ASSEMBLY 1

by

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[redacted]

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PERSONNEL

The tests described in this report were conducted by J.W. Day, with the assistance of C.A. Wagley, E.P. Donoghue, C.L. Pittiglio, and F.W. Bird, all of the David Taylor Model Basin. The report is the work of J.W. Day.

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ABSTRACT

Static tensile tests were performed on a 3000-pound lightweight anchor, Type (LWT), Mark II, Assembly 1, designed especially by the Bureau of Ships for use on minesweepers and patrol and landing craft. The anchor was made of cast silicon-manganese steel by the Navy Yard, Norfolk.

The anchor was loaded in tension through the shackle and the fluke points, simulating the severest service conditions. Strain measurements were taken on the extreme fibers of a number of sections of the shank, on each of the two flukes, and on the sides of the crown.

The measured strains were in good agreement with the computed values for the respective sections. The measurements taken at the proof load of 55,000 pounds indicated that strains in the side webs of the crown-stop structure had reached the plastic range. The crown was reinforced with welded plates and the test was carried to destruction. The shank broke cleanly off near the stock at a load of 95,000 pounds. By the addition of a relatively small amount of metal to the crown structure the proof strength of the anchor can be greatly increased.

INTRODUCTION

The present approved designs for commercial anchors do not adequately fulfill the requirements for a lightweight anchor for use on minesweepers and on patrol and landing craft. For this reason the Bureau of Ships designed two new lightweight anchors, known as Type (LWT), Marks I and II, to provide non-fouling characteristics and high holding power, which incorporated simplicity of design and ease of manufacture. The Bureau requested (1)* that the Navy Yard, Norfolk, test the holding power of these new designs so that the better one might be adopted as a standard.

After the holding power of the anchors in sand bottom had been tested, the Bureau of Ships requested (2) that the David Taylor Model Basin undertake static tensile tests of the Mark II anchor, Assembly 1, to provide stress data, to determine the breaking load of the anchor, and to verify the accuracy of the design computations.

As there was no standard method for the strength tests of lightweight anchors, it was planned to establish such a standard on this occasion. The Northill Company, a contracting manufacturer, had cast some 500-pound

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* Numbers in parentheses indicate references on page 12 of this report.

anchors and had tested them by wedging a railroad rail between the flukes and the shank and pulling the anchor against the rail on the horizontal bedplate of a testing machine. Little bending action was induced in the anchor members by this test, which did not simulate service conditions. Northill also conducted some tests by loading the anchor in a vertical testing machine with clamping plates attached to the ends of the flukes; various widths of plates were used, which produced different conditions of bending in the specimen. The Northill method was abandoned in favor of point loading of the flukes, since it permitted investigation of sections near the fluke points.

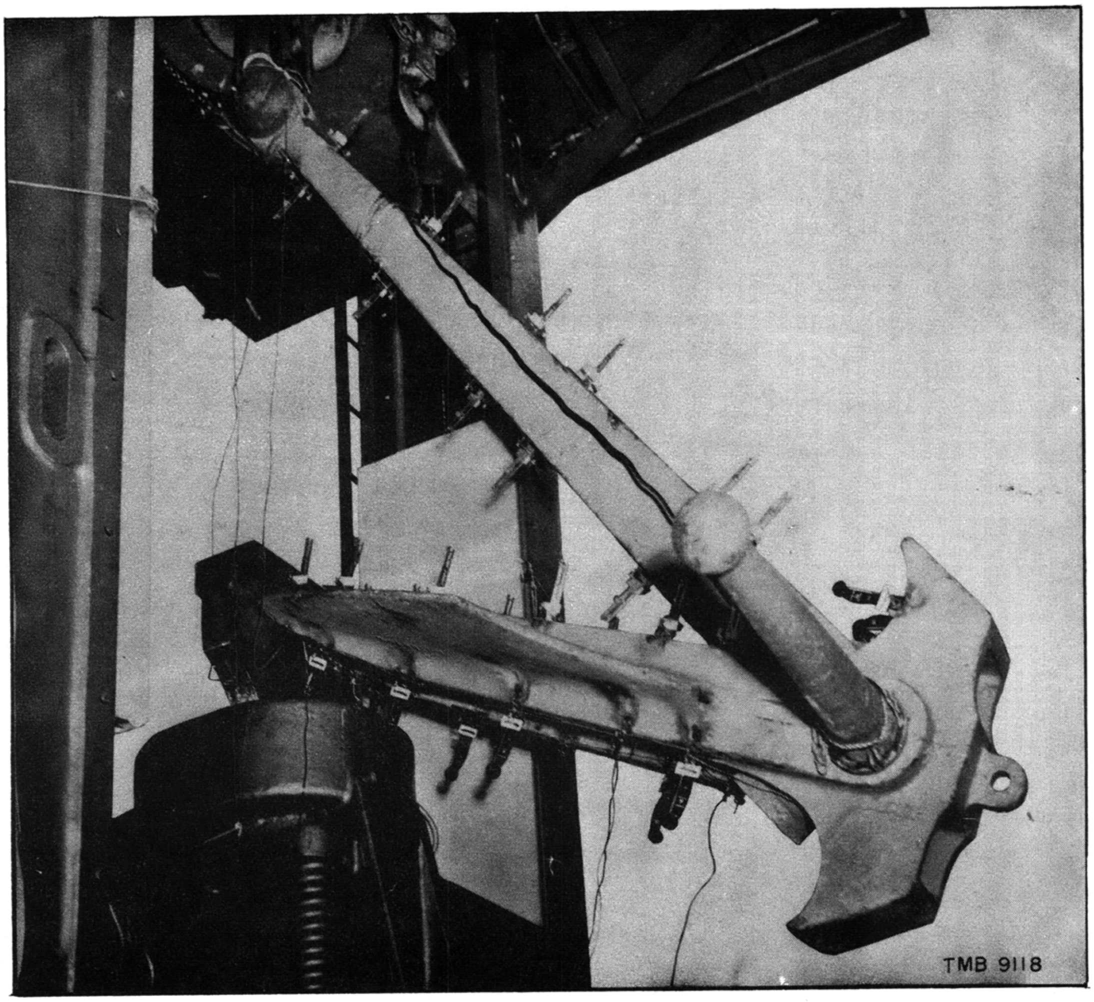


Figure 1 - Side View of Anchor Mounted for Tensile Loading Test

A tensile load was applied to the anchor by the crossheads of the testing machine, acting to open out the flukes and shank. The component of the load which acted normal to the neutral plane of the shank set up bending stresses in the shank, and the component of the load parallel to the neutral plane of the shank set up tensile stresses in the shank. The component of the load normal to the neutral plane of the flukes set up bending stresses in the flukes, and the component of the load parallel to the neutral plane of the flukes set up compressive stresses in the flukes. The tensometers and SR-4 Type A-1 metalectric strain gages, shown mounted on the anchor members, measured the combined strains in the extreme fibers of the sections.

The original pilot model of the 3000-pound lightweight anchor, Mark II, Assembly 1, was cast in silicon-manganese steel at the Navy Yard, Norfolk. This specimen anchor was shipped to the David Taylor Model Basin for test as outlined in Reference (2).

TEST PROCEDURE

The anchor was prepared for testing in the 600,000-pound universal machine as shown in Figures 1 and 2. Huggenberger tensometers and SR-4 metalectric strain gages, Type A-1, were mounted on the shank, flukes, and crown members of the anchor at sections where the stresses had previously been computed in design of the anchor; see Figure 3.

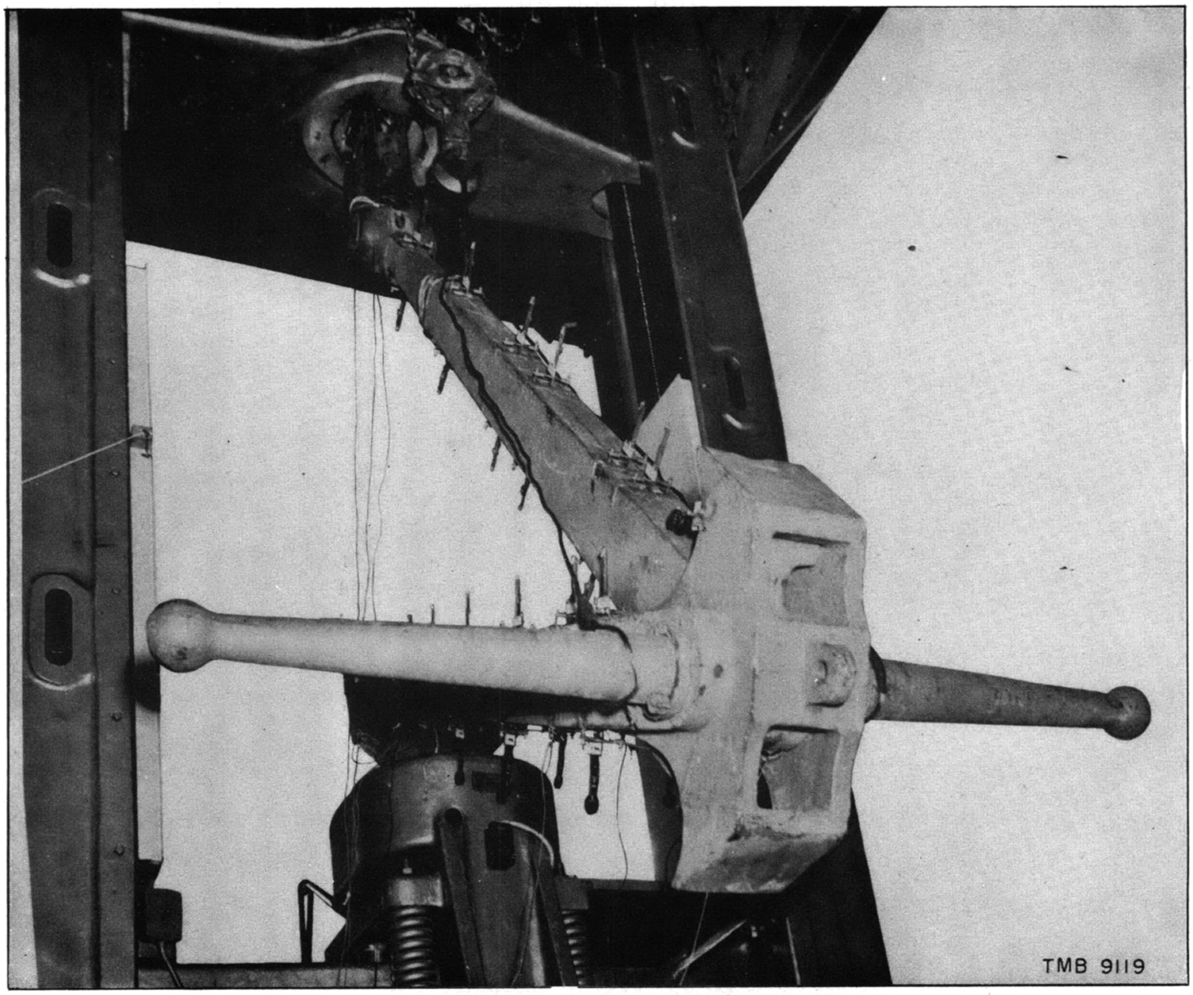
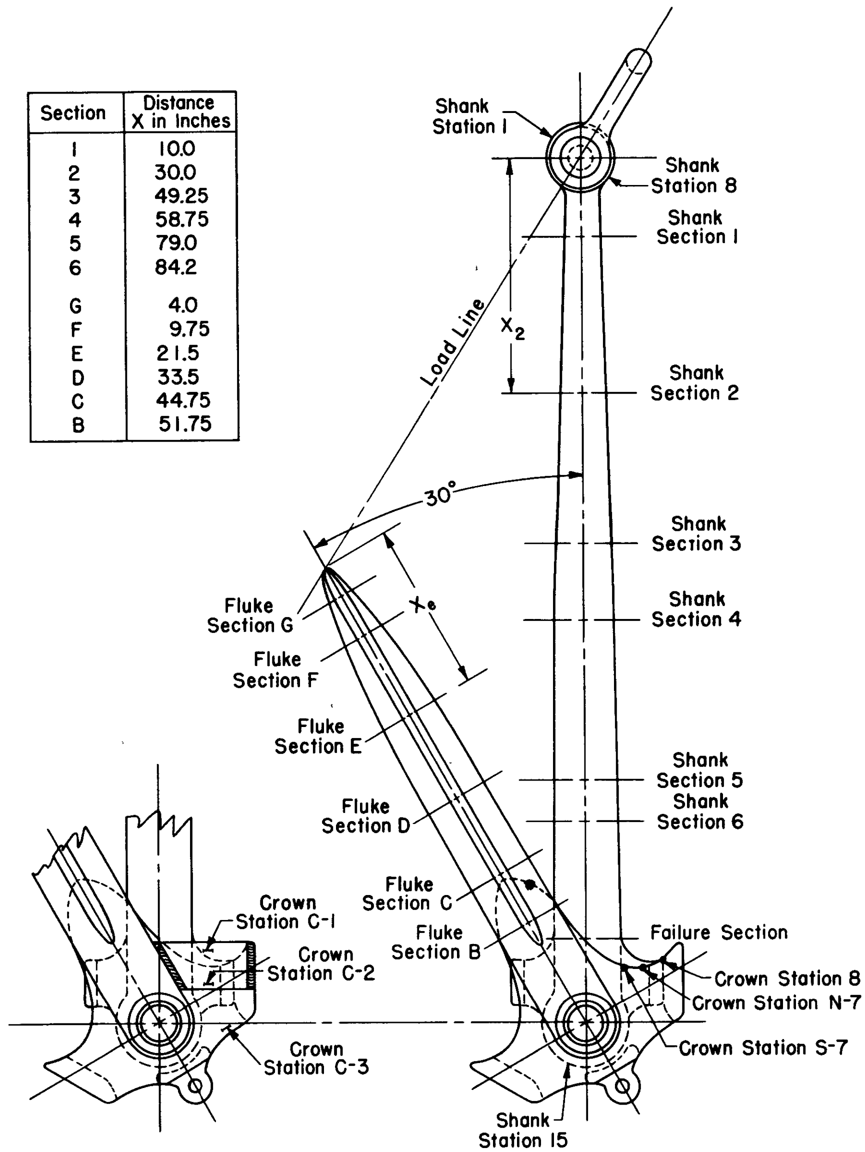


Figure 2 - Oblique View of Anchor Mounted for Tensile Loading Test

The crown is shown here in detail, also the manner in which the shank boss bears on the inner surface of the crown, to limit the angle between the shank and the flukes. The SR-4 metalectric strain gages on the shackle-pin ring of the shank and on the lower side of the hinge ring are shown here.



Section	Distance X in Inches
1	10.0
2	30.0
3	49.25
4	58.75
5	79.0
6	84.2
G	4.0
F	9.75
E	21.5
D	33.5
C	44.75
B	51.75

Figure 3 - Diagram Showing Strain Gage Positions

Preliminary tests of the anchor under small loads showed that the shank stops bore unevenly on the crown-stop surfaces,* which caused unequal strains in the two sides of the crown. Shims were inserted between the shank stop and the crown to make the stop bear more uniformly.

In the first regular test, designated as Test 1, the anchor was loaded up to 60,000 pounds. At a load of 54,000 pounds yielding occurred in the curved or tension edge of one side of the crown, in way of Crown Station S-7; see Figure 3 and Table 1. This threw more load on the other side of the crown, which yielded at Station N-7 at a load of 60,000 pounds.

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* These surfaces were intended to match each other in the "as cast" condition.

At the oral request of representatives of the Bureau of Ships, reinforcing plates were welded to the sides of the crown so that the tests could be continued to determine the strength of the other sections of the anchor members. The reinforcing plates are shown in the photograph, Figure 4. Test 2 was then conducted, at suitable load increments, to 90,000 pounds. To determine the increase in angle between the flukes and the shank with increase in load, a convenient reference point was marked on the inside surface of one fluke a few inches from the end, and another reference point was marked on the side of the shank about one third of the distance from the shackle ring to the stock hinge. Trammels were used to measure the distance between these reference points for each load applied. Gage and trammel data were recorded for each load increment.

The anchor failed suddenly in the shank near the crown at a load of 95,000 pounds. Large flaws were found in the section at which failure occurred, as can be seen in Figures 5 and 6.

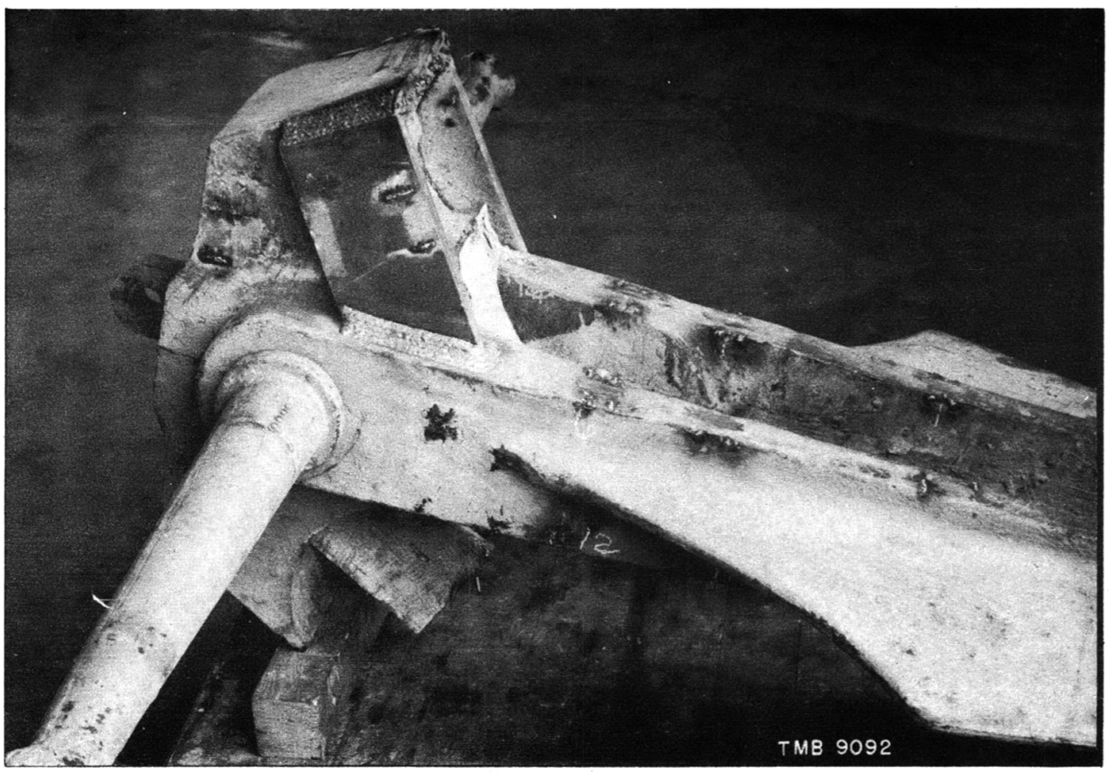


Figure 4 - View of Flukes, Crown, Stock, and Fractured Shank after Testing

During the first part of the test the side webs of the crown stops yielded at a load of 54,000 pounds, corresponding to a stress of 60,250 pounds per square inch in the extreme fibers. Two reinforcing plates 1 inch thick and 6 inches wide were welded to the sides of the crown as shown, and the tests were continued.

A wood wedge, not a part of the anchor, is shown driven between the shank and the lower stop of the crown to hold the parts in position for this photograph; see Figure 5.

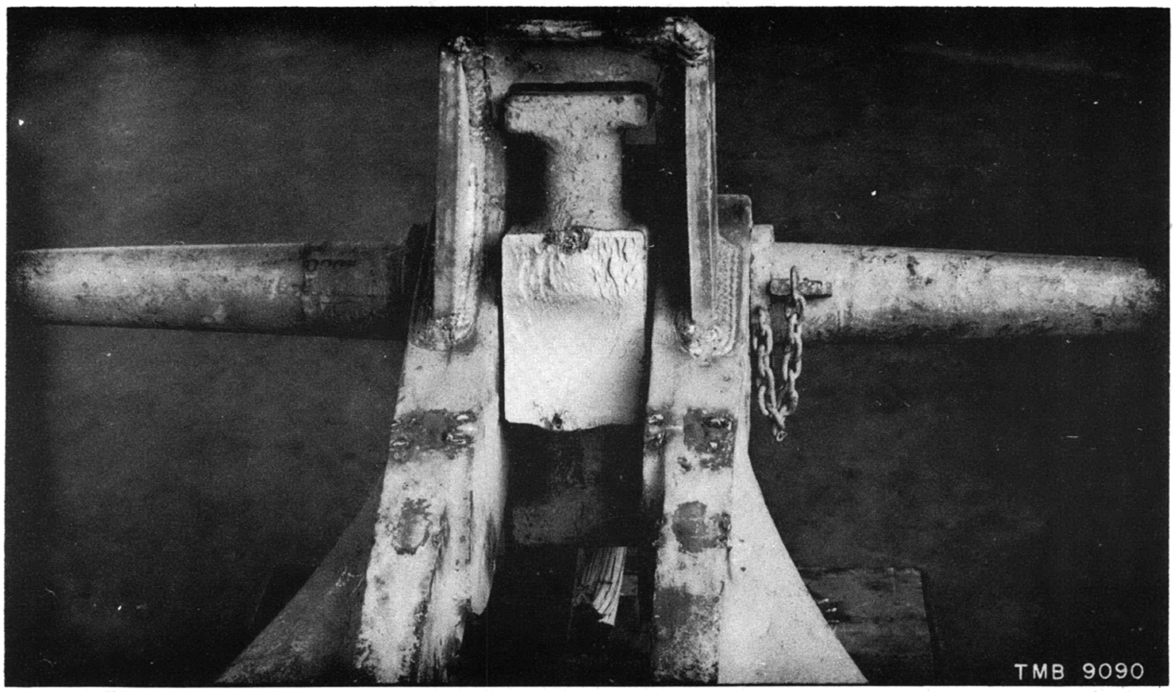


Figure 5 - View of Anchor after Tensile Loading Test

Figure 6 - View of Shank Failure Section after Tensile Loading Test

This closeup shows the flaw areas in detail. The fractured section measured 55 square inches in area, of which 2.6 square inches, or roughly 5 per cent, was not sound metal. The maximum stress in the extreme fibers of the section was computed as 69,100 pounds per square inch. Initial failure occurred at the lower flaw area, which was under tension from the bending action caused by the loading. The failure occurred at a load of 95,000 pounds.

The lines on the broken surface radiating from this defect would make it possible to determine the starting point of the fracture even if it were not known from other considerations.

TEST RESULTS

Table 1 lists the loads at which the elastic limit was reached and yielding occurred in the crown of the anchor during Test 1.

Table 2 gives the maximum stresses at all sections at which strain data were taken for the top load of 60,000 pounds in Test 1.

The results of a tensile-coupon test of the anchor metal, made at the Norfolk Navy Yard, are given in Table 3.

Figure 7 contains the diagram of load components at the specified proof load of 55,000 pounds on the anchor. A comparison of the computed and measured maximum fiber stresses in the various sections is given in Table 4.

Table 5 shows the loads at which the elastic limit was reached and at which yielding occurred in the various sections during Test 2.

When carried beyond the proof load, the shank failed near the crown at a load of 95,000 pounds. This corresponds to a maximum fiber stress of approximately 70,000 pounds per square inch at the section where failure occurred.

DISCUSSION OF RESULTS

The crown proved by test to be the weak point in the structure of the anchor. The metal in one of the crown-stop side webs yielded at a load of 54,000 pounds, slightly less than the proof load. The metal in the other crown web yielded at a load of 60,000 pounds. Had the loading been equal on both sides of the crown stop the yield strength of the crown might have been reached at a load slightly greater than the proof load of 55,000 pounds. The proof strength of the anchor can be greatly increased by increasing the strength of the crown-stop structure.

TABLE 1

Loads at Which Elastic Limit and Yielding Occurred in the Crown, Test 1

Strain Gage Station Figure 3	Load in pounds	Maximum Tensile Fiber Stress* lb/in^2	Condition at Section
S-7	50,000	51,500	Elastic Limit**
S-7	54,000	60,250	Yielding
N-7	56,000	54,000	Elastic Limit
N-7	60,000	61,000	Yielding

* Stresses were derived from strains by the use of the slope of the load-strain curves and an assumed modulus of elasticity of 30,000,000 pounds per square inch.

** Elastic Limit is defined here as the limit of stress intensity within which a material will return to its original size and shape when the load is removed, and hence not take a permanent set.

TABLE 2

Stresses in Members at a Load of 60,000 Pounds, Test 1

Strain Gage Station Figure 3	Tensile Stress* in Extreme Fiber lb/in^2	Compressive Stress* in Extreme Fiber lb/in^2
Shank		
Section 1	40,200	28,400
2	40,500	38,700
3	43,200	35,100
4	42,000	33,250
5	42,000	39,900
6	43,200	42,600
Fluke N		
Section G	25,500	27,300
F	30,000	25,750
E	30,900	28,500
D	37,200	36,900
C	38,100	30,600
B	32,100	27,500
Fluke S		
Section G	23,100	26,100
F	26,100	24,250
E	31,800	27,000
D	33,300	36,000
C	38,700	32,000
B	26,000	38,100
Shank 15	16,500	

* Stresses were derived from strains by the use of the slope of the load-strain curves and an assumed modulus of elasticity of 30,000,000 pounds per square inch.

TABLE 3

Tensile Coupon Test of Anchor Metal at Navy Yard, Norfolk

Coupon Location	Yield Strength lb/in^2	Ultimate Strength lb/in^2
Shank	57,500	79,500
Fluke	61,000	89,500

Table 2 gives the stress conditions in all sections of the anchor where strains were measured at a load of 60,000 pounds. The maximum fiber stresses in the shank are higher on the tension side of the plane of the neutral axis than on the compression side. The component of the load acting parallel to the plane of the neutral axis, as shown in Figure 7, is tensile and therefore increases the stresses on the tensile side of the neutral axis and reduces the stresses on the compressive side.

In the flukes the situation is reversed, as the component of the load acting parallel to the plane of the neutral axis is compressive, and therefore the maximum compressive fiber stresses should be higher than the tensile stresses. This condition exists for some stations but not for all, as may be noted from the data of Table 2. This apparent discrepancy may be explained by the fact that the magnitude

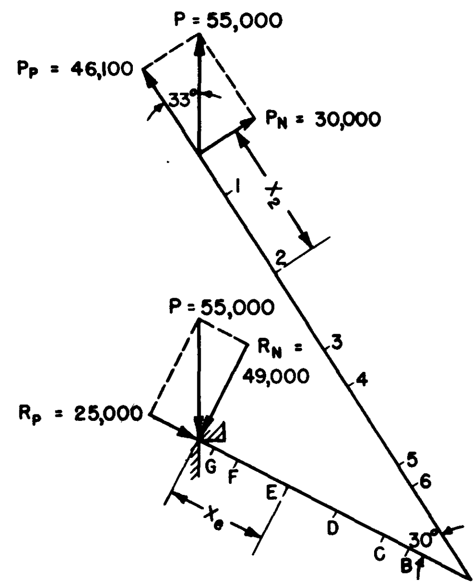


Figure 7 - Diagram of Load Components at the Proof Load of 55,000 Pounds

TABLE 4

Comparison of Computed and Measured Stresses in Members at the Proof Load of 55,000 Pounds

Strain Gage Station Figure 3	Section Area square inches	Moment of Inertia, I, of Section inches[4]	Moment Arm X†	Maximum Fiber Stress in Tension pounds per square inch	
				Computed*	Measured**
Shank					
Section 1	13.6	20.4	10.00	34,600	36,600
2	25.4	71.6	30.00	37,800	37,200
3	34.9	134.8	49.25	38,700	39,600
4	39.9	174.5	58.75	37,750	38,100
5	48.0	256.0	79.00	38,100	37,500
6	50.6	287.0	84.20	37,200	38,400
Fluke					
Section G	21.3	10.6	4.00	26,200	23,300††
F	36.4	40.8	9.75	33,100	24,200
E	67.1	112.4	21.50	32,400	27,000
D	84.3	189.5	33.50	33,000	31,500
C	59.8	264.4	44.75	35,100	30,500
B	69.0	416.0	51.75	26,400	28,400
Crown N-7	28.9	163.8		75,200	60,250

† The moment arm X is shown in Figure 7.

* Computed stresses were derived from the bending components of the load, P_N and R_N of Figure 7. The axial components, P_P/A and R_P/A in Figure 7, were added algebraically.

** Measured stresses were calculated by the use of the slope of the load-strain curves and an assumed modulus of elasticity of 30,000,000 pounds per square inch.

†† These are average tension and compression values for both flukes.

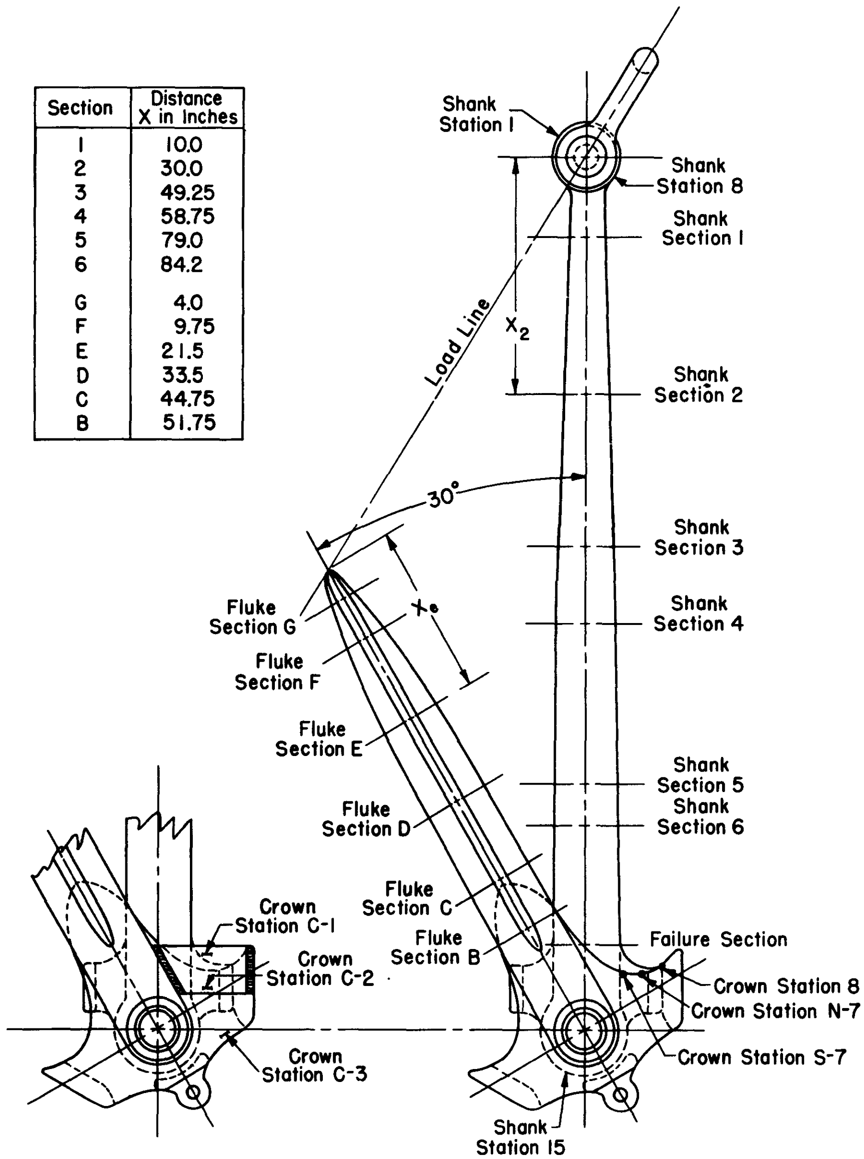
TABLE 5

Stresses in Members at Loads of 70,000 Pounds to 95,000 Pounds, Test 2

Strain Gage Station Figure 3	Load in pounds	Tensile Stress* in Extreme Fiber lb/in²	Load in pounds	Compressive Stress* in Extreme Fiber lb/in²	Condition at Section
Shank					
Section 1	90,000	49,800	90,000	40,500	
2	70,000 80,000	46,200 55,800	85,000 90,000	53,100 58,500	Elastic Limit** Yielding
3	80,000 90,000	57,300 66,300	85,000 90,000	54,600 63,300	Elastic Limit Yielding
4	70,000 80,000	50,700 63,600	82,000 90,000	47,000 56,750	Elastic Limit Yielding
5	72,000 80,000	50,700 60,900	80,000 85,000	52,500 61,200	Elastic Limit Yielding
6	75,000 85,000	51,600 63,600	75,000 80,000	42,250 48,000	Elastic Limit Yielding
Fluke N					
Section G	80,000	26,100	80,000	36,600	
F	90,000	37,800	90,000	39,000	
E	90,000	45,900	95,000	50,700	
D	90,000	56,100	75,000 90,000	37,000 49,000	Elastic Limit Yielding
C	90,000	49,800	90,000	45,300	
B	90,000	41,400	90,000	47,100	
Fluke S					
Section G	75,000	23,400	80,000	29,700	
F	90,000	32,700	90,000	33,000	
E	90,000	41,700	90,000	46,500	
D	90,000	49,800	90,000	54,000	
C	75,000 85,000	46,200 57,900	80,000 90,000	49,200 59,700	Elastic Limit Yielding
B	90,000	45,000	85,000 95,000	54,300 62,700	Elastic Limit Yielding
Welded Plate Crown N-1	90,000	23,500			
2			90,000	14,500	
3			90,000	24,000	
Welded Plate Crown S-1	90,000	25,000			
2			90,000	21,750	
3			90,000	30,000	

* Stresses were calculated by the use of the slope of the load-strain curves and an assumed modulus of elasticity of 30,000,000 pounds per square inch.

** Elastic Limit is defined here as the limit of stress intensity within which a material will return to its original size and shape when the load is removed, and hence not take a permanent set.



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C	44.75
B	51.75

Figure 3 - Diagram Showing Strain Gage Positions

of the compressive stress parallel to the neutral axis is of about the same order of magnitude as the experimental error.

The axial stresses in the shank ranged from 900 to 3400 pounds per square inch, or from 2.5 to 10 per cent of the bending stresses. The corresponding stresses in the flukes ranged from 400 to 1200 pounds per square inch at the proof load of 55,000 pounds, or from 1 to 4.5 per cent of the bending stresses. The shank stresses are generally higher than the stresses in the flukes because the fluke sections were more rigid, as substantiated by the computed values shown in Table 4 on page 9.

The stresses in the shank around the stock and the shackle pin were low compared to the stresses elsewhere.

Table 5 on page 10 shows the sequence of yielding in all the sections of the shank and in a few of the sections in the flukes during Test 2, in which the crown side webs were reinforced with welded plates.

Figure 7 on page 9 shows the diagram of load components for the proof load of 55,000 pounds on the anchor. Table 4 on the same page gives a direct comparison between the maximum fiber stresses computed for a proof load of 55,000 pounds and the maximum fiber stresses derived from the measured strains with a load of 55,000 pounds on the anchor. The calculated and the measured stresses are in good agreement.

The increase in the angle between the flukes and the shank as the load increased was 3 degrees. The no-load angle was 30 degrees and the angle at 90,000 pounds load was 33 degrees. Computing the stresses in the shank at a load of 90,000 pounds and neglecting the 3-degree change in angle introduces a 3 per cent error in the stress value; the stress increases with the angle.

CONCLUSION

The 3000-pound lightweight anchor, Type (LWT), Mark II, Assembly 1, was found to have side webs in the crown-stop structure considerably weaker than the remainder of the anchor.

When these crown webs are sufficiently reinforced the anchor can carry a total load in excess of 90,000 pounds, applied at the tips of the flukes.

RECOMMENDATIONS

The design of the anchor should be modified to increase the strength of the crown-stop structure. This can be done at a small increase in weight and with probably no loss in holding power.

The production anchors should in all cases be examined for casting flaws, by X-ray or magnaflux methods, especially in the regions of high stress.

Specifications should be enforced to assure uniform bearing of the shank stops and the crown-stop structure when the anchor is in operating position.

REFERENCES

(1) BuShips letter S26-2(3681) of 2 September 1943 to Commandant, Norfolk.

(2) BuShips letter S26-2(681)(350) of 10 May 1943 to TMB.