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# INVESTIGATION OF STRESS DISTRIBUTION IN STUD LINK ANCHOR CABLE

by

F. W. MARSH & R. C. A. THURSTON

PHYSICAL METALLURGY DIVISION

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F. W. Marsh* and R. C. A. Thurston**

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## SUMMARY OF RESULTS

Experimental stress-analysis of nine three-link samples of one-inch diameter "special steel", stud link, chain anchor cable, indicates that "integral", as opposed to "inserted", studs afford no significant advantage in stress distribution.

Tensile tests to destruction on the same samples showed that two samples with "integral" studs withstood the highest maximum loads.

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* Senior Scientific Officer, and ** Head, Engineering Physics Section, Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

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## INTRODUCTION

In a letter, ref. NS7051-140(NCC) dated 10 November, 1959, the Royal Canadian Navy (RCN) requested a stress analysis of nine samples of stud link chain anchor cable. Subsequent meetings with RCN representatives led to the decision that the cables would be subjected to pure tension only, in this investigation, and that the effects of stresses induced by hoisting machinery, dropping the chain into holds, etc., would be studied by the RCN. The prime reason for the investigation was to determine the desirability, or otherwise, of specifying integral studs, as opposed to welded or pressed studs, in the cable links.

Nine three-link samples of nominal one-inch diameter chain from six manufacturers were to be provided for the tests. The investigation was carried out in four stages - theoretical analysis, "Stresscoat" examination under load, electrical strain-gauge examination under load, and tensile tests to failure.

## DESCRIPTION OF SAMPLES

All samples were said to comply with Specifications for Special Steel Cable, 1-inch nominal diameter, contained in RCN "Specifications for Chain Cables and Associated Articles, CDA/NC/WRCC 1-1-1". Specified dimensions and tolerances are shown in Figure 1, and measured dimensions are given in Table 1. Two samples were over the 1-inch

TABLE 1

Description of Samples

| Manufacturer | Identi-fication | Dimensions in Inches 2A' | 2B' | C | D | E | F | G | Stud |
|---|---|---|---|---|---|---|---|---|---|
| (Nominal Values) | | $6.0^{+0.6}_{-0.0}$ | $3.6 \pm 0.4$ | 1.0−.13 | 0.6 | 1.0 | 1.6 | 0.75 | |
| Baldt Co. | N1 | 6-1/16 | 3-5/8 | 1 | 5/8 | 2-15/16 | 1-5/16 | 11/16 | CTR Weld |
| " " | USN1 | 6 | 3-5/8 | 1 | 11/16 | 3 | 1-5/16 | 5/8 | Integral |
| " " | 110 | 5-7/8 | 3-1/2 | 1 | 11/16 | 13/16 | 1-1/2 | 11/16 | Inserted |
| McKinnon Columbus | 55* | 6-5/16 | 3-15/16 | 1-1/8 | 11/16 | 1-1/16 | 1-5/8 | 13/16 | " |
| N. B. Welding Co. | NB1957 | 6 | 3-5/8 | 1-1/16 | 5/8 | 1-1/4 | 1-9/16 | 13/16 | " |
| " " " | NB1959 | 6-1/16 | 3-13/16 | 1-1/16 | 1 | 1-1/16 | 1-9/16 | 15/16 | " |
| Taylor & Sons Co. | 16 TAY | 6 | 3-5/8 | 1-1/16 | 1/2 | 1 | 1-5/16 | 1/2 | CTR Weld |
| Winter Co. | 11** | 6-3/8 | 3-15/16 | 1 | 1 | 1-5/16 | 1-13/16 | 15/16 | Inserted |
| Keatings & Sons | GWEC. | 6-3/16 | 3-13/16 | 1 | 3/4 | 1-1/16 | 1-11/16 | 13/16 | One side weld |

* Nominal Diameter 1-3/32 inch. **Nominal Diameter 1-1/16 inch.

nominal diameter. Dimensions A', B and C of all samples, with the exception of 110, fall within the tolerance limits, the A' dimension of 110 being low. No tolerances were given for dimensions D, E, F and G. The D dimension for all samples, with the exception of 16 Tay, was higher than that specified, by from 4% to 70%. The E dimension, for all but two samples, was high by from 6% to 200%, being 19% low for 110, and to specification for NB 1957. The F dimension was low by from 2% to 18% for six samples, and high by from 2% to 13% for 55, GWEC, and 11. The G dimension was low by from 8% to 17% for four samples, and high by from 8% to 25% for five samples. Variation in these dimensions would, of course, cause variation in stress distribution.

The forms of the various samples are shown in Figure 11. This is a photograph of individual links after being sectioned longitudinally, and deep etched.

## THEORETICAL STRESS ANALYSIS

Since no formulae were available, for the stress distribution in a studded link of the form specified, the minimum strain energy method employed by Gough, Cox, and Sopwith, (Design of Crane Hooks, etc., Proc. Inst. Mech. Eng. 128, 253 (1934)), was followed, to determine the theoretical stress distribution.

It can be shown that the stress, due to a bending moment M, in a curved beam of radius r, and radius of curvature R, at distance y from the neutral axis is

$$f = \frac{M}{\pi r^2 R}\left(1 + \frac{y}{R + y}\cot^2\omega\right) \quad \text{where } \frac{r}{R} = \sin 2\omega.$$

At the extrados and intrados respectively, $y = \pm r$,

$$\therefore \quad f = \frac{M}{ar}\cdot\frac{2\cos\omega(\sin\omega \pm 2\cos\omega)}{(\cos\omega \pm \sin\omega)^2} \quad \text{where } a = \pi r^2.$$

At the extrados, let

$$\frac{2\cos\omega(\sin\omega + 2\cos\omega)}{(\cos\omega + \sin\omega)^2} = \rho_o; \qquad f_o = \rho_o\frac{M}{ar}$$

At the intrados, let $\dfrac{2\cos\omega(\sin\omega - 2\cos\omega)}{(\cos\omega - \sin\omega)^2} = \rho_1;\ f_1 = \rho_1\dfrac{M}{ar}$

Thus, if the direct stress at any section is P, the total stress, $\sigma = f + P$, can be determined when M and P at the section are known.

Figure 2(a) indicates the form of the centre line of one quadrant of the specified link. A force, W, applied to the link, will induce a bending moment $M_o$ and force H, as shown, to maintain equilibrium. One quadrant only need be considered, due to symmetry. At the point of tangency of circles of radii $R_1$ and $R_2$,

$$\theta = \varphi = \psi = \cos^{-1}\frac{l}{R_2} = \cos^{-1}\frac{R_1 - (A-l)}{R_1}$$

whence $l = \dfrac{R_2(A - R_1)}{R_2 - R_1}$.

The bending moments are:

$$M_\theta = M_o + HR_1(1 - \cos\theta) - \frac{W}{2}R_1\sin\theta, \quad \left[0 \leq \theta \leq \psi\right.$$

$$M_\varphi = M_o + H(F - R_2\cos\varphi) - \frac{W}{2}(R_2\sin\varphi - G), \left[\psi \leq \varphi \leq \frac{\pi}{2}\right.$$

where $F = R_1(1 - \cos\psi) + l = A$

$G = R_2 - B$.

If U = total strain energy of the quadrant,

EI = flexural rigidity of the cross section,

$$2EIU = \int_0^{\psi} M_\theta^{\,2} R_1\,d\theta + \int_{\psi}^{\frac{\pi}{2}} M_\varphi^{\,2} R_2\,d\varphi .$$

Since, by symmetry, no change in slope occurs between the ends of the quadrant, $\frac{\partial U}{\partial M_o} = o$, and, neglecting compressive strains compared with displacements due to bending, no displacement of the ends in direction of H occurs, so that $\frac{\partial U}{\partial H} = o.$

$$EI\frac{\partial U}{\partial M_o} = R_1\int_o^{\psi}\left[M_o + HR_1(1 - \cos\theta) - \frac{W}{2}R_1 \sin\theta\right]d\theta \;+$$

$$R_2\int_{\psi}^{\frac{\pi}{2}}\left[M_o + H(F - R_2\cos\varphi) - \frac{W}{2}(R_2\sin\varphi - G)\right]d\varphi = o$$

$$\therefore\; M_o(R_1\psi + R_2K) + H\left[R_1^{\,2}(\psi - \sin\psi) + R_2FK - R_2^{\,2}(1 - \sin\psi)\right] = \frac{W}{2}\left[R_1^{\,2}(1 - \cos\psi) + R_2^{\,2}\cos\psi - R_2GK\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad I$$

$$EI\frac{\partial U}{\partial H} = R_1\int_o^{\psi}\Big[HR_1{}^2(1 - \cos\Theta)^2 + M_oR_1(1 - \cos\Theta) -$$

$$R_1(1 - \cos\Theta)\frac{W}{2}R_1\sin\Theta\Big]d\Theta + R_2\int_{\psi}^{\frac{\pi}{2}}\Big[H(F - R_2\cos\varphi)^2 +$$

$$M_o(F - R_2\cos\varphi) - \frac{W}{2}(F - R_2\cos\varphi)(R_2\sin\varphi - G)\Big]\,d\varphi \quad = o$$

$$\therefore\; M_o\Big[R_1{}^2(\psi - \sin\psi) + R_2FK - R_2{}^2(1 - \sin\psi)\Big] +$$

$$H\Big[R_1{}^3(\tfrac{3}{2}\psi + \tfrac{1}{4}\sin 2\psi - 2\sin\psi) + R_2\Big\{F^2K + R_2{}^2(\tfrac{1}{2}K - \tfrac{1}{4}\sin 2\psi)$$

$$- 2FR_2(1 - \sin\psi)\Big\}\Big] = \frac{W}{2}\Big[R_1{}^3(1 - \cos\psi - \tfrac{1}{2}\sin^2\psi) +$$

$$R_2\Big\{FR_2\cos\psi - FGK - \tfrac{1}{2}R_2{}^2(1 - \sin^2\psi) + R_2G(1 - \sin\psi)\Big\}\Big]$$

$$\ldots\ldots\ldots\ldots\text{II}$$

where $K = \frac{\pi}{2} - \psi$ .

From the specifications, $A = 2.5$ in. $B = 1.3$ in.

$R_1 = 1.05$ in. $R_2 = 5.38$ in.

$r = 0.5$ in. $a = 0.785$ in.$^2$

$\therefore\ l = 1.802$ in. $\psi = 70^\circ 26' = 1.229$ radians

$\rho_o = 2.88$ $\rho_1 = -6.28$ for $o \leq \theta \leq \psi$

$\rho_o = 3.74$ $\rho_1 = -4.31$ for $\psi \leq \varphi \leq \frac{\pi}{2}$

Assuming $W = 50,000$ lb, using the above values, and solving I and II, $M_o = 14,000$ lb in.

$H = 9300$ lb

The direct stress at any section is

$$P_\theta = \frac{W}{2a}\sin\theta + \frac{H}{a}\cos\theta \text{ , for } o \leq \theta \leq \psi$$

and

$$P_\varphi = \frac{W}{2a}\sin\varphi + \frac{H}{a}\cos\varphi \text{ , for } \psi \leq \varphi \leq \frac{\pi}{2}$$

Hence the total stress,

$$\sigma_\theta = f_\theta + P_\theta = \frac{\rho}{ra}(M_o + HR_1) - H\left(\frac{\rho}{ra}R_1 - \frac{1}{a}\right)\cos\theta -$$

$$\frac{W}{2}\left(\frac{\rho}{ra}R_1 - \frac{1}{a}\right)\sin\theta$$

$$\sigma_\varphi = f_\varphi + P_\varphi = \frac{\rho}{ra}\left(M_o + HF + \frac{W}{2}G\right) - H\left(\frac{\rho}{ra}R_2 - \frac{1}{a}\right)\cos\varphi -$$

$$\frac{W}{2}\left(\frac{\rho}{ra}R_2 - \frac{1}{a}\right)\sin\varphi$$

so that the stresses, in psi x $10^{-3}$, are:

Extrados:
$$\sigma_\theta = 174 - 59.7\cos\theta - 161\sin\theta$$
$$\sigma_\varphi = 1330 - 465\cos\varphi - 1250\sin\varphi$$

Intrados:
$$\sigma_\theta = -381 + 168\cos\theta + 452\sin\theta$$
$$\sigma_\varphi = -1530 + 560\cos\varphi + 1510\sin\varphi.$$

These stresses are plotted as functions of distance along the centre line of the quadrant, in Figure 3.

Gough, Cox, and Sopwith derived stress formulae for studded links having semi-circular ends, and straight sides of length L, as follows: (See Figure 2(b))

$$\sigma_\theta = \frac{W}{2a}\left\{\frac{\rho R_1}{r}(N + Q) + \left(1 - \frac{\rho R_1}{r}\right)(\sin\theta + Q\cos\theta)\right\} \quad 0 \leq \theta \leq \frac{\pi}{2}$$

$$\sigma_x = \frac{W}{2a}\left\{1 \pm \frac{4R_1}{r}(N + Q - 1) \pm \frac{4Q}{r}x\right\} \quad 0 \leq x \leq \frac{L}{2}$$

where
$$N = (m + 2)\left\{m^3 + 6m^2 + 12(4 - \pi)m + 48(\pi - 3)\right\}Z$$
$$Q = 12(m + 2)\left\{(\pi - 2)m + 2(4 - \pi)\right\}Z$$
$$\frac{1}{Z} = m^4 + 4\pi m^3 + 48m^2 + 24\pi m + 24(\pi^2 - 8)$$
$$m = \frac{L}{R_1}$$

$x$ = distance along straight side from $\theta = \frac{\pi}{2}$

Assuming L = 2.9 in. $\left[= 2(A - R_1)\right]$, and using the values specified above for the other variables, the stresses, in psi x $10^{-3}$, are:

<u>Extrados</u>: $\sigma_\Theta = 156.8 - 57.0 \cos\Theta - 160.7 \sin\Theta$

$\sigma_x = 75.6x - 18.5$

<u>Intrados</u>: $\sigma_\Theta = -341 + 133 \cos\Theta + 452 \sin\Theta$

$\sigma_x = -75.6x + 82.3$

These stresses are also plotted in Figure 3. It should be noted that in the above developments, loads are assumed to be acting at points, and strains due to shear and direct compression have been neglected, in comparison with displacements due to bending.

## STRESSCOAT EXAMINATION

All paint was removed from the sample chains, and they were degreased and cleaned. The centre link of each chain, as well as a calibration strip, were sprayed to a uniform thickness with Stresscoat No. 1205 over the entire surface. After the specified drying time, the chains were loaded in a tensile testing machine to 50,000 lb in 10,000 lb increments, the Stresscoat being examined for crack indications at each increment. Wet and dry bulb thermometer readings were taken at the time of spraying and at the time of testing, and the calibration strip was loaded at the time of testing, in order to determine the threshold of indication. Areas of indication are shown in Figure 4, and results of the tests are given in Table 2. Indications shown at any load were, of course, visible and in general extended over increased areas at higher loads. Results of the Stresscoat examination suggested that positions 1, 2, 3, 4, 5, and 6 would be the most highly strained.

TABLE 2

Stresscoat Indications

| Identification | Threshold Stress (psi) | Positions Giving Indications, at 10,000 lb | 20,000 lb | 30,000 lb | 40,000 lb | 50,000 lb |
|---|---|---|---|---|---|---|
| N1 | 23,900 | - | - | 1,2,3,5, 6 | - | - |
| USN 1 | 23,900 | - | 1 | 5,6 | - | - |
| 110 | 23,900 | - | - | - | 1,2,3,4, 5,6 | - |
| 55 | 24,200 | - | - | - | 1,2 | 3,4 |
| NB 1957 | 26,900 | - | 5,6 | 1,2,3,7 | 13,14, | 9,10, 11,12 |
| NB 1959 | 28,400 | - | - | 1,2,3,5,7 | 4,6 | - |
| 16 TAY | 26,900 | - | - | 1,2,3,5 | 6 | 8 |
| 11 | 31,400 | - | - | - | - | 1,2,3 |
| GWEC | 28,400 | - | - | - | 1 | 3,4 |

STRAIN-GAUGE TESTS

Strain gauges were mounted at the positions indicated in Figure 5, on the centre link of each chain, the positions being suggested by results of the Stresscoat examination. One-half inch gauges, Baldwin type A5-1, were used for positions 1, 2, 3, 8; type A7 gauges, having one-quarter inch gauge length, were used for positions 4 and 5: and rectangular rosettes, type AX-5, one-half inch gauge length, were used at positions 6 and 7. Nos. 4 and 5 were placed, as nearly as possible, at $\varphi = 78^{o}$. Temperature-compensating gauges were mounted on a spare chain, which was placed on the tensile machine near the chain being tested.

Each chain was loaded to 50,000 lb and unloaded at least ten times, to cycle the gauges and check zero stability. Readings were then taken on each gauge at 10,000 lb increments, loading and unloading from zero to 50,000 lb. At least five runs were made on each chain, and the readings were averaged, average deviations from the mean being calculated in each case.

The results of these tests are plotted in Figures 6 to 10 inclusive. Results are not given for gauge No. 8, since these stresses were relatively low (less than 32,000 psi) and only two chains were tested at this position. Maximum stresses, reached at 50,000 lb load, and maximum average deviations from the mean at any load are given in Table 3.

TABLE 3

Stresses at 50,000 lb Load and Maximum Average Deviations at any Load,

All Stresses Tensile, Except Gauge 3, Compressive

| Identification | Gauge 1 Stress psi | ad psi | 2 Stress psi | ad psi | 3 Stress psi | ad psi | 4 Stress psi | ad psi | 5 Stress psi | ad psi | 6 Stress psi | ad psi | 7 Stress psi | ad psi | 8 Stress psi | ad psi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N1 | 86,100 | 270 | 16,920 | 150 | -27,600 | 450 | - | - | 83,760 | 450 | 28,740 | 150 | 43,620 | 280 | - | - |
| USN1 | 73,860 | 150 | 40,260 | 150 | -26,460 | 100 | 74,160 | 480 | 124,200 | 1020 | 29,610 | 120 | 35,160 | 100 | - | - |
| 110 | 62,460 | 600 | 29,580 | 180 | -12,420 | 360 | 91,500 | 420 | 98,100 | 240 | - | - | 14,640 | 520 | - | - |
| 55 | 58,800 | 330 | 26,460 | 120 | -28,900 | 930 | 74,790 | 150 | 48,750 | 750 | 23,550 | 150 | 15,240 | 210 | - | - |
| NB 1957 | 67,200 | 100 | 42,660 | 210 | -33,000 | 200 | 96,150 | 300 | 81,450 | 210 | - | - | 50,400 | 690 | 31,350 | 100 |
| NB 1959 | 70,680 | 240 | 38,220 | 270 | -13,220 | 150 | 96,480 | 870 | 91,290 | 780 | 35,160 | 1350 | 11,640 | 660 | 25,860 | 150 |
| 16 TAY | 76,140 | 220 | 32,100 | 150 | -56,340 | 150 | 107,160 | 210 | 75,420 | 120 | 16,260 | 240 | 34,260 | 270 | - | - |
| 11 | 53,880 | 90 | 29,160 | 210 | -32,460 | 90 | 48,180 | 1860 | 45,600 | 240 | 16,560 | 200 | 20,880 | 150 | - | - |
| GWEC | 71,740 | 630 | 41,820 | 150 | -30,540 | 150 | 62,940 | 240 | 121,680 | 630 | 9,060 | 210 | 29,940 | 400 | - | - |

Note: ad = maximum average deviation.

The range of stresses at 50,000 lb load for gauges 1, 2, 4, 5 are indicated in Figure 3.

Gauges 4 and 6, for which no readings are quoted in three cases, failed during the testing, mainly due to unavoidable accidents in mounting the chains in the testing machine. Lack of these three readings was not considered to be of sufficient importance to warrant mounting new gauges and repeating the tests.

## TENSILE TESTS TO FAILURE

After removing all strain gauges, each chain was loaded at an approximately uniform rate (about 3000 lb/sec) to failure. Curves of load vs. total extension of the three links were made throughout each test. Results of the tests are given in Table 4. The column headed "YIELD" refers to the point at which the load-extension curve first deviated from a straight line. Extension, in the "MAXIMUM" column, refers to the extension at maximum load; the maximum extension, of course, occurred at the breaking load, and is given in the "FAILURE" column.

TABLE 4

Results of Tensile Tests to Failure

| Identification | YIELD Load lb | YIELD Extension in. | MAXIMUM Load lb | MAXIMUM Extension in. | FAILURE Load lb | FAILURE Extension in. | Position of Failure | Remarks |
|---|---|---|---|---|---|---|---|---|
| N1 | 84,000 | 0.33 | 123,000 | 1.00 | 123,000 | 1.00 | Centre link, $\theta = 75^{\circ}$ | Stud parted at centre. Crack at dilock joint |
| USN1 | 123,000 | 0.65 | 137,000 | 0.85 | 137,000 | 0.85 | End link, $\theta = 0^{\circ}$ | |
| 110 | 80,000 | 0.58 | 118,000 | 1.40 | 93,000 | 2.10 | Centre link, $\theta = 40^{\circ}$ | Stud came out. |
| 55 | 56,000 | 0.48 | 112,500 | 2.40 | 99,000 | 2.78 | Centre link, $\theta = 10^{\circ}$ | Stud loose both ends. |
| NB 1957 | 56,000 | 0.30 | 83,700 | 1.75 | 64,000 | 2.43 | Centre link, $\theta = 0^{\circ}$ | " " " " |
| NB 1959 | 56,000 | 0.30 | 90,000 | 1.75 | 64,000 | 2.40 | End link, $\theta = 60^{\circ}$ | " " " " |
| 16 TAY | 54,000 | 0.60 | 94,300 | 1.85 | 75,000 | 2.55 | End link, $\theta = 0^{\circ}$ | Stud parted at centre. |
| 11 | 60,000 | 0.35 | 91,000 | 2.35 | 61,000 | 2.45 | Centre link, $\theta = 70^{\circ}$ | Stud loose both ends. |
| GWEC | 52,000 | 0.15 | 88,500 | 1.80 | 66,000 | 2.30 | End link, $\theta = 70^{\circ}$ | Stud loose at one end (unwelded) |

DISCUSSION OF RESULTS

The stresscoat tests, which indicate tensile stresses only, confirmed that the most highly stressed areas were those predicted by theory. Only two chains had gauges at position 8 because NB 1957 was the only sample giving a stresscoat indication at this area, and NB 1959 was similar to it. Sample 16 TAY, the only one giving a stresscoat indication at gauge position 3, was the most highly stressed at this area, as indicated by the strain-gauge tests.

The maximum stresses, at gauge positions 4 and 5, are nearly all considerably higher than the theoretical stress at this point (Figure 3), and the spread, from 45,600 psi for sample 11 to 124,200 for USN1, is quite large. The stresses at gauge position 1 are about two thirds of the theoretical stress. This difference is probably largely due to the fact that the theoretical load is concentrated at $\theta = 0^{\circ}$, whereas in the actual tests the load was distributed over the range $0<\theta<70^{\circ}$, for each quadrant. The stresses at gauge position 2 ranged from 16,920 psi tension for N1 to 42,660 psi tension for NB 1957, compared with a theoretical stress of 78,000 psi tension. Here again, the theoretical compressive force, H, in the stud is applied to the point $\varphi = 90^{\circ}$, while in the most extreme case, that of USN1, the half stud covers the range $73^{\circ}<\varphi<90^{\circ}$. This would undoubtedly alter the stress distribution, and may largely account for the difference in magnitude. Variation in measured stresses between samples for the same gauge position would be largely due to variation in dimensions, as shown in Table 1, but in addition a slight error in mounting a gauge exactly along the extrados or intrados would cause a reduction in measured stress.

Referring to Figures 6 to 10 inclusive, it is seen that the stresses, in general, increased more or less linearly with load, and most samples displayed little hysteresis. The spread in individual stress readings between runs, as indicated by the average deviations, was relatively small and was largely due to variations in setting and maintaining loads, since zero stability for all gauges was good.

As seen in Figure 6, the stresses at the crown of the extrados for six samples were fairly well grouped. Samples 55 and 11 exhibited low stresses, as would be expected since their dimensions were based on nominal diameters of more than one inch. Although the measured diameter of sample 11 was only one inch, the A and B dimensions of both 55 and 11 were the largest of all samples. Sample N1 exhibited a noticeably higher stress than any other sample. This was probably due to the pronounced difference in form of this sample, arising from the dilock construction, and the fact that the stress was measured at the end having the smaller diameter. Four samples, 16 TAY, NB 1959, NB 1957, and 110 showed marked hysteresis, and most of the stress-load curves are fairly linear.

Stresses at the extrados, $\varphi = \frac{\pi}{2}$, as indicated in Figure 7, varied widely between samples and in some cases were noticeably non-linear with load. The unusual behaviour of N1, which showed compression at low loads and the lowest tensile stress of all samples, was again probably due to its form of construction. Samples 110, 55 and 11, as for position 1, showed comparatively low stresses.

Compressive stresses in the studs as seen in Figure 8 were, in general, quite low. Sample 16 TAY, the only one giving a Stresscoat indication at this area, was the most highly stressed. It should be noted that in samples with a centre joint in the stud, such as N1, and 16 TAY, the strain gauge was mounted off-centre to avoid the joint. The theoretical compressive force in the half-stud, H = 9300 lb, would result in a theoretical compressive stress of from 20,000 psi for NB 1959 to 75,000 psi for 16 TAY at the centre of the stud, depending on the D and G dimensions of the sample. The maximum compressive stresses for six of the samples were fairly well grouped about 30,000 psi, with two being much lower and one much higher. This variation in stud loading, compared with the theoretical value of H, is probably due to the 1/2E dimension, which was considered to be zero in theory and ranged from 0.406 to 1.50 in. in practice. The resulting higher value of H would, of course, give a higher stress at the extrados of the crown, but, as suggested above the distributed loading, in practice, would cause a large reduction in stress at this area. NB 1959 and 16 TAY gave respectively low and high compressive stud stresses, as would be expected from the stud cross-sections. The unusual behaviour of 110, showing tensile stress at low loads, is difficult to explain, although it must presumably be associated with the particular method of construction adopted. The manufacturer's description of this sample stated that the chain had ".....inserted forged steel studs assembled under pressure, and mechanically locked in place".

The intrados stresses at $\varphi = 78°$, gauge Nos. 4 and 5, showed a wide spread between positions, as well as between samples, as seen in Figure 9. The spread between positions 4 and 5 is undoubtedly due, in large part, to unavoidable error in placing the A-7 gauges exactly along the intrados, since a small error in "y" or $\varphi$ would result in a relatively large change in stress. The significant difference in stresses between samples is most likely due to the large variation in the E and F dimensions. This variation not only results in a difference in section, but also a change in radius of curvature at the area in question, from sample to sample. The most extreme case was sample USN1, which also indicated the highest stress. Although this stress was over 124,000 psi, the zero stability was within 360 psi, indicating no permanent deformation.

The rectangular rosette gauges, positions 6 and 7, were mounted as a matter of interest to investigate the magnitude of the stresses indicated by the Stresscoat tests at position 7, Figure 4, for NB 1959 and NB 1957. Results of the strain gauge tests, however, indicated that the stresses were quite low, being well under 50,000 psi tension in most cases. Figure 10 shows that these stresses are not of great significance.

The tensile tests to failure show a wide variation in ductility and maximum load between samples. The high maximum loads, in general, were coupled with low elongation. The two samples giving the highest maximum loads, USN1 and N1 had so-called integral studs, but 16 TAY, which also had an integral stud, showed a lower maximum load than 110, with an inserted stud. Sample 55, which also showed a higher maximum load, with an inserted stud, should not be compared, as its nominal diameter was over one inch. A metallurgical examination of the samples, which is being carried out and will be reported by the Ferrous Metals Section should shed more light on the results of these tests. The maximum loads were all above the 75,000 lb load specified in Art. 3.07(4) of the specifications.

## CONCLUSIONS

An experimental stress analysis, employing resistance strain gauges, of nine samples of one-inch diameter "special steel", studded link, chain anchor cable, indicated that no significant advantage in stress distribution in direct tension is afforded by "integral" studs, as opposed to "inserted" studs. Three of the samples tested had "integral" studs; the remaining six, two of which were over the nominal one-inch diameter, had "inserted" studs. In tensile tests to destruction, however, two of the "integral" stud chains withstood the highest maximum loads.

More detailed examination of stress distribution by photo-elastic techniques was considered by the RCN to be unnecessary.

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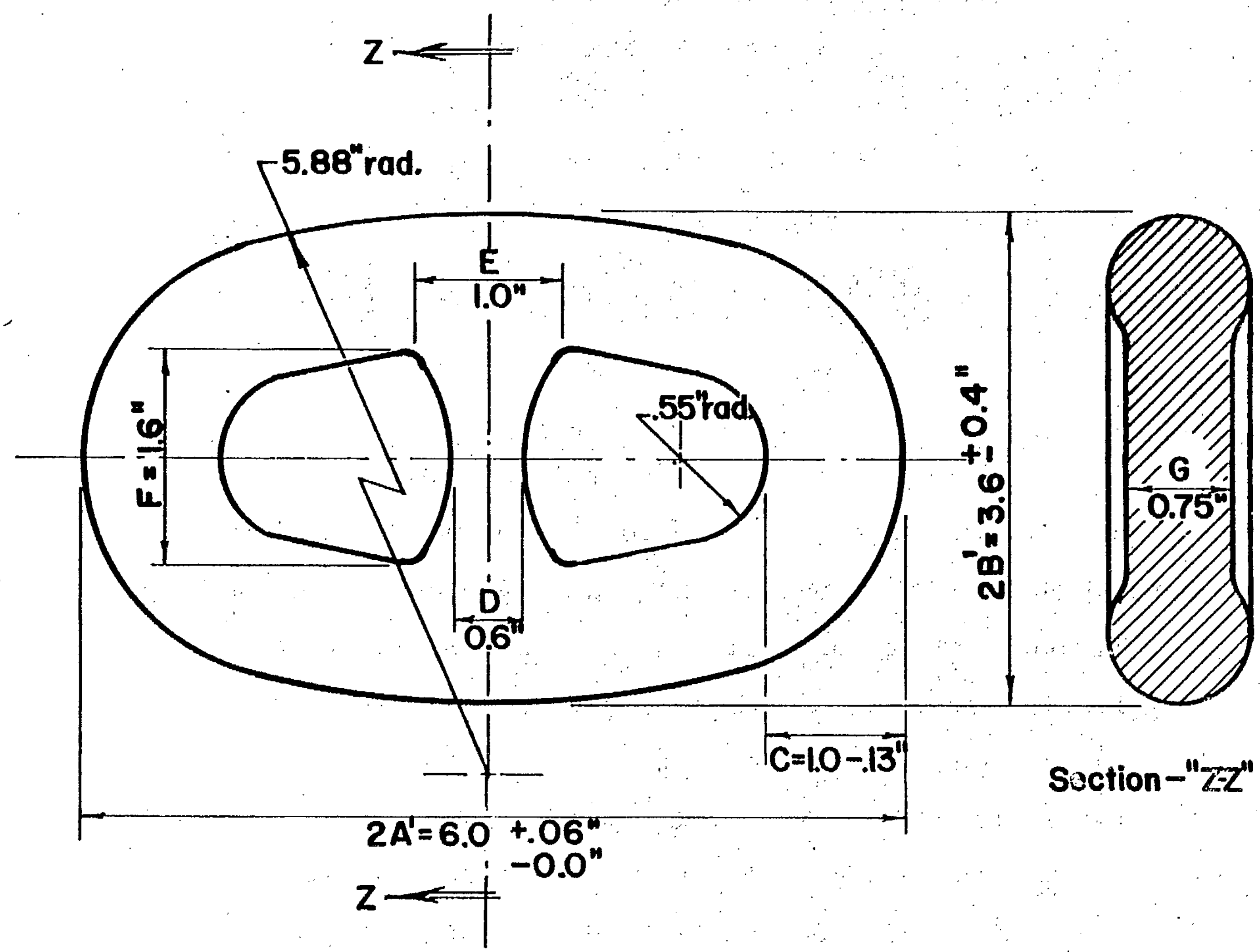


Figure 1. - Dimensions of one-inch diameter link.

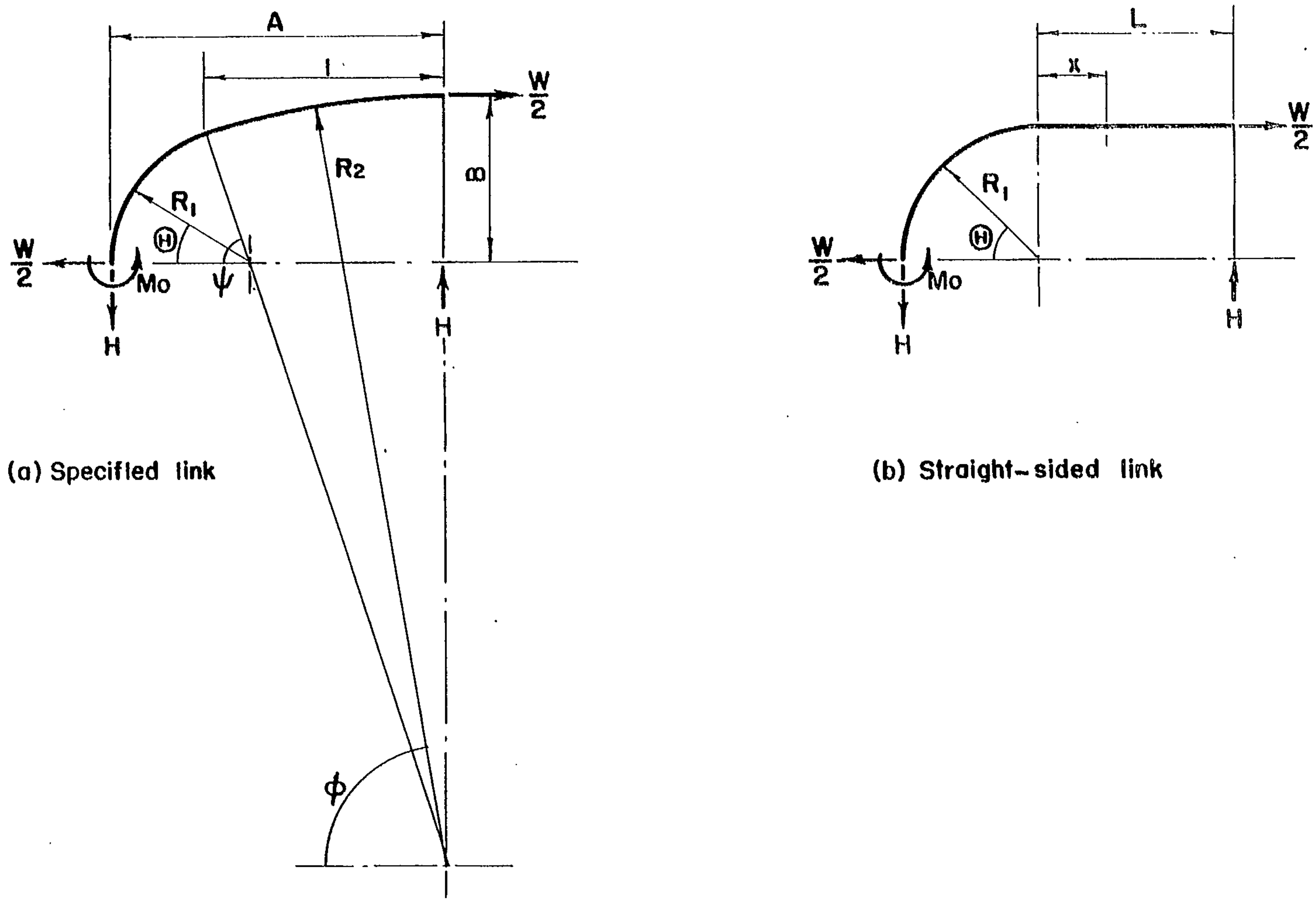


Figure 2. - Dimensions and forces for studded-link quadrants.

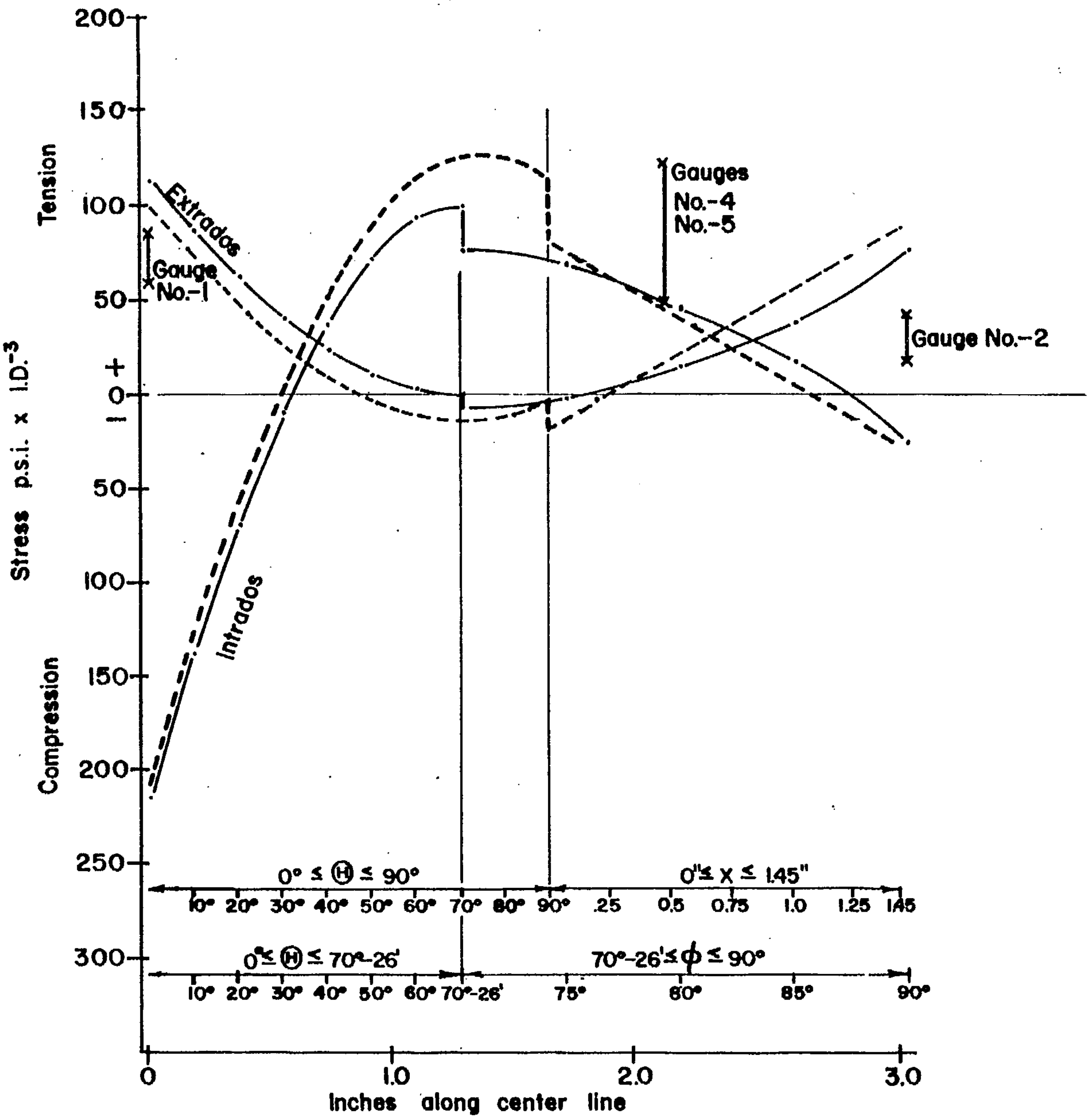


Figure 3. - Theoretical stress distribution.

Solid lines - specified form, Fig. 2(a)
Dotted lines - semi-circular ends, straight sides, Fig. 2(b)

-

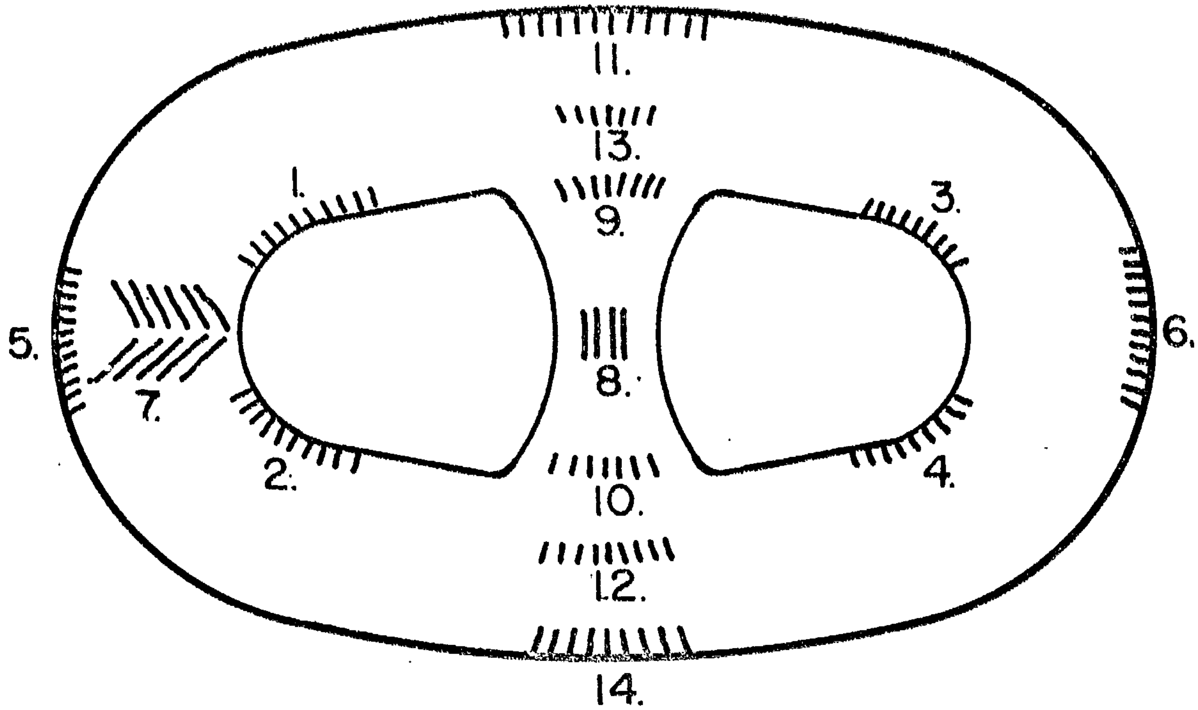


Figure 4. - Stresscoat crack indication positions.

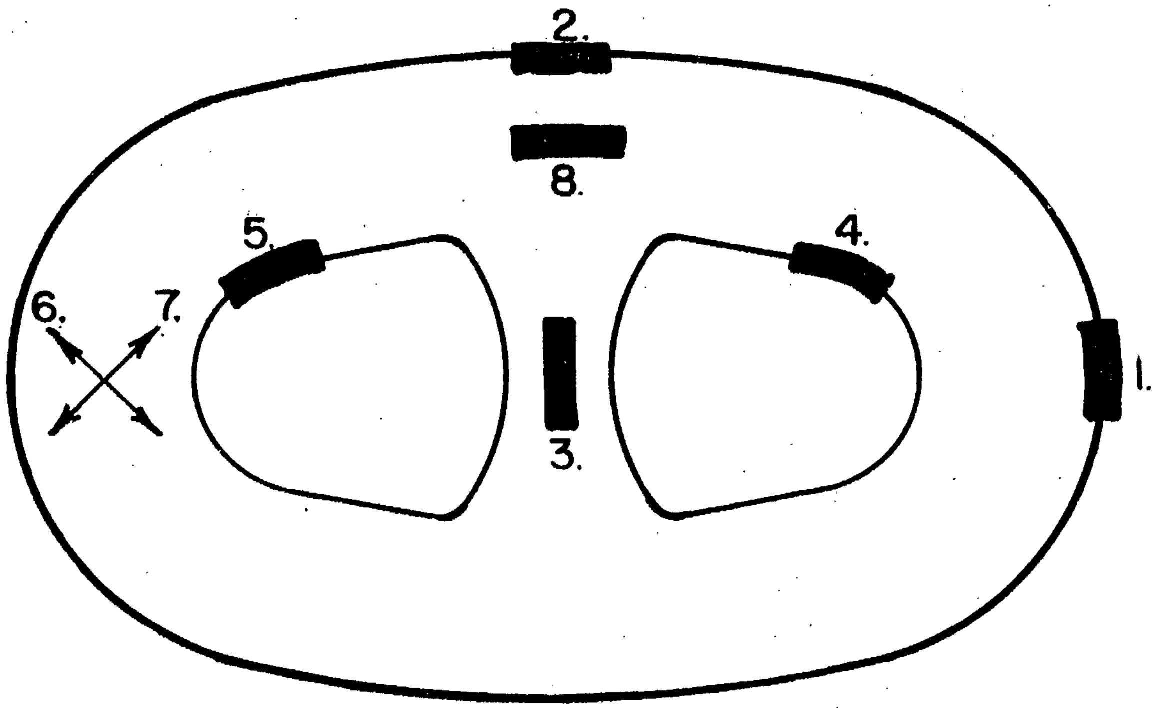


Figure 5. - Strain gauge positions.

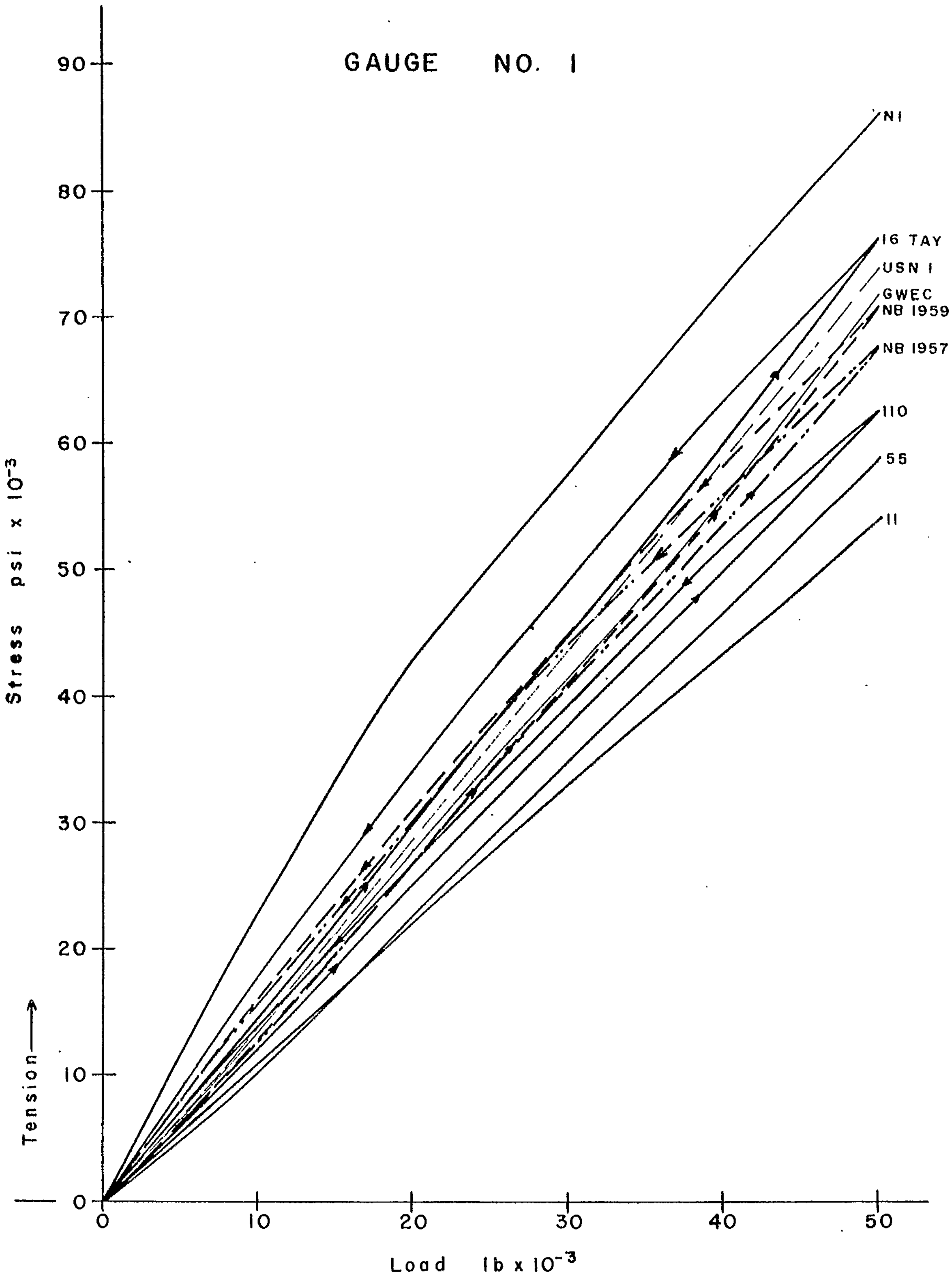


Figure 6. - Load-stress curves for gauge No. 1.

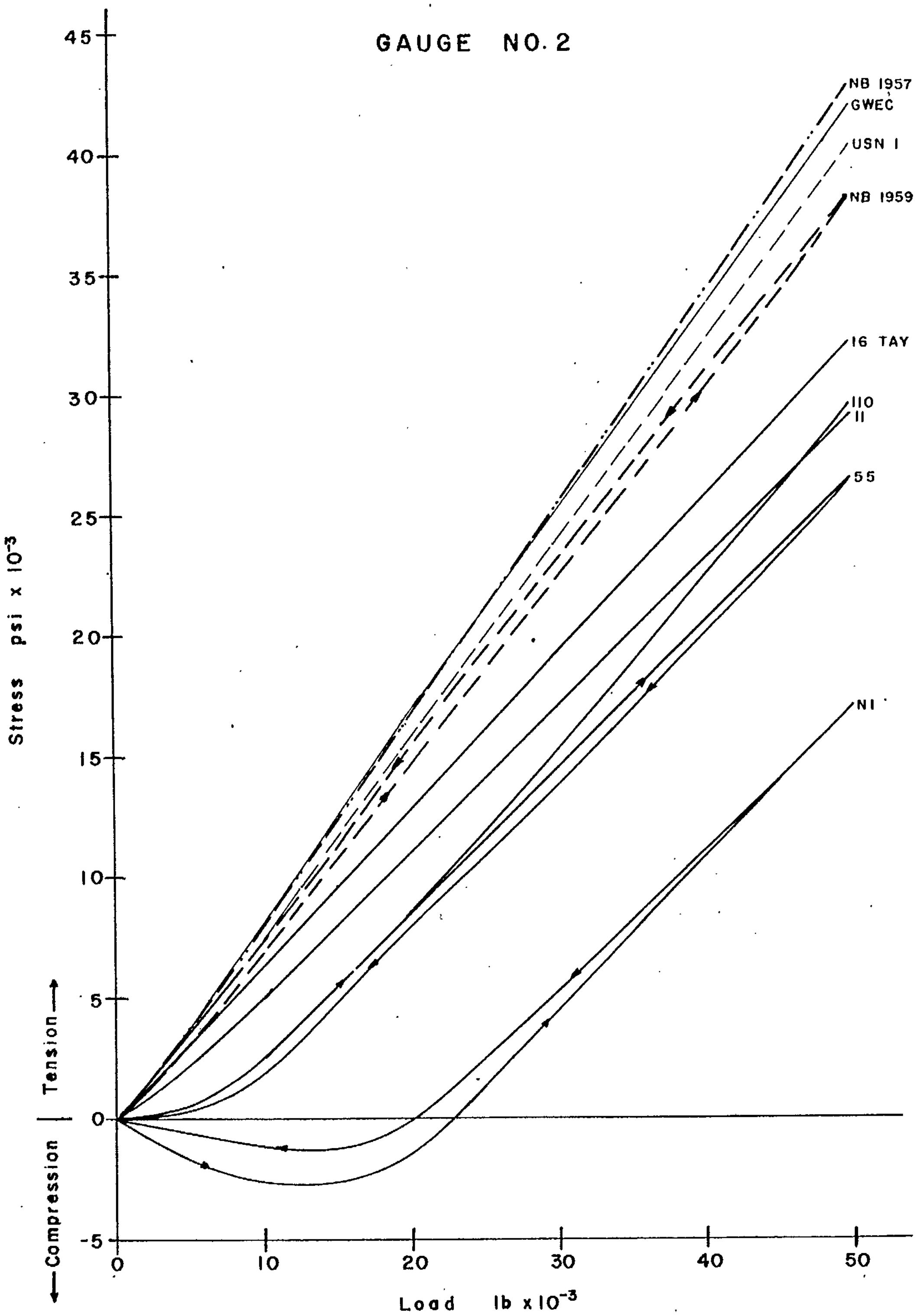


Figure 7. - Load-stress curves for gauge No. 2.

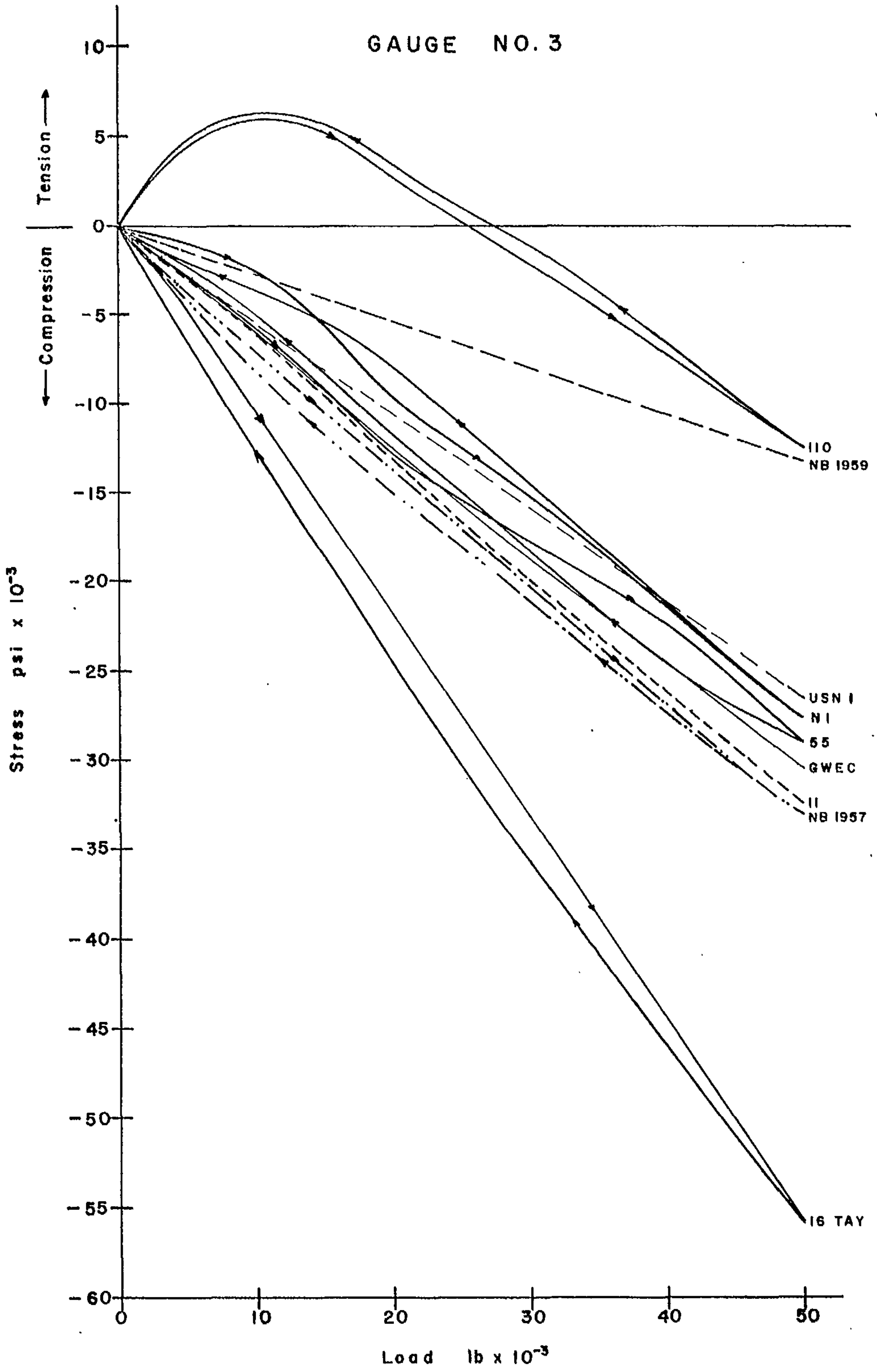


Figure 8. - Load-stress curves for gauge No. 3.

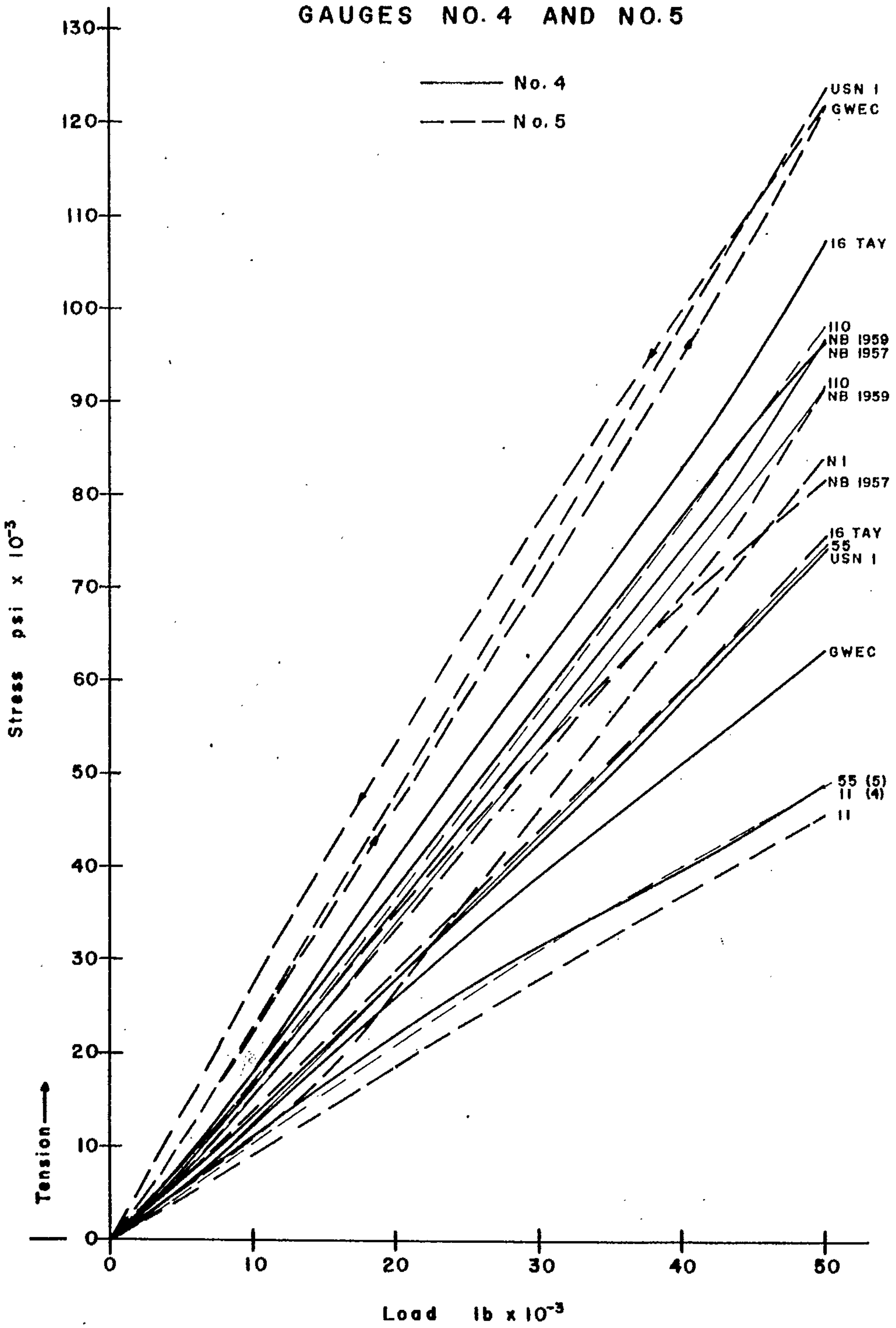


Figure 9. - Load-stress curves for gauges No. 4 and No. 5.

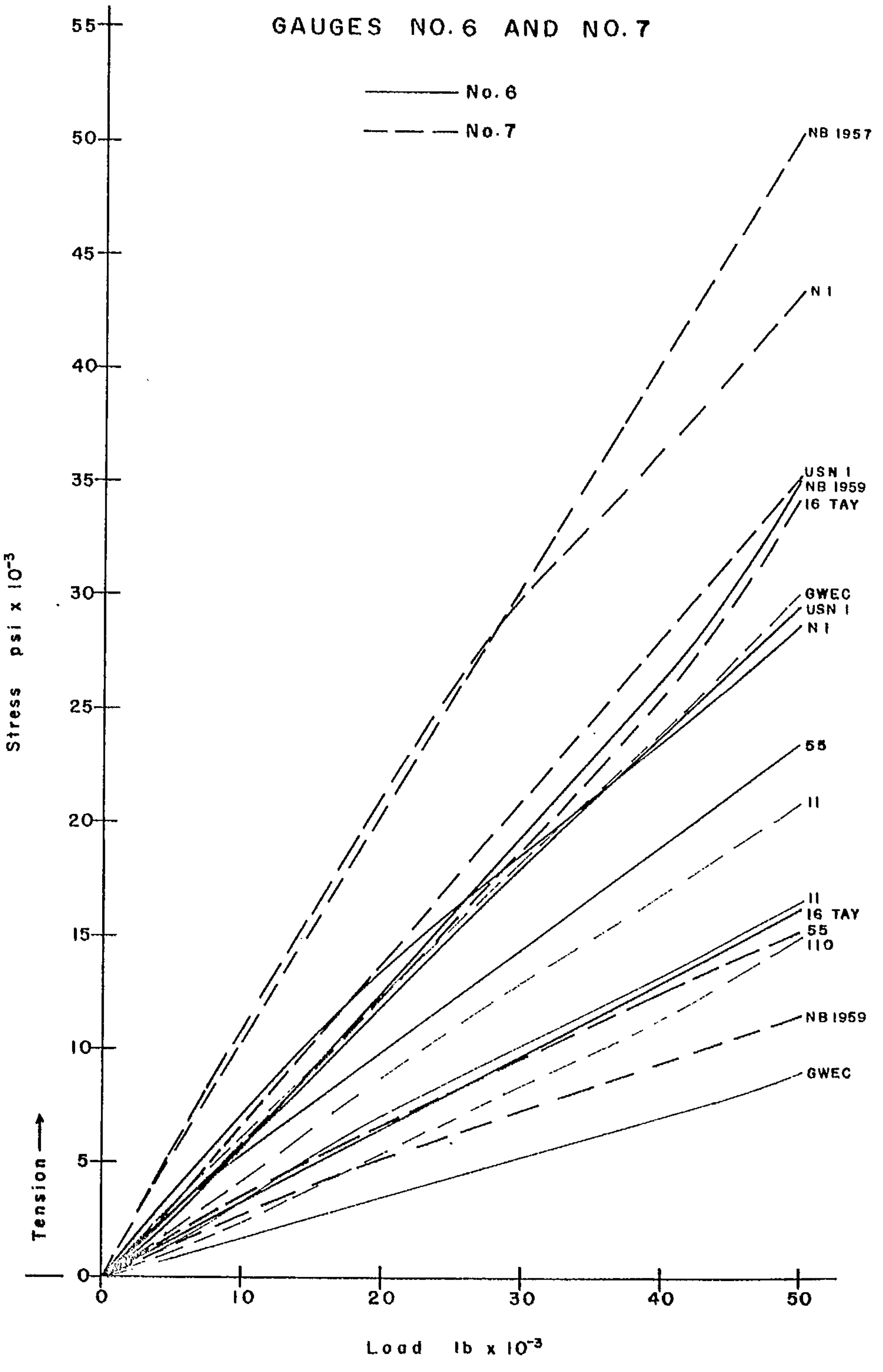


Figure 10. - Load-stress curves for gauges No. 6 and No. 7.

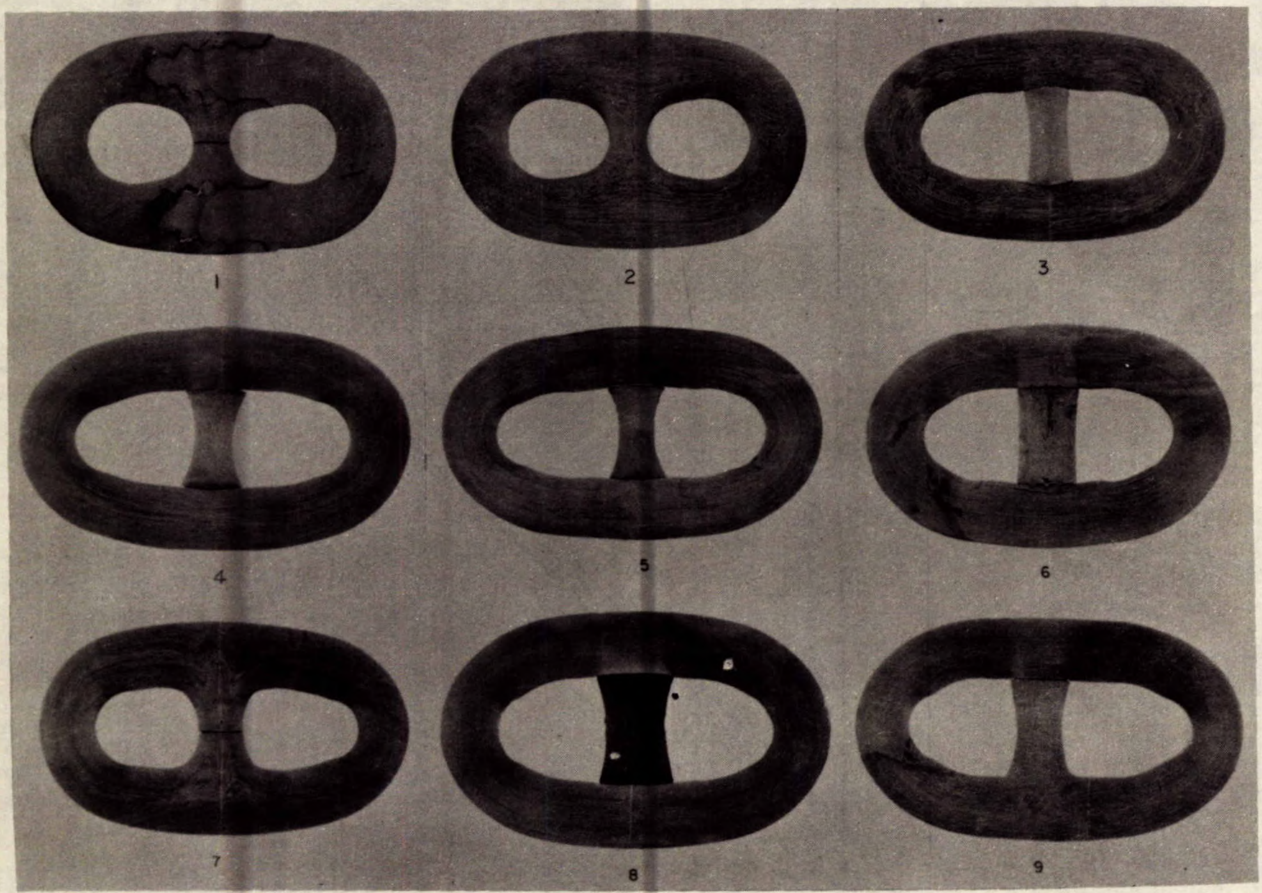


Figure 11. - Individual Links, Sectioned and Deep Etched.

1. N1
2. USN1
3. 110
4. 55
5. NB 1957
6. NB 1959
7. 16 TAY
8. 11
9. GWEC

# MINES BRANCH INVESTIGATION REPORT IR 61-46

## APPENDIX

Subsequent to completion of the above-noted report, three additional three-link samples of nominal one-inch diameter, stud link, chain anchor cable were received for testing. The tests were carried out in a manner similar to that described in the report, and the results obtained are presented below.

### Description of Samples

Two samples were stated to be from an Australian manufacturer, one sample bearing no identification, and the other being stamped "FAMAC". The third sample bore identification marks "1" STW" and was said to be manufactured by Baldt Company. The three samples have been identified as Nos. 10, 11, and 12, respectively, for this appendix. Measured dimensions are given in Table 5. All dimensions with the exception of "D", sample 12, are within the range covered by the nine original samples (Table 1 of the report) but it should be noted that the A' dimensions of samples 10 and 12 are below the specified tolerance limits. The studs of all three samples were welded at both ends. Figure 12 is a photograph of the three samples, taken after removal of strain gauges, before the tests to failure.

TABLE 5

Description of Samples

| Manufacturer's Mark | Identi-fication | Dimensions in inches 2A' | 2B' | C | D | E | F | G | Stud |
|---|---|---|---|---|---|---|---|---|---|
| (Nominal values) | | $6.0^{+0.6}_{-0.0}$ | $3.6 \pm 0.4$ | 1.0 - 0.13 | 0.6 | 1.0 | 1.6 | 0.75 | |
| No identification | 10 | 5-15/16 | 3-11/16 | 1 | 13/16 | 1-11/16 | 1-1/2 | 13/16 | End welds |
| Famac | 11 | 6 | 3-5/8 | 1 | 13/16 | 1-9/16 | 1-1/2 | 13/16 | " " |
| 1" STW | 12 | 5-15/16 | 3-5/8 | 1 | 1-1/8 | 1-5/8 | 1-1/2 | 13/16 | " " |

## Strain-Gauge Tests

The strain-gauge tests were similar to those for the original nine samples, with the exception that an additional type A5-1 gauge, designated No. 2', was mounted on sample 12, in a position corresponding to gauge No. 2, but on the opposite side of the link. In effect, two No. 2 gauges were mounted on this sample, No. 2' being over the butt weld. The results of the strain-gauge tests are given in Table 6 for maximum loads only , and are plotted as load-stress curves in Figure 13.

## Tensile Tests to Failure

Tensile tests to failure were carried out as for the original samples, and the results are given in Table 7.

TABLE 6

Stresses at 50,000 lb Load and Maximum Average Deviations at any Load

All Stresses Tensile, Except Gauge 3, Compressive

| Sample | Gauge 1 | | Gauge 2 | | Gauge 2' | | Gauge 3 | | Gauge 4 | | Gauge 5 | | Gauge 6 | | Gauge 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identification | Stress psi | ad psi | Stress psi | ad psi | Stress psi | ad psi | Stress psi | ad psi | Stress psi | ad psi | Stress psi | ad psi | Stress psi | ad psi | Stress psi | ad psi |
| 10 | 63110 | 90 | 37550 | 100 | - | - | -28300 | 90 | 102900 | 310 | 108410 | 370 | 36042 | 350 | 9380 | 260 |
| 11 | 63930 | 340 | 37460 | 190 | - | - | -36100 | 250 | 125450 | 670 | 122180 | 740 | 25200 | 230 | 12800 | 230 |
| 12 | 66640 | 180 | 46020 | 140 | 38780 | 100 | -22690 | 530 | 94450 | 320 | 97240 | 150 | 17910 | 90 | 23350 | 130 |

TABLE 7

Results of Tensile Tests to Failure

| Sample | Yield | | Maximum | | Failure | | | |
|---|---|---|---|---|---|---|---|---|
| Identification | Load lb | Extension in. | Load lb | Extension in. | Load lb | Extension in. | Position of Failure | Remarks |
| 10 | 57000 | 0.49 | 74500 | 1.95 | 32000 | 2.70 | End Link θ = 10° | Ductile |
| 11 | 54000 | 0.60 | 91000 | 1.85 | 32000 | 2.65 | Centre Link θ = 10° | Ductile |
| 12 | 80000 | 0.80 | 122000 | 1.85 | 122000 | 1.85 | End Link θ = 90° | Brittle - through stud weld |

Discussion of Results

With the exception of position 4, sample 11, (see Figure 5 of report) and position 2, sample 12, all stresses fell within the limits of those recorded for the original nine samples, the stresses at these points being slightly higher than those for the corresponding positions of samples USN 1, and NB 1957 respectively. Comparing Figure 13 with Figures 6 to 10 of the report, it is seen that:

(a) Position 1 stresses for the three samples are closely grouped together, and compare favourably with corresponding stresses for the original nine samples.

(b) Stresses at position 2 for samples 10 and 11, and at position $2_1$ for sample 12 are closely grouped, and are comparable with the corresponding stresses for samples NB 1959, USN 1, NB 1957 and GWEC. The stress at position 2, sample 12, was slightly higher than that for all other samples.

(c) Position 3 stresses compared favourably with those for the six original samples which were grouped together. It is apparent that welding the studs at both ends produced no significant effect on stud loading.

(d) Stresses at positions 4 and 5 were all in the higher ranges of those recorded for the original samples, with the stresses for sample 11 being slightly higher than all others.

(e) Stresses at positions 6 and 7 were relatively low and fell within the range of those for the original samples.

Sample 10 withstood the lowest maximum load of all samples, (c.f. Table 7, above, and Table 4 of the report) and was just below the specified 75,000 lb of Art. 307(4) of the specifications. The failure loads for samples 10 and 11 were extremely low compared with those for the original samples, and the corresponding extensions were not significantly higher. Sample 12 exhibited the largest extension at the "yield" load, and its maximum and failure stresses were relatively high.

The results of the tests do not appear to indicate any marked advantage for studs welded at both ends.

FWM:RCAT:kw:vb July 14, 1961

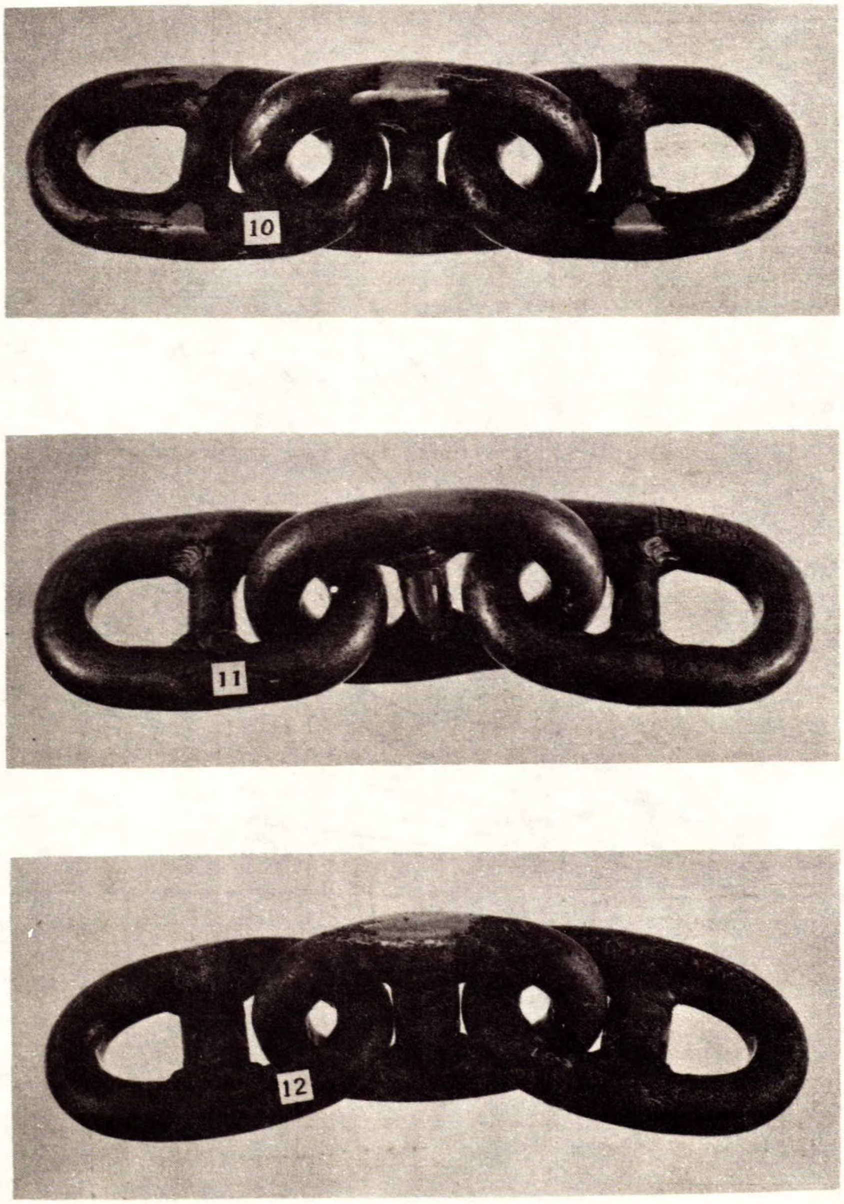


**Figure 12.- Photograph of samples.**

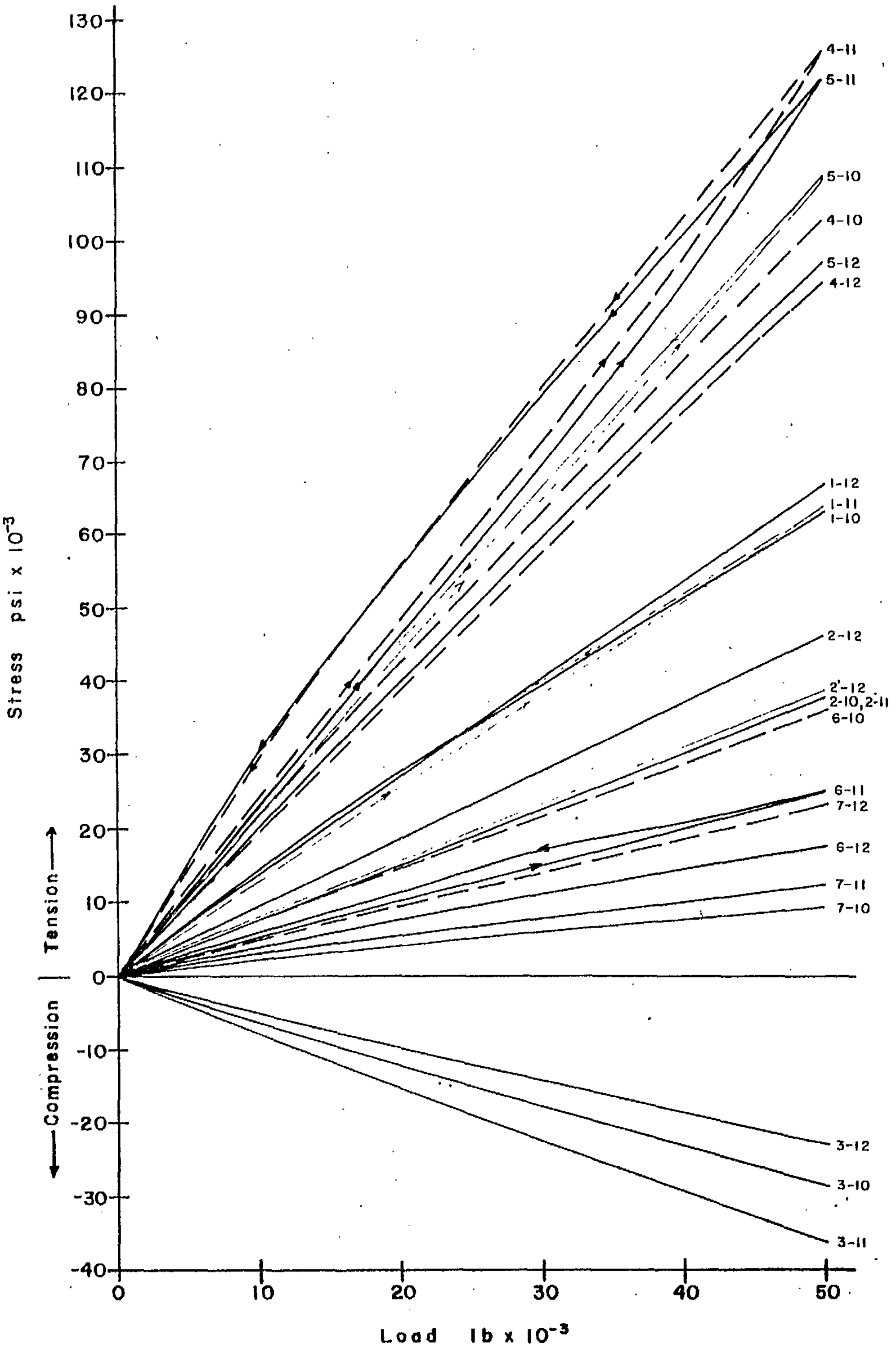


Figure 13. - Load-stress curves for all gauges, samples 10, 11 and 12.