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Cornell University School of Civil Engineering Tests on light beams of cold-formed steel

Cornell University School of Civil Engineering

SCHOOL OF CIVIL ENGINEERING, CORNELL UNIVERSITY
TESTS ON LIGHT BEAMS OF COLD FORMED STEEL
FOR THE AMERICAN IRON AND STEEL INSTITUTE

EIGHTH PROGRESS REPORT, MARCH 23, 1940

I. SCOPE OF THIS REPORT

1. A stress investigation has been made on beam E-18-12-816 b at the load points with 6 and 12 ft. span and center load and with 12 ft. span and quarter point load.

2. The results of these tests seem to show that, after the completion of similar tests on two more beams of the present shipment enough data will have been gathered to answer the question of stress distribution. It was therefore thought advisable to carry out a more complete investigation on this beam. For this purpose the stress distribution at five additional cross sections (besides the load points) has been investigated on this beam with 12 ft. span and quarter point loading. It seemed appropriate to make this investigation on this particular beam, since it is the widest of all beams tested.

3. An investigation of the strain distribution was also undertaken in order to determine the influence of the bent up edges of the bottom flange.

II. GRAPHICAL REPRESENTATION OF RESULTS

The results of the tests mentioned are given in the accompanying 12 drawings:

Drawings 77 and 78 show the stress distribution at the load points of the beam with center loading and with 6 ft. and 12 ft. span respectively.

Drawings 79 to 84 show the stress distribution at six different cross sections of the beam with 12 ft. span and quarter point loading. The positions of the respective cross sections are indicated on the loading sketches on each drawing.

Drawing 85 shows the stress distributions at the load points averaged over both halves of the flanges for the three types of loading investigated. These graphs were obtained by averaging the values of the stresses given on drawings 77, 78 and 81. Thus each stress value on sheet 85 represents an average of the stresses measured at four different points, as indicated on the bottom line of drawing 85.

Drawings 86 to 88 show load strain curves at the load points for comparison with the corresponding drawings 73 to 75 of the seventh progress report.

III. STRESS DISTRIBUTION IN BEAM E-18-12-816b

a) Method of representing and evaluating the experimental stress data.

The stress distribution at the load points is given on drawings 77, 78 and 81 and the averaged values on drawing 85. The bent up stiffeners on the bottom flange are shown in dotted lines on the flange sketch and are represented as bent down into the plane of the flange, since this is the most convenient way of representing the results. The heavy lines join the actual measured stress values. These lines, as in previous reports, are prolonged in to the web in order to obtain the maximum stress. The stress picture at and near the bent up stiffener has been obtained in the following way: As seen from drawing 77, where the actual location of the investigated points is given, points a, g, f, m are located .75 in. from the edge of the flange. Points n, o, p, q on the bent up part are spaced .25 in. from the upper edge of the stiffener or .75 in. from the flange surface. Since no discontinuities can be expected at these points, chosen for experimental reasons only, the stress curve (heavy line) of the flange proper was extended in a straight line out to the line of joint between the flange and the stiffener. The point so obtained was joined by a straight line with that corresponding to the measured stress in the stiffener (points o, n, p, q) and this straight line was further extended outward to the edge of the stiffener. This process is to a certain degree arbitrary. A more exact knowledge of the stress distribution in this part of the flange would have been obtained if the stresses directly at the joint of flange and stiffener as well as those directly at the upper edge of the stiffener were measured. This, however, is impossible for instrumental reasons. It is believed that the method chosen is the best possible and that the accidental errors involved are of no principal importance.

The analytical values with which the experimental ones are to be compared, are worked out for a plane flange only. An exact theoretical solution for a flange provided with stiffeners would be extremely cumbersome. It is therefore of interest to check, whether the analytical values for plane flanges apply with sufficient accuracy to flanges with 1 in. bent up stiffeners. In order to answer this question, a "deduced stress" has been computed from the stress values measured in the stiffener, in the following way: The distance from the flange to the neutral axis is 4.0 in. while the distance of the points n, o, p, q (on the stiffener) from the axis is 3.25 in. Consequently from the theory of flexure it is to be expected that the stresses at these points are decreased in the ratio 3.25 : 4.0 with respect to the stresses that would have been observed if the stiffener were bent back into the flange plane. Therefore the actual stresses measured in the stiffener were multiplied by the ratio 4.0/3.25 to obtain the "deduced stresses" which are indicated on the drawings by the points through which the dotted lines are drawn. If the values of these "deduced stresses" conform to the analytical values, then the analysis of the plane flange can be applied to the flange with stiffeners. One has then simply to reduce the actual width of the flange in the way pointed out in the analysis and with this reduced width (or equivalent width) the section modulus of the whole cross section, including the stiffeners, can be calculated in the usual way.

b) Stress distribution at load points; comparison with analytical values.

The graphs of the stress distribution on top and bottom surfaces of this beam show a considerable degree of irregularity, the significance of which will be discussed later in the report. The general picture of the stress distribution is more clearly represented by the graphs of the mid-plane stresses (bottom graphs of drawings 77, 78, 81) which, as in previous reports, give the average values between the stresses at top and bottom surface of the flange. These curves show a greater degree of regularity than those of the surface stresses. In order to further exclude the influence of local disturbances, the corresponding stresses on both halves of the symmetrical flange have been averaged. The results thus obtained are given on drawing 85. The smoothness of these curves is highly satisfactory. The ratios of "stress at web : stress at edge" were computed from the latter drawing. (It should be noted that the stress ratios given in previous reports were arrived at in exactly the same manner; cf. fifth report, section IV, table 2 and comments to it. In previous reports this averaging was carried out algebraically without graphical representation.)

In the following table a comparison of the experimental with the analytical values of the stress ratios is given:

Table 1

Ratio "r" of stresses at joint of web and flange to stresses at upper edge of stiffener at load point. Beam E-18-12-816 b.

Span	Load	r_{act}	r_{theor}	For l/b	Diff.	r_{theor}	For l/b'	Diff
6 ft.	Center	2.0	1.92	4.5	+4%	2.08	4.0	-4%
12 ft.	Center	1.25	1.25	9.0	0%	1.28	8.0	-3%
12 ft.	Quarter-point	1.31	1.25	9.0	+5%	1.28	8.0	+2%

In the table above, the theoretical values are given for two ratios of span to width. In column five the actual width, b = 16 in., of the flange without stiffener was used; for the eighth column the width, b' = 18 in., of the flange including the bent up stiffeners was taken. For this purpose, it was assumed for computation that the stiffeners were bent back into the plane of the flange. As seen from the table, the coincidence of the experimental and the analytical values is very close for both b and b'. Thus, for this particular beam, it seems to be of no particular importance for which width the $r_{theor.}$ is determined.

The evidence obtained from this beam therefore shows that the reduced (equivalent) width of flanges with 1 in. bent up stiffeners may be obtained with sufficient accuracy from the analytical values for the plane flange and that, employing this reduced width, the section modulus can be determined in the usual way.

c) The stress distribution over the whole length of the beam loaded at the quarter-points.

Previously it was assumed that the largest stress concentration takes place directly at the load points. This assumption was based on the results of a complete stress survey carried out on beam A-14-612 a. (Cf. fifth report, section IV and drawing 47.) The analytical investigation led to the same result. However later considerations (cf. 6th report, section VII, 4 and 7th report, section III) indicated that the results of the investigation on that beam may not be regarded as representative. The reason for this, as pointed out, was that, due to the location of the welds in the web, both parts of the flange were free to move sideways individually, which resulted in distortions of the stress distribution.

In order to arrive at results free from this error, a detailed survey was carried out on beam E-18-12-816 b. It will be remembered (cf. 7th report, section V) that this beam has been especially reconstructed to practically exclude this sideway motion.

The results of this survey are given in drawings 79 to 84. The general character of the stress distribution can be seen most clearly from the following Table 2.

Table 2.

Ratio "r" of stresses at joint of web and flange to stresses at upper edge of stiffener at different cross sections on one half of beam E-18-12-816 b.

Section	Drawing	Location with respect to load point	Stress ratio r
C	79	18" to support	1.29
D	80	9" to support	1.20
E	81	At load point	1.31
F	82	4.5" to center	1.16
G	83	9" to center	1.09
H	84	At center of span	.81 (≈1.0)

The values given in this table confirm the results cited above, namely; the most pronounced concentration of stresses occurs at the load point itself. Between the load points and the supports the presence of a marked stress concentration is also observed, but it is of smaller magnitude than that at the load point. It should be noted that in this part of the beam the shearing force is constant and equal to the reaction. The stress concentration decreases very rapidly from the load point toward the center of the beam. As close as 9" from the load point toward the support the stress ratio decreased from 1.31 to 1.09. In the center of the beam actual observations gave a stress ratio of .81, i.e., the stresses are smaller at the web than at the edge. For reasons to be discussed in the next section of this report it is believed however, that the latter value is due to individual properties of this beam and that the actual stress ratio in a flange without edge stiffeners would be 1.0 in the center of the span (for quarter point loading). Again it should be noted that in the portion of the beam between the loads there is no shearing force, i.e. the beam there is in pure bending.

Hence this survey confirmed that the most critical cross-section, so far as the bottom flange is concerned, is that at the load point.

(The stress values at section C and to a lesser extent at section D are not as reliable as the remainder of these values. Since at these sections the ending moment is less (1/2 and 3/4 respectively) than that at the other sections, the increments on the strain gages at these sections are correspondingly smaller, which results in a lesser accuracy. In fact the transverse strains at section C are so small that they could not be measured with any sufficient degree of accuracy. Therefore the stresses at that section were determined from the longitudinal strains only by means of the approximate formula, $\sigma = e_x.E$).

d) Irregularities in the stress distribution.

Looking at the graphical representations of the stress distributions at the different sections it will be observed that the curves show a considerable degree of irregularity. It should be noted that in the present drawings the scale of the stresses was doubled as compared with the curves in previous reports. This, of course, exaggerates the irregularities. However, two facts stand out (a) that irregularities exist and, (b) that the irregularities in this beam are especially pronounced.

A stress distribution with little or no irregularities looks like that on drawing 77, bottom graph, or the averaged curves on drawing 85, top and bottom graphs. In other words, they show comparatively small curvature, the stresses uniformly decreasing from the web outward towards the edge of the flange.

Inspection of the different stress distribution curves reveals that the stresses at top and bottom surfaces (top and center graphs on all drawings) are far from showing such regular characteristics. The averaged midplane stresses (bottom graphs) are in general more regular and closer to the above described character, than those at the top and bottom surfaces. The curves of the stresses averaged over both sides of the flange (drawing 85) are still more regular.

In particular it is easily observed that considerable irregularities take place at the outer edge of the flange along the joint with the stiffener. Again, if the stiffener would act monolithically with the rest of the flange according to the simple theory of bending, the graph would look like the bottom graph on drawing 77 and like the top and bottom graphs on drawing 85. That is, the dotted line of the "deduced stress" in the stiffener should be a direct prolongation of the full curve. Instead of such behavior all kinds of irregularities are observed. The stresses in the stiffener are sometimes smaller (downward break in the curve), sometimes larger (upward break) than should be expected. In order to make sure that these irregularities are not due to erroneous measurements, repeated observations have been made on 24 points (12 pairs). Only in 2 cases an error of measurement was detected, the other 22 measurements checked within the experimental accuracy.

The influence of these irregularities is distinctly seen on drawing 84. There the stresses are of practically constant magnitude all over the main (Horizontal) part of the flange, as should be expected in the center section of the beam. However the "deduced stresses" in the stiffener, instead of being of the same magnitude, rise suddenly. (In order to check this behavior, the stresses at the points n, o, p, q have been measured twice, with the same result). For this reason the stress ratio for this section in table 2 is .81. The value "($\gtrsim$ 1.0)" in this table is thus meant to indicate that in the main part of the flange the stresses are of uniform magnitude.

An analytical solution, of course, cannot account for these local irregularities. For purposes of building code specifications it will be necessary to investigate these local effects numerically. Eventually a somewhat lower safety factor may have to be chosen in order to avoid local overstressing. There is, however, no point in doing such a numerical investigation for each individual beam. After completion of the stress distribution tests it will be necessary to investigate this effect systematically for all beams tested.

IV. STRAIN OBSERVATIONS

Drawings 86 to 88 show the load-strain curves for the longitudinal strains at the load points. Comparing these graphs with the corresponding drawings 73 to 75 of the 7th report one sees immediately that for the present beam these curves are much more regular and straight than those of the beam D-18-12-816 a. Indeed, except for two out of twenty-four points, the curves are as nearly straight as can be expected. This shows that the bent up stiffener in this beam produced the expected effect (cf. Summary Report, VIII, a). The stiffeners practically prevented the formation of waves in the horizontal part of the bottom flange. As a result the outer parts of the flange fully take part in the work of the beam and thus the efficiency of the flange as a whole is increased. In addition, and despite the local irregularities, the stress curves reveal that the stiffener itself carries its corresponding stress and therefore may be included in the determination of I and S of the cross section. So, at least so far as the results from this beam are concerned, it can be said that the presence of bent up stiffeners greatly improves the properties of the beam.

V. CONCLUSIONS

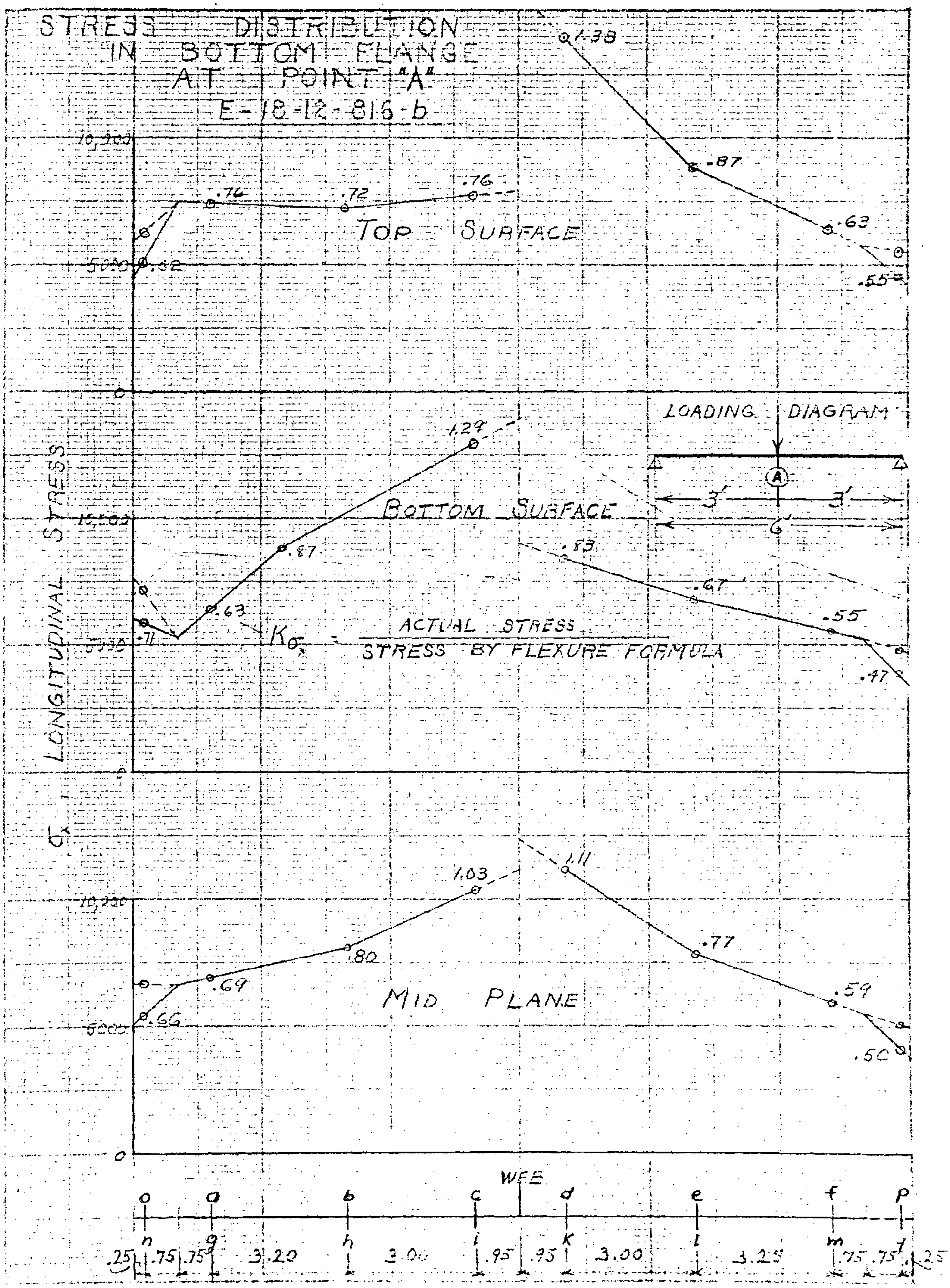
1. The analytical solution for a plane flange, according to present observations, may fully be applied to flanges with bent up edge stiffeners. It seems appropriate to limit this statement at present to edge stiffeners of width not more than 1/8 of the depth of the beam.

2. The coincidence of experimental and analytical results is very satisfactory, the deviations being from -3% to +5%.

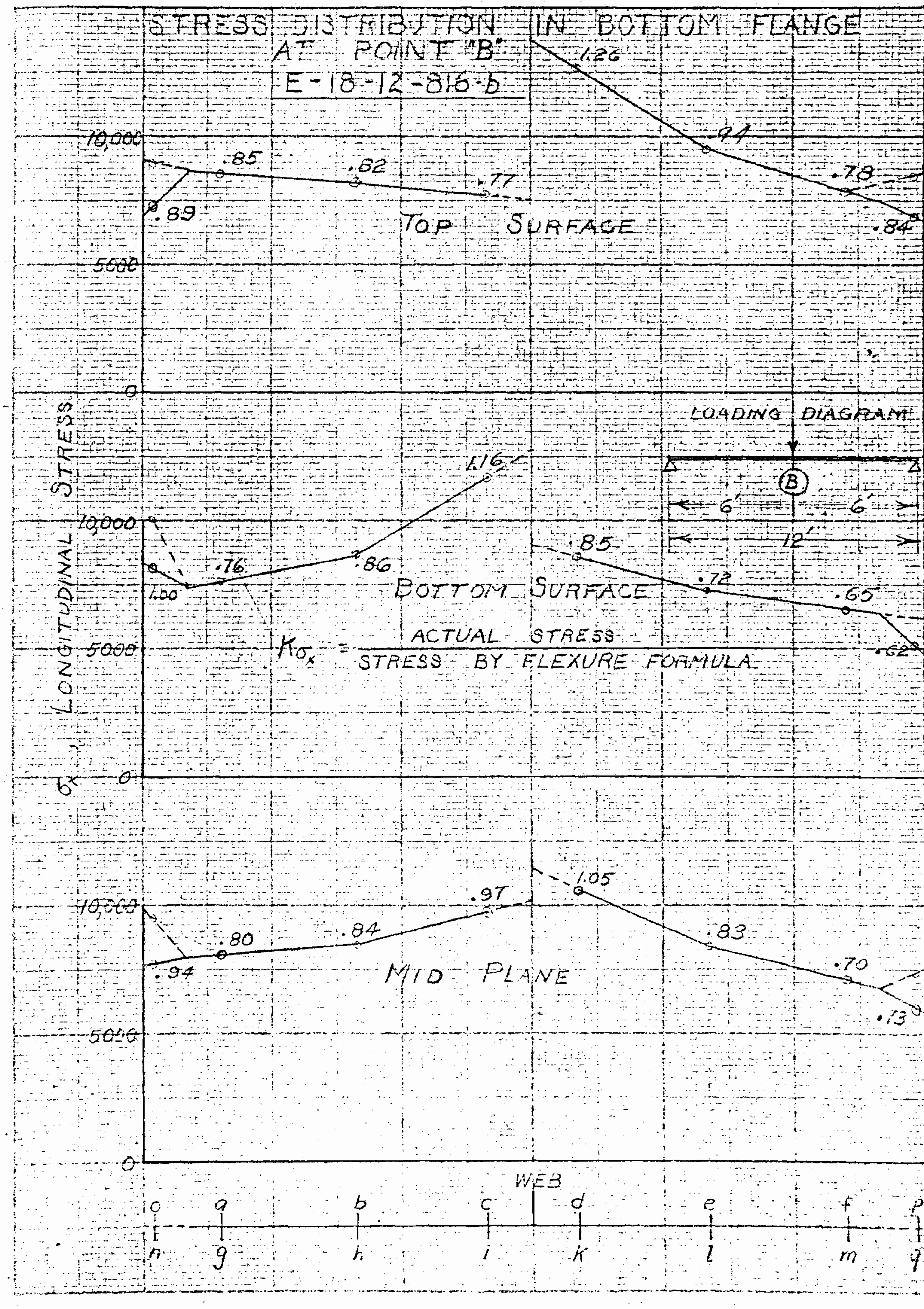
3. The previous assumption that the stress concentration is largest at the load point is confirmed by an extensive survey. It is also confirmed that, except for local irregularities, the stresses are of uniform magnitude in the center portion of the beam (pure bending).

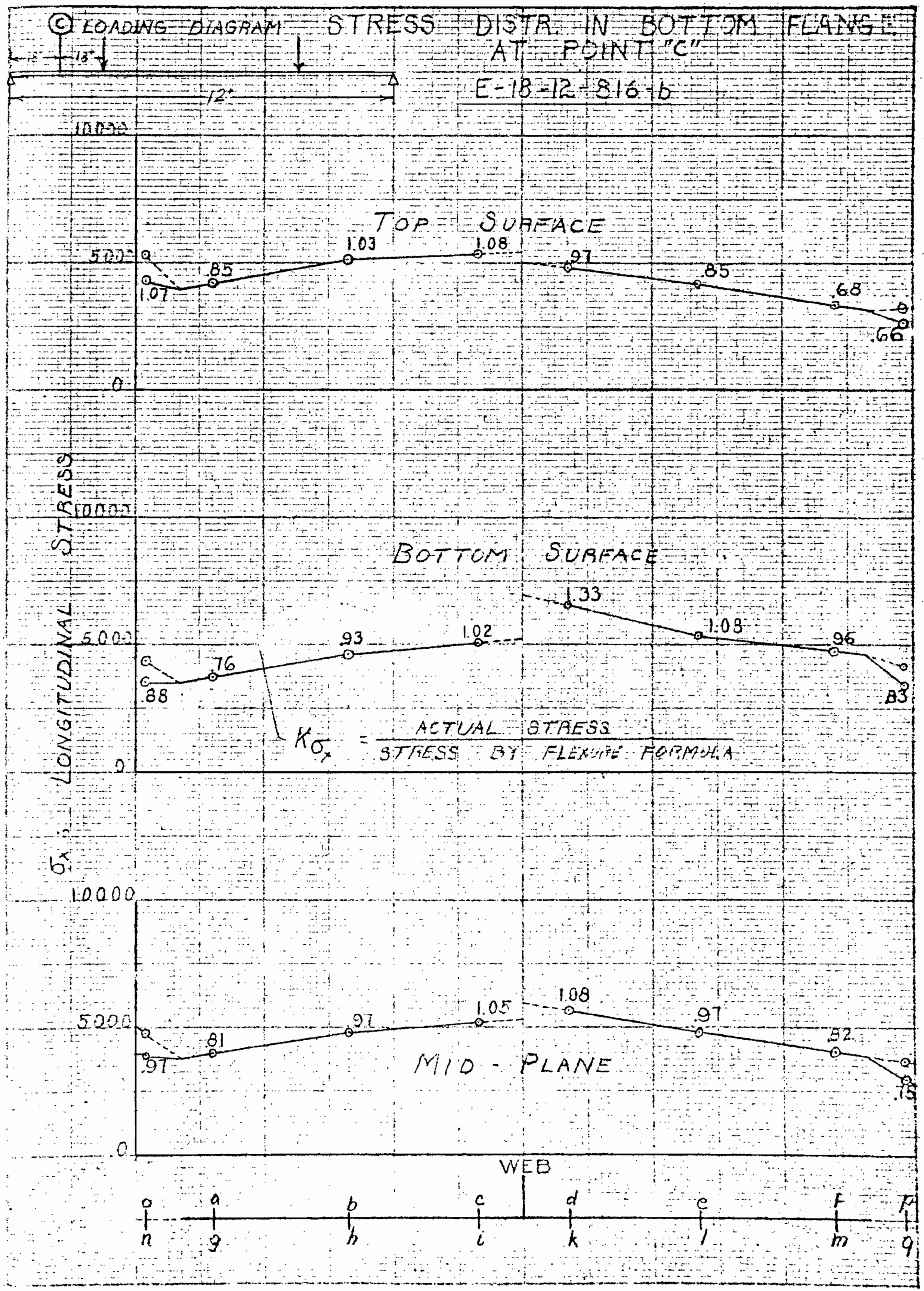
4. Local irregularities in the stress distribution of this beam are of considerable magnitude and will require special consideration in the final evaluation of the present tests.

5. The presence of bent up flange stiffeners markedly improved the properties of the beam. The result has been that the entire flange, including the stiffeners fully takes part in the action of the beam. No waves could be detected in the flange, except for local bumps.

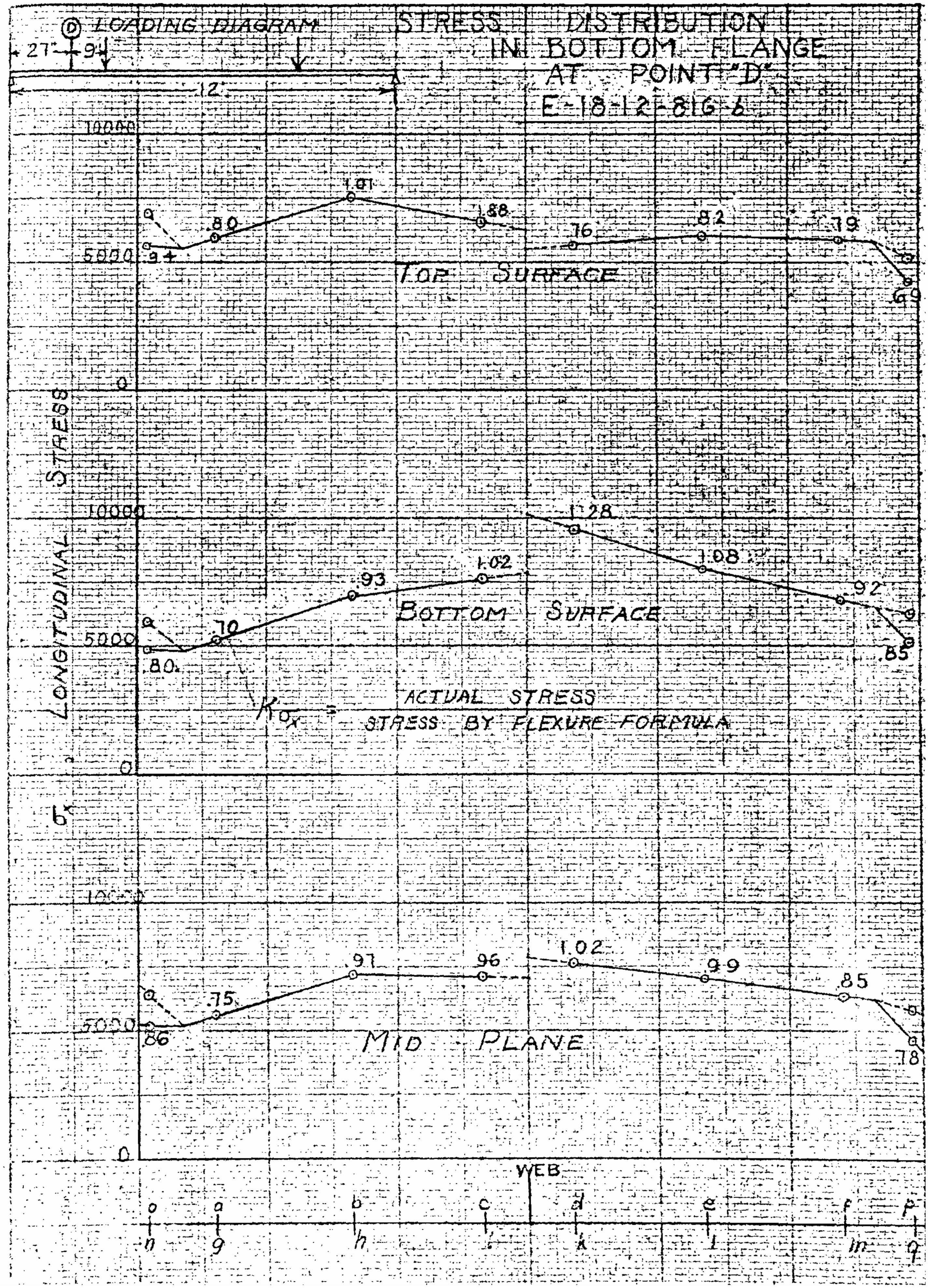


STRESS DISTRIBUTION
IN BOTTOM FLANGE
AT POINT "A"
E-18-12-816-b
LONGITUDINAL STRESS
σ_x
10,000
5000
0
TOP SURFACE
1.38
.87
.63
.55
.76
.72
.76
.52
BOTTOM SURFACE
1.29
.87
.63
.71
.83
.67
.55
.47
K_{σ_x} = ACTUAL STRESS / STRESS BY FLEXURE FORMULA
LOADING DIAGRAM
A
3'
3'
6'
MID PLANE
1.03
1.11
.82
.69
.66
.77
.59
.50
WEE
o
a
b
c
d
e
f
p
n
g
h
i
k
l
m
.25
.75
.75
3.20
3.00
.95
.95
3.00
3.25
.75
.75
.25

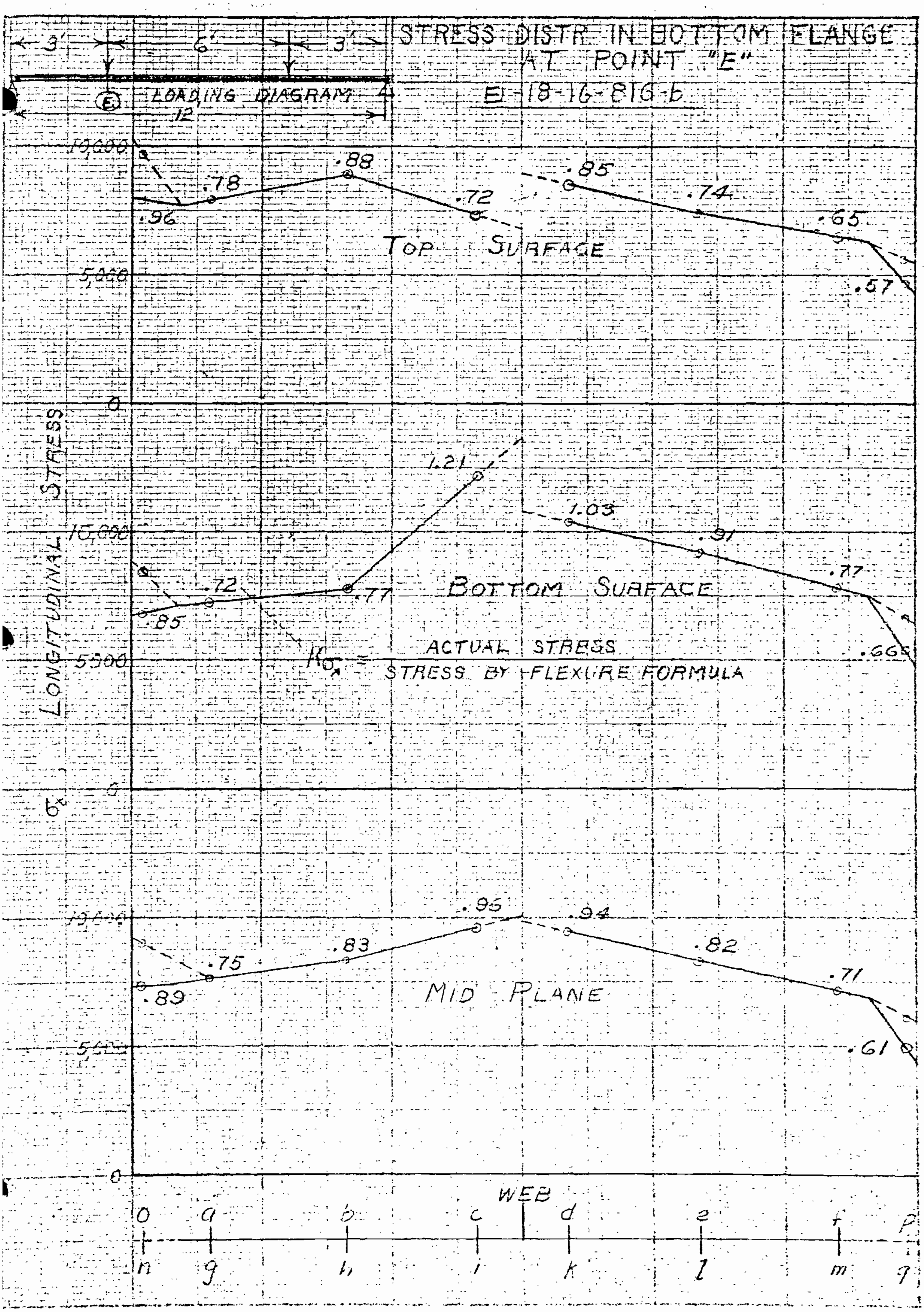

STRESS DISTRIBUTION IN BOTTOM FLANGE
AT POINT "B"
E-18-12-816-b
10,000
5000
0
.85
.82
.77
.89
1.26
.94
.78
.84
TOP SURFACE
LOADING DIAGRAM
B
6'
6'
12'
1.16
.85
1.00
.76
.86
.72
.65
.62
BOTTOM SURFACE
$K_{\sigma_x} = \frac{\text{ACTUAL STRESS}}{\text{STRESS BY FLEXURE FORMULA}}$
σ_x, LONGITUDINAL STRESS
1.05
.97
.80
.84
.83
.70
.94
.73
MID PLANE
WEB
o a b c d e f p
n g h i k l m q

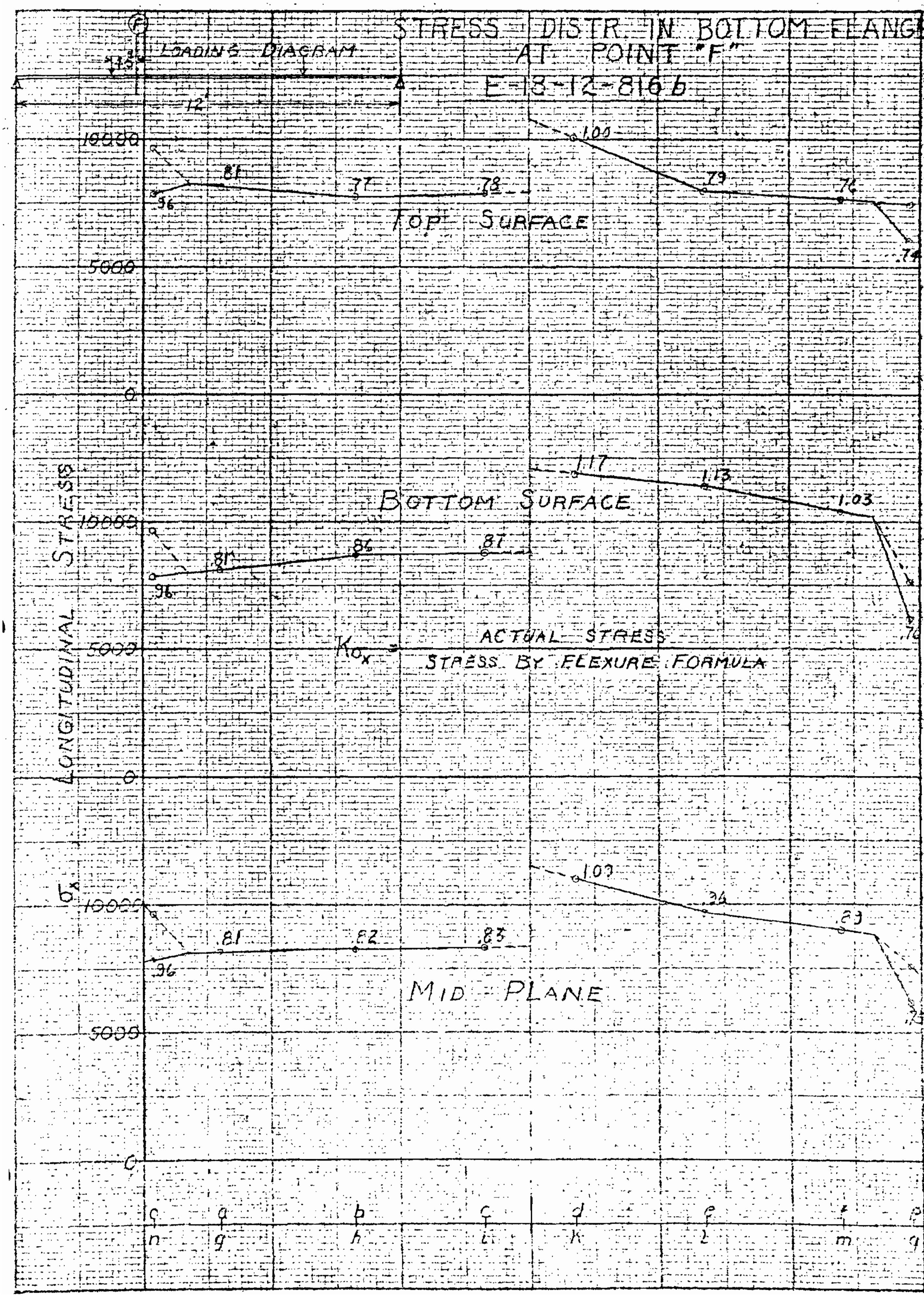


© LOADING DIAGRAM
STRESS DISTR. IN BOTTOM FLANGE AT POINT "C"
E-18-12-816-b
12"
18"
TOP SURFACE
BOTTOM SURFACE
MID - PLANE
LONGITUDINAL STRESS σ_x
10000
5000
0
1.07
.85
1.03
1.08
.97
.85
.68
.66
.88
.76
.93
1.02
1.33
1.08
.96
.83
.97
.81
.97
1.05
1.08
.97
.82
.75
$K_{\sigma_x} = \frac{\text{ACTUAL STRESS}}{\text{STRESS BY FLEXURE FORMULA}}$
WEB
o a b c d e f p
n g h i k l m q

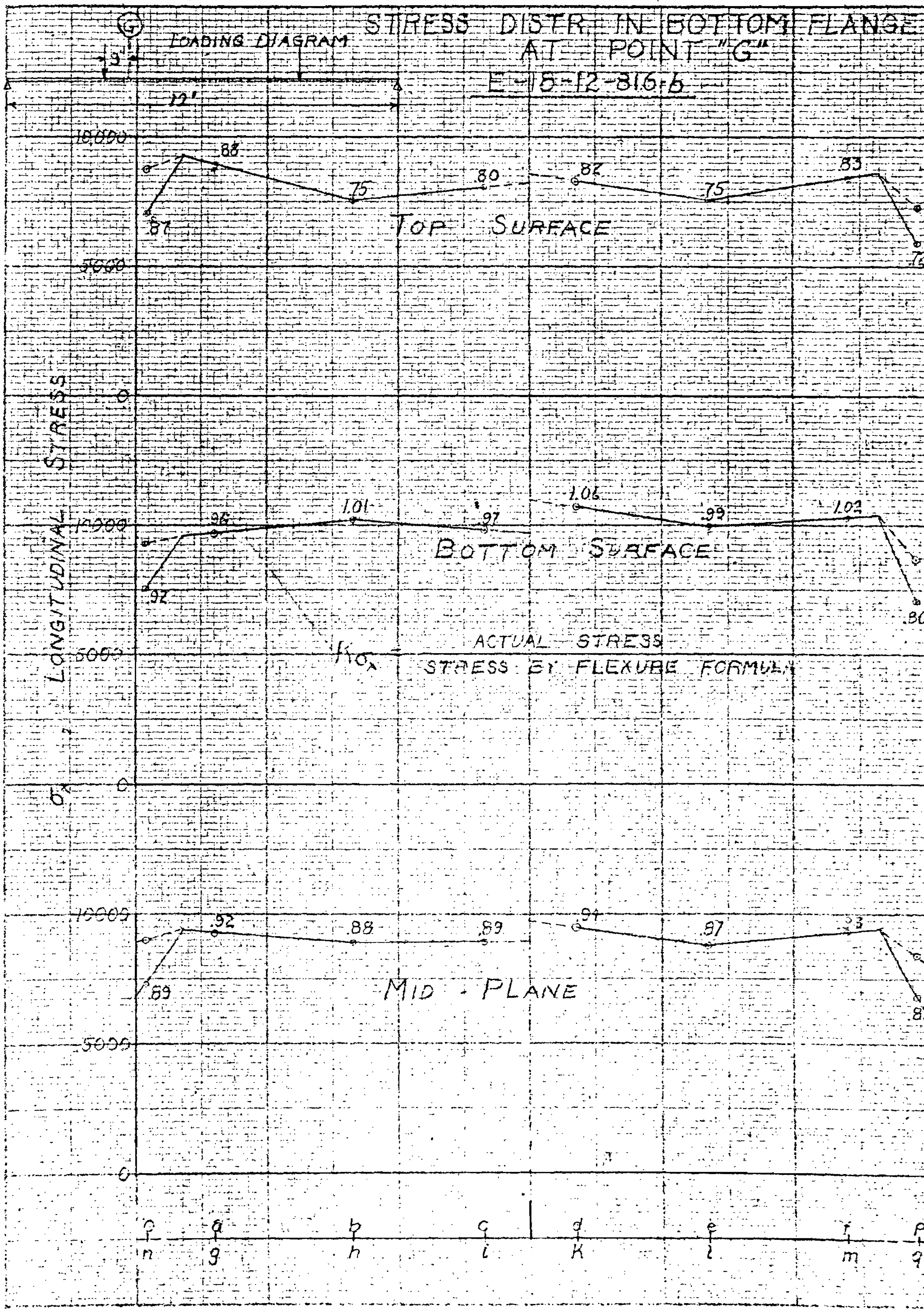


D LOADING DIAGRAM
27" 9"
12"
STRESS DISTRIBUTION IN BOTTOM FLANGE AT POINT "D"
E-18-12-816-6
10000
5000
0
LONGITUDINAL STRESS
σ
TOP SURFACE
.94
.80
1.01
.88
.76
.82
.79
.69
BOTTOM SURFACE
.80
.70
.93
1.02
1.28
1.08
.92
.85
K_{σ_x} = ACTUAL STRESS / STRESS BY FLEXURE FORMULA
MID PLANE
.86
.75
.97
.96
1.02
.99
.85
.78
WEB
o a b c d e f p
n g h i k l m q

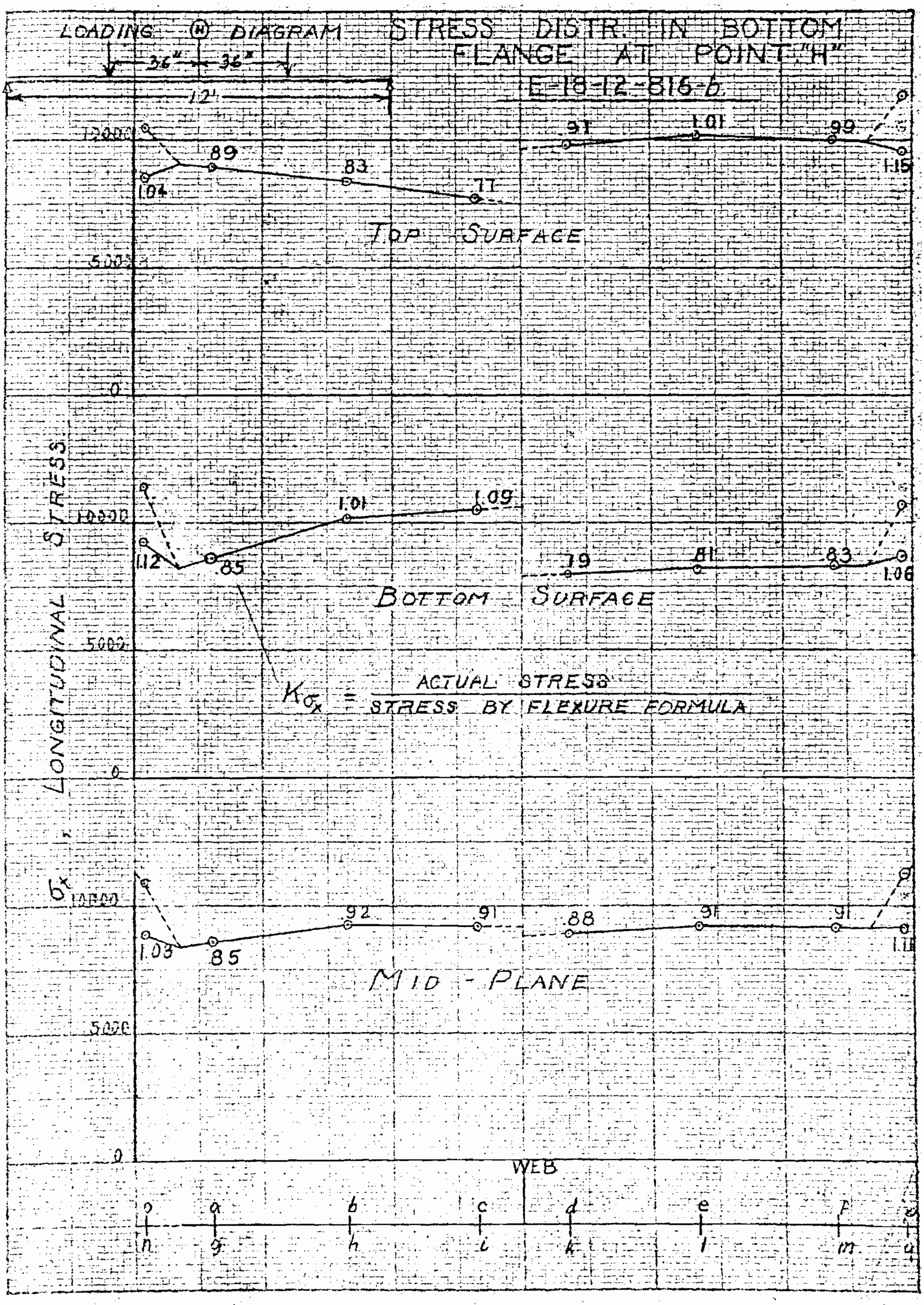

STRESS DISTR. IN BOTTOM FLANGE
AT POINT "E"
EI-18-16-8TG-b
3'
6'
3'
E
LOADING DIAGRAM
12
LONGITUDINAL STRESS σ_x
10,000
5,000
0
TOP SURFACE
BOTTOM SURFACE
MID PLANE
.96
.78
.88
.72
.85
.74
.65
.57
.85
.72
.77
1.21
1.03
.91
.77
.66
.89
.75
.83
.95
.94
.82
.71
.61
$K_\sigma = \frac{\text{ACTUAL STRESS}}{\text{STRESS BY FLEXURE FORMULA}}$
WEB
0 a b c d e f p
n g h i k l m q

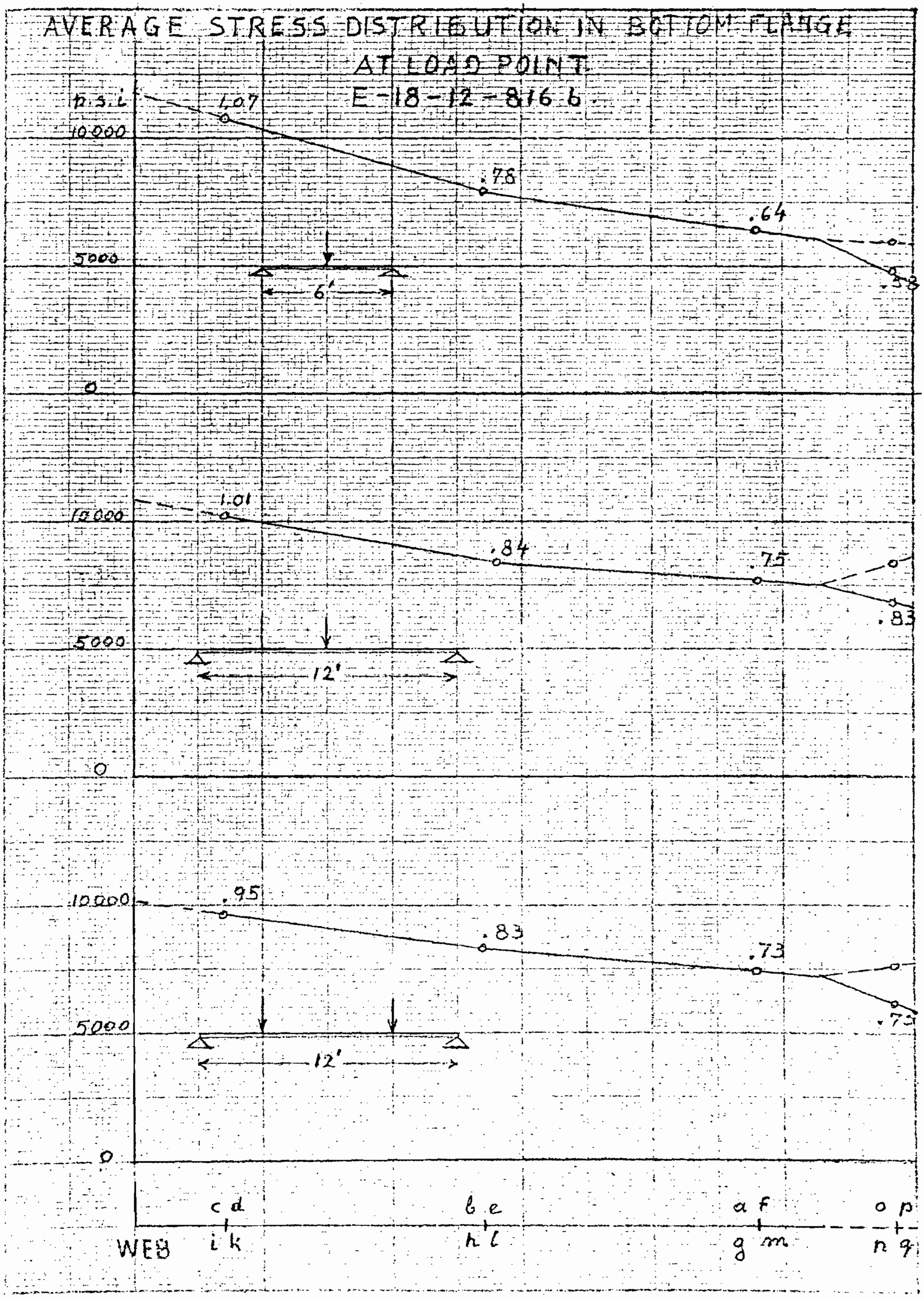


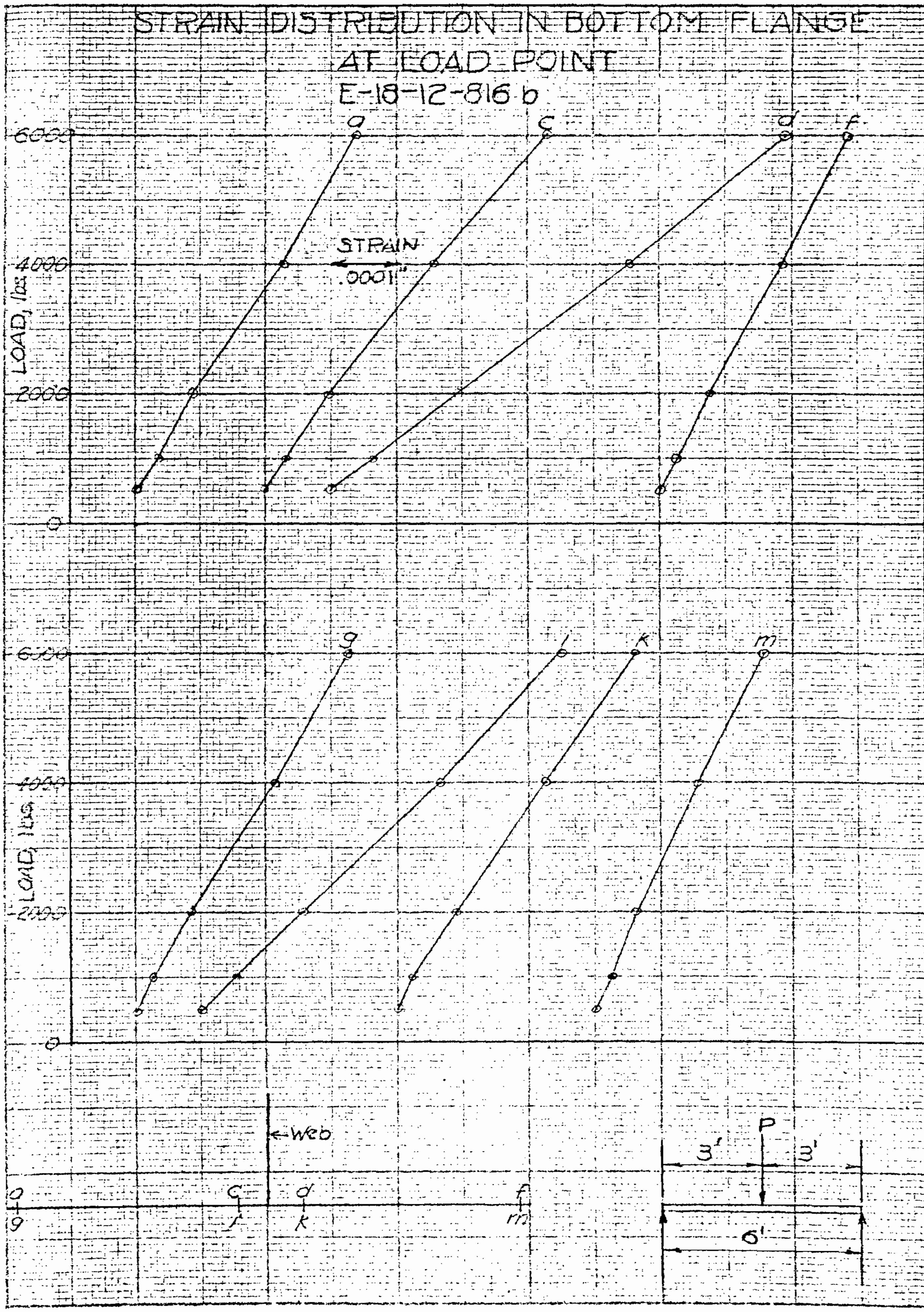
STRESS DISTR. IN BOTTOM FLANGE
AT POINT "F"
E-13-12-816 b
LOADING DIAGRAM
12'
TOP SURFACE
BOTTOM SURFACE
MID - PLANE
LONGITUDINAL STRESS
σ_x
10000
5000
0
K_{σ_x} = ACTUAL STRESS / STRESS BY FLEXURE FORMULA
.96
.81
.77
.78
1.00
.79
.76
.74
.86
.87
1.17
1.13
1.03
.76
.82
.83
.96
.89
.75
o a b c d e f p
n g h i k l m q

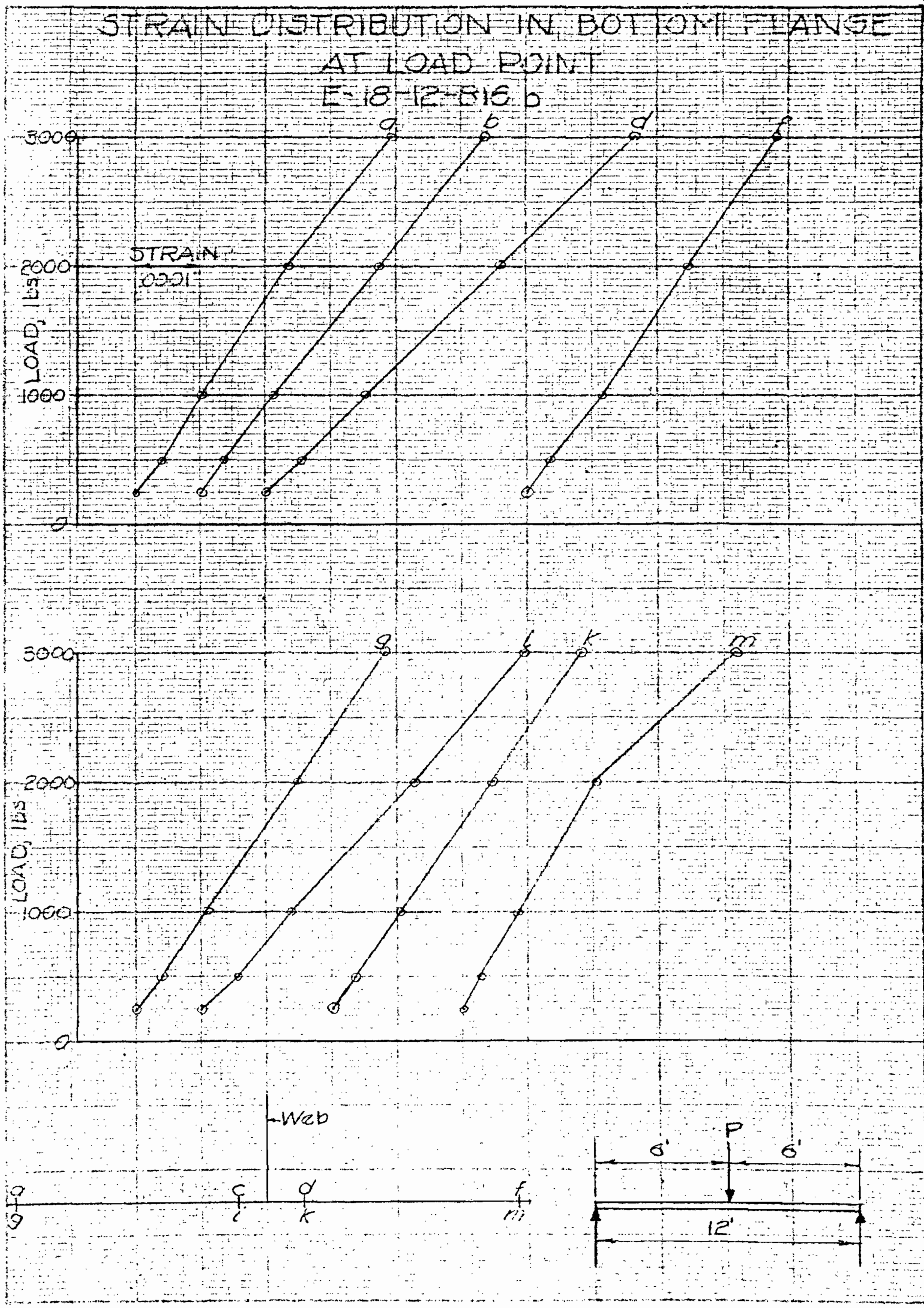


STRESS DISTR. IN BOTTOM FLANGE AT POINT "G"
E-15-12-816-b
G
LOADING DIAGRAM
3'
12'
LONGITUDINAL STRESS σ_x
10,000
5000
0
10000
5000
0
10000
5000
0
TOP SURFACE
.87
.88
.75
.80
.82
.75
.83
.76
BOTTOM SURFACE
.92
.96
1.01
.97
1.06
.99
1.02
.80
$K_{\sigma_x} = \frac{\text{ACTUAL STRESS}}{\text{STRESS BY FLEXURE FORMULA}}$
MID - PLANE
.89
.92
.88
.89
.94
.87
.93
.83
o a b c d e f p
n g h i k l m q


LOADING (H) DIAGRAM
36" 36"
12'
STRESS DISTR. IN BOTTOM FLANGE AT POINT "H"
E-18-12-816-b
12000
1.04
.89
.83
.77
.91
1.01
.99
1.15
TOP SURFACE
5000
0
10000
1.12
.85
1.01
1.09
.79
.81
.83
1.06
BOTTOM SURFACE
5000
$K_{\sigma_x} = \frac{\text{ACTUAL STRESS}}{\text{STRESS BY FLEXURE FORMULA}}$
0
LONGITUDINAL STRESS σ_x
10000
1.03
.85
.92
.91
.88
.91
.91
1.11
MID - PLANE
5000
0
WEB
o a b c d e f
n g h i k l m


AVERAGE STRESS DISTRIBUTION IN BOTTOM FLANGE
AT LOAD POINT
E-18-12-816.6
p.s.i.
10000
5000
0
1.07
.78
.64
.58
6'
1.01
.84
.75
.83
12'
.95
.83
.73
.73
12'
WEB
c d
i k
b e
h l
a f
g m
o p
n q


STRAIN DISTRIBUTION IN BOTTOM FLANGE
AT LOAD POINT
E-18-12-816 b
a
c
d
f
6000
4000
2000
0
LOAD, lbs.
STRAIN
.0001"
g
l
k
m
6000
4000
2000
0
LOAD, lbs.
←Web
P
3'
3'
6'
0
g
c
l
d
k
f
m


STRAIN DISTRIBUTION IN BOTTOM FLANGE
AT LOAD POINT
E-18-12-B16 b
a
b
d
f
3000
2000
1000
0
STRAIN
.0001"
LOAD, lbs
g
i
k
m
3000
2000
1000
0
LOAD, lbs
Web
a
g
c
i
d
k
f
m
P
6'
6'
12'

STRAIN DISTRIBUTION IN BOTTOM FLANGE AT LOAD POINT
E-18-12-8I6 b