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BEHAVIOR OF WEBS OF ROLLED SECTIONS UNDER IN-PLANE COMPRESSIVE EDGE LOADS.

by

Mohamed Elgaaly, and
Raghuvir Salkar

DEPARTMENT
OF
CIVIL
ENGINEERING

COLLEGE OF
ENGINEERING AND SCIENCE

UNIVERSITY OF MAINE
BOARDMAN HALL
ORONO, MAINE 04473

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AMERICAN INSTITUTE OF STEEL CONSTRUCTION, INC.
One East Wacker Drive ■ Suite 3100 ■ Chicago, Illinois 60601-2001 ■ Telephone (312) 670-2400
TELEX: (910) 350-6816 FAX: (312) 670-5403

November 1, 1990

To: AISC Committee on Specifications

Gentlemen:

Enclosed are suggested modifications to the LRFD Web Crippling equations by M. Elgaaly.

Please review for the upcoming Committee meetings.

Sincerely,

Cynthia J. Zahn

Cynthia J. Zahn
Senior Staff Engineer/Structures

CJZ/pab
Enclosures

UNIVERSITY OF MAINE

Department of Civil Engineering

103 Boardman Hall
Orono, Maine 04469-0110
207/581-2171

10/31/90

Mr. Nestor R. Iwankiw
American Institute of Steel Construction
One East Wacker Drive, Suit 3100
Chicago, Illinois
60601-2001

Dear Nestor:

This note is to suggest a modification to the LRFD web crippling equations, as follows

1. Equation (K1-4) is to be replaced by equation (1), on page 4 of my report submitted to you on 9/28/90, and
2. Equation (K1-5) is to be replaced by equation (3), on page 6 of the same report.

These modifications are to be carried on to the ASDS, by multiplying the new equations by 0.75xo.67. My conclusions regarding the local web yielding equations (K1-2) and (K1-3) are very well documented in my report and I will be addressing these conclusions in the next Specification Committee meeting.

Attached herewith is a table showing the S.O.M. standard design for beam seat width. As you can see the suggested modifications to the equations result in better correlation with the S.O.M. standard practice.

I am attaching also the Specification Committee attendance sheet, I trust that AISC will take care of my hotel reservation. The airline ticket costs $693.00 and a statement from my travel agent is attached; I have paid already for the ticket.

If you have any questions please advise. Looking forward to seeing you in the next AISC Specification Committee meeting.

Sincerely yours

Mo

Mo Elgaaly

10/29/90

SECTION	Tf/Tw	REACTION (kips)	C (in)	C/d	N (in)	N' (in)
W 12x14	1.125	25.0	4.00	.336	9.05	5.54
W 12x16	1.205	25.0	4.00	.334	7.00	4.34
W 12x19	1.489	25.0	4.00	.329	6.13	3.11
W 12x26	1.652	25.0	4.00	.327	7.06	3.02
W 14x22	1.457	30.0	4.00	.291	10.63	5.14
W 14x26	1.647	30.0	4.00	.288	7.60	3.28
W 14x30	1.426	30.0	4.00	.289	5.51	3.09
W 14x34	1.597	30.0	4.00	.286	4.17	1.99
W 16x26	1.380	38.0	4.50	.287	13.19	6.62
W 16x31	1.600	38.0	4.50	.283	10.30	4.57
W 16x36	1.458	38.0	4.50	.284	7.31	3.87
W 16x40	1.656	38.0	4.50	.281	6.45	2.82
W 18x35	1.417	42.0	4.50	.254	9.31	5.00
W 18x40	1.667	42.0	4.50	.251	7.95	3.41
W 21x44	1.286	50.0	5.50	.266	7.81	5.04
W 24x55	1.278	60.0	5.50	.233	7.72	5.19
W 24x62	1.372	60.0	5.50	.232	4.68	3.18
W 27x84	1.391	80.0	6.50	.243	8.52	5.14
W 30x99	1.289	100.0	6.50	.219	8.80	5.99
W 33x118	1.346	115.0	7.50	.228	10.57	6.68
W 36x135	1.317	140.0	7.50	.211	12.06	7.75
W 36x150	1.504	140.0	7.50	.209	9.77	5.31

C = seat width from standard practice.
N = seat width from equation K1.5 of LRFD specification.
N' = seat width from equation (3) of report (incorporates modifications to equation K1-5).

BEHAVIOR OF WEBS OF ROLLED SECTIONS UNDER IN-PLANE COMPRESSIVE EDGE LOADS.

By Mohamed Elgaaly[a] and Raghuvir Salkar[b]

Introduction :

Webs of rolled sections can be subjected to local in-plane compressive edge loads. Examples are, wheel loads, loads from purlins, reactions at bearing plates, and roller loads during construction. For practical and/or economic reasons, transverse stiffeners are to be minimized or avoided, except at critical sections. It is, therefore, necessary to check the strength of the unstiffened web under edge compressive loading to ensure that no localized failure will occur.

During the past 60 years, tests have been performed to study the web behavior under in-plane compressive edge loads. They are mostly of the type shown in figure (1); however, the compression of webs over a support bearing plate, as shown in figure (2), was also investigated. All test results indicate that the web ultimate capacity 'P_u' is

a Professor,

b Graduate Research Assistant

Department of Civil Engineering, University of Maine, Orono, ME 04469.

almost independent of the web slenderness ratio and the flange width to thickness ratio. It is, however, more or less directly proportional to the square of the web thickness, and is influenced to a lesser extent by the length of the patch load 'N', the flange thickness 't_f', and the web material yield stress 'F_y'[1].

The ratio of the length of the patch to the web depth, (N/d), in most of the tests conducted to-date, was limited to a maximum value of 0.33. Recently, work has been carried out in Japan by Shimizu and others, where the ratio N/d was as much as 0.50 [2]. At the University of Maine, work began in June 1990, to study the web behavior for N/d ratio varying from 0.2 to as high as 0.8. Failure of the web under loads between the supports as well as over bearing plates at the supports, as shown in figures (1) and (2), respectively, was studied. The AISC formulae for local web yielding and crippling were examined in the light of the new test results. This report contains a brief description of the work done at the University of Maine.

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Experimental Investigation :

Thirty-three tests were conducted on beams made of rolled shapes donated by Cives Steel Co. of Augusta, ME. These tests were of two types, one to study the web failure under loads between supports, and the other to study the failure over bearing plates at the supports. The specimens were of five different shapes, namely W12x14, W14x22, W16x31, W18x35 and W21x50. The ratio N/d for the loads between the supports, varied from 0.2 to 0.8, and from 0.2 to 0.6, for the loads at the supports. For the loads at the supports the bearing plate was placed flush with the edge of the beam. A detailed description of the test specimens can be found in Tables (1) and (2).

All tests were carried out in a Baldwin Testing Machine, with a capacity of 400 kips. The load was applied to the specimens through thick steel plates, placed symmetrically with respect to the plane of the web. The thickness of the plate increased with the ratio N/d. For the tests examining crippling between the supports, two rollers were used as supports, and transverse web stiffeners were placed over the supports, as shown in Figure (1). Two 0.5" thick steel plates were used as bearing plates for the tests examining crippling at the supports, and transverse web stiffeners were provided under the load, as shown in Figure (2). A photograph showing a typical test set-up for the second case is shown in Figure (3).

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<u>**Discussion Of Test Results :**</u>

Tables (1) and (2) give the ultimate web strength of the 33 rolled section specimens, obtained from the tests. They also show the actual specimen dimensions and web material yield stress. The ratio R_1 is seen to range from 0.73 to 1.20, with an average value of 0.90, and R_2 from 0.503 to 1.04, where R_1 and R_2 are as defined under the tables. In general, within a series of tests, R_2 increased with the ratio N/d. It appears that this is due to the fact that for higher N/d ratios, a bigger portion of the load is applied further away from the free edge of the web.

Load Between Supports: It can be seen that, the LRFD equation (K1-4) gives an average value which is 90% of the average test result. However, it appears that equation (k1-4) does not adequately provide for the factor t_f/t_w. If this equation is multiplied by the square root of t_f/t_w, it will provide better correlation with the test results (See- the Appendix in page 12). Hence, it is suggested that equation (K1-4) can be modified as follows,

$$R'_n = 135\ t_w\ t_f\ [1 + 3(N/d)\ (t_w/t_f)^{1.5}]\ (F_y)^{0.5}\ \ldots\ (1).$$

It has been observed in the past as well as during the recent test program at the University of Maine that stocky webs, as those of rolled shapes, yield before crippling. On the other hand, in slender webs crippling occurs before yielding. The photograph given in Figure (4) shows the latter mode of failure in a built-up section. All the tests reported herein, failed in the former mode; yield line (in-the form of an arc of a circle) under the load or over the bearing plates at the supports was observed before crippling occurred. The out-of-plane deformations (crippling) of the web were observed only near or at failure. The photographs given in Figures (5) to (8) show this mode of failure.

In Table (3), P_{uc}, P_{uy}, and P'_{uc} values, calculated from equations (K1-4), (K1-2), and (1), respectively, are given. Nominal and actual values of section dimensions and web material yield stresses were used, and the formulas were multiplied by the corresponding resistance factor. It is seen from Table (3-b) that, equation (K1-2) gives higher values of P_u than those calculated from equation (k1-4) or equation (1). Furthermore, the values given by equation (k1-2) are higher than the values obtained from the tests. For rolled sections, as explained earlier, yielding occurs before crippling and by itself it does not cause failure. Hence, it appears that equation (K1-2) needs to be modified. It is suggested that equation (k1-2) can be modified as follows, $R'_n = (2k + N)\ F_y\ t_w$ .... (2).

Values of P'_{uy} calculated from equation (2) are given in Table (3). It can be seen from Table (3-b) that, P'_{uy} is lower than P'_{uc} only for lower values of N/d (0.2 and 0.4). This is due to the fact that for lower values of N/d, yielding begins much before crippling; however, for large values of N/d, yielding is soon followed by crippling.

The values of P_{uc}, P_{uy}, P'_{uc}, and P'_{uy} given in Table (3-a) are plotted in Figures (9) to (13) together with the test results to illustrate the aforementioned issues. Furthermore, ultimate loads calculated from equations (k1-4) and (k1-2) and the corresponding modifications "equations (1) and (2)", using the actual cross-sectional dimensions and yield stresses (Table 3-b), are given together with the test results in Figures (14) - (18).

Load At Supports: Table (4) shows the P_{uc} and P_{uy} values for all tests where the load was at the support, calculated based on equations (K1-5) and (K1-3), of the LRFD specification , respectively . It is seen from Table (4-b) that, the values of P_{uy} are higher than the test results while the P_{uc} values are lower. Also, it is seen that there is a big discrepancy between the P_{uc} values and the test results. A reduction factor of 0.5 was applied to equation (K1-4) to give equation (K1-5). The research reported herein, however, has shown that the reduction factor "R2" is not constant but rather a function of N/d, as can be noted from Table (2). Average values of R_2 are 0.57, 0.68 (ignoring the .402), and 0.87 for N/d equals 0.2, 0.4 and 0.6, respectively; as can be noted from Table (2). In Figure (19) R_2 is plotted as a function of N/d and as can be seen the straight line, $R_2 = 0.4 + 0.5(N/d)$, gives conservative values of R_2. Combining the modification of equation (k1-4) "equation (1)" and the equation for R_2 provides a modification of equation (k1-5), namely

$P'_{uc} = R_2 * P'_{uc}$ (for load between supports) ... (3).

As can be noted from the Appendix, there is a better correlation between P'_{uc} and the test results than P_{uc}. Furthermore, if equation (k1-3) is modified as follows,

$P'_{uy} = (k + N)\ F_y\ t_w$ ... (4); it will still provide conservative results. As can be noted from Table (4-b), the P'_{uy} values are higher than the P_{uc} or the P'_{uc} values.

Bar-charts showing the results from the tests under support loading vs. the corresponding values obtained from the AISC-LRFD Specification formulas (k1-3) and (k1-5), for N/d values of 0.2, 0.4, and 0.6 are shown in Figures (20) to (22), respectively. Values calculated from the modified (k1-5) "equation (3)" and the modified (k1-3), "equation (4)" are also shown in the figures. In these figures, the top bar charts are based on nominal cross-sectional dimensions and nominal yield stress and the bottom bar charts are based on actual dimensions and yield stresses.

Stiffeners: In tests not reported in any of the above tables, a pair of transverse stiffeners failed, without any failure in the web. One failure was for stiffeners over a support and the other was for stiffeners under load between the supports, as shown in the photographs given in Figures (23) and (24), respectively. For both of these cases, the provisions in chapter K (article 8) of the LRFD specification were found to be conservative, i.e., the Specification failure load is lower than the test failure load. The provisions in the LRFD specification recommend that stiffeners be designed as columns. However, as can be seen, the mode of failure of the stiffeners is not that of a column, but local crippling instead. In some tests, yielding occurred in the web in the vicinity of the stiffeners without failure of the stiffeners, as shown in the photograph given in figure (25). More research needs to be done to study the strength of transverse stiffeners.

Transverse stiffeners under loads acting with a small eccentricity with respect to the stiffener vertical axis also needs to be studied, since such eccentricities should be allowed due to fabrication and erection tolerances.

Conclusions :

Crippling: One of the conclusions from this research is that the LRFD Specification equation (K1-4) predicts the ultimate crippling capacity under in-plane edge loads between the supports with a reasonable degree of accuracy. More accurate results, however, may be obtained by using equation (1) suggested in this report. With respect to crippling over the bearing plate at the supports, equation (k1-5) gives conservative results for large values of N/d. As suggested in this report, a reduction factor R_2, which is a function of N/d, when multiplied by equation (1) will give equation (3), which predicts the crippling load at the supports with a reasonable degree of accuracy.

The above conclusions are based on the results obtained from the tests reported herein, where the test samples are made of rolled beams. For built-up sections, where the slenderness ratio of the web is much higher than in rolled shapes; one would anticipate that the conclusion regarding web crippling under loads between the supports will apply. This can not be said for crippling of unstiffened slender webs over the supports. In such a case, however, one would expect stiffeners to be provided.

Yielding: In the study reported herein, the yielding formulas in the LRFD Specification (k1-2) and k(1-3), consistently provided higher strength than the crippling formulas (k1-4) and (k1-5); hence they do not control the design. The suggested modifications, which are the old AISC

Specification formulas, in most cases, provided higher strength than the crippling formulas. Only for loads between the supports when N/d equals 0.2 or 0.4, the suggested modified yield formula gave lower ultimate capacity than the crippling formula.

Crippling occurs in slender webs prior to yielding, and in such a case, there is no need to provide a yielding limit state. In stocky webs, however, yielding occurs prior to crippling and the beam continues to carry more load. It is not until after crippling when the load carrying capacity of the beam drops down. Hence, one would wonder if there is a need to specify a yielding limit-state at all.

Stiffeners: One can conclude based on the limited results obtained from this study that there is a need to examine the strength of the stiffeners under a direct vertical load. Also, transverse stiffeners loaded under vertical loads, acting at a small eccentricity with respect to the vertical axis of the stiffeners need to be investigated.

Acknowledgements :

This project was sponsored by AISC. The material needed for the tests was provided by Cives Steel Co., Augusta, ME.

References :

1. Elgaaly, M., "Web design under compressive edge loads", AISC Engineering Journal, 153-171, Fourth Quarter, 1983.

2. Shimizu S. , Yabana H., and Yoshida S.," A collapse model for patch-loaded web plates", J. Construct. Steel Research 13, 61-73, 1989.

3. Load and Resistance Factor Design Specification, for Structural Steel Buildings, September 1, 1986; AISC.

APPENDIX - STATISTICAL ANALYSIS

WEB CRIPPLING

i- LOAD BETWEEN SUPPORTS : 20 TESTS

	LRFD (k1-4)	EQUATION (1)
$P_{calculated}/P_{test}$:		
Mean	0.905	1.062
SD	0.127	0.127
Correlation Between Calculated and Test Values:	0.945	0.963
Relative Error, (Ptest-Pcalculated)/Pcalculated:		
Mean	0.122	-0.039
SD	0.149	0.123

ii- LOAD AT SUPPORTS : 13 TESTS

	LRFD (k1-5)	EQUATION (3)
$P_{calculated}/P_{test}$:		
Mean	0.676	0.890
SD	0.099	0.134
Correlation Between Calculated and Test Values:	0.951	0.956
Relative Error, (Ptest-Pcalculated)/Pcalculated:		
Mean	0.513	0.145
SD	0.233	0.144

Note: Calculated values are based on actual cross-sectional dimensions and actual yield stresses.

Table(1)-Web failure under load between supports.

No	Sect	N/d	b/d	d/t_w	b_f/t_f	t_f/t_w	t_w	F_y	P_{tst}	R_1
1	W 12	0.2	1.59	59.39	19.35	1.05	.201	50.4	52.50	0.88
2		0.4	1.59	59.39	19.35	1.05	.201	50.4	74.50	0.85
3		0.6	1.58	60.29	19.35	1.06	.198	53.4	75.25	1.05
4		0.8	1.60	59.69	19.04	1.08	.200	52.4	90.00	1.07
5	W 14	0.2	1.61	56.35	15.30	1.37	.244	51.6	89.00	0.78
6		0.4	1.61	56.35	15.30	1.37	.244	51.6	97.00	0.92
7		0.6	1.60	60.57	15.53	1.45	.227	46.4	86.25	1.01
8		0.8	1.63	60.57	15.53	1.45	.227	47.9	107.5	0.96
9	W 16	0.2	1.59	60.37	12.79	1.63	.264	56.4	112.0	0.78
10		0.4	1.59	60.37	12.79	1.63	.264	56.4	145.0	0.74
11		0.6	1.59	59.92	13.08	1.62	.266	52.7	169.5	0.73
12		0.8	1.59	60.14	13.08	1.62	.265	56.9	173.5	0.85
13	W 18	0.2	1.59	58.39	13.94	1.43	.304	48.0	110.0	0.95
14		0.4	1.59	58.39	13.94	1.43	.304	48.0	125.0	1.06
15		0.6	1.60	61.42	14.10	1.49	.289	61.1	185.0	0.87
16		0.8	1.58	58.20	14.44	1.38	.305	52.4	165.0	1.20
17	W 21	0.2	1.58	59.65	12.62	1.50	.351	57.9	194.0	0.79
18		0.4	1.58	59.65	12.62	1.50	.351	57.9	232.0	0.83
19		0.6	1.58	59.31	12.62	1.49	.353	56.9	296.0	0.78
20		0.8	1.58	59.31	12.62	1.49	.353	56.9	273.0	0.99

In the above table,
b, d, N, b_f, t_f, and t_w are as shown in figure (1),
F_y = Actual yield stress,(ksi)
P_{tst} = Ultimate load from test,
R_1 = P_{uc}/P_{tst}, where
P_{uc} = Web crippling strength calculated from equation (K1-4) of the AISC-LRFD specification, taking into account the resistance factor of 0.75. *
In calculating P_{uc}, the actual section dimensions and actual yield stresses were used.

Table(2)-Web failure under load at supports.

No	Sect	N/d	L/d	d/t_w	b_f/t_f	t_f/t_w	t_w	F_y	P_{tst}	R_2
1	W 12	0.2	1.77	59.08	18.75	1.07	.201	53.2	28.25	.524
2		0.4	1.75	59.41	18.90	1.06	.202	51.9	46.25	.612
3		0.6	1.76	60.00	18.90	1.08	.199	54.2	64.75	.854
4	W 14	0.2	1.74	58.28	15.53	1.39	.237	54.4	46.00	.503
5		0.4	1.74	60.10	15.53	1.44	.230	49.9	58.50	.613
6		0.6	1.74	57.10	15.30	1.38	.242	52.5	95.50	1.04
7	W 16	0.2	1.69	60.60	13.08	1.64	.263	57.6	67.50	.596
8		0.4	1.69	64.26	13.25	1.67	.248	69.6	64.75	.402
9		0.6	1.69	60.83	12.79	1.64	.262	58.8	127.0	.709
10	W 18	0.2	1.69	60.37	14.10	1.46	.294	62.6	73.25	.583
11		0.4	1.69	60.37	14.27	1.45	.294	60.1	99.00	.708
12	W 21	0.2	1.58	57.84	12.61	1.45	.362	62.8	127.5	.631
13		0.4	1.58	59.82	12.61	1.50	.350	59.0	180.0	.769

In the above table,
Same notations are as defined before under Table (1),
L = The length of the specimen as shown in figure (2), and
R_2 = The ratio of P_{tst} from table (2) to its corresponding value in table (1), adjusted to account for the variation in the actual yield stresses.

Table(3)-P_{uc} and P_{uy} for tests with load between supports.

(a)-Using nominal yield stress and cross-section dimensions.

No	Sect	N/d	P_{uc}	P_{uy}	P'_{uc}	P'_{uy}	P_{tst}
1	W 12	0.2	38.73	41.90	41.08	27.05	52.50
2		0.4	51.69	59.10	54.83	44.20	74.50
3		0.6	64.65	76.20	68.57	61.35	75.25
4		0.8	77.61	93.35	82.32	78.50	90.00
5	W 14	0.2	52.02	58.98	62.78	37.24	89.00
6		0.4	65.26	81.73	78.76	60.00	97.00
7		0.6	78.50	104.5	94.74	82.75	86.25
8		0.8	91.74	127.2	110.7	105.5	107.5
9	W 16	0.2	75.34	87.13	95.30	53.72	112.0
10		0.4	92.57	118.6	117.1	85.16	145.0
11		0.6	109.8	150.0	138.9	116.6	169.5
12		0.8	127.0	181.5	160.7	148.1	173.5
13	W 18	0.2	88.23	98.98	105.0	62.53	110.0
14		0.4	111.4	137.2	132.6	100.8	125.0
15		0.6	134.6	175.5	160.2	139.0	185.0
16		0.8	157.7	213.7	187.7	177.2	165.0
17	W 21	0.2	141.5	146.8	167.9	92.90	194.0
18		0.4	178.9	203.8	212.3	149.9	232.0
19		0.6	216.2	260.8	256.6	206.9	296.0
20		0.8	253.6	317.7	301.0	264.4	273.0

(b)-Using actual yield stress and cross-section dimensions.

No	Sect	N/d	P_{uc}	P_{uy}	P'_{uc}	P'_{uy}	P_{tst}
1	W 12	0.2	46.37	59.06	47.52	38.15	52.50
2		0.4	62.97	83.27	64.53	62.36	74.50
3		0.6	79.22	112.4	81.56	90.50	75.25
4		0.8	95.89	136.2	99.42	114.6	90.00
5	W 14	0.2	69.64	89.65	81.60	56.62	89.00
6		0.4	88.56	124.3	103.8	91.23	97.00
7		0.6	86.85	133.0	104.7	105.3	86.25
8		0.8	103.1	167.2	124.4	138.6	107.5
9	W 16	0.2	87.17	131.2	111.3	80.97	112.0
10		0.4	106.7	178.7	136.2	128.4	145.0
11		0.6	124.0	212.9	157.8	165.6	169.5
12		0.8	147.7	277.1	188.0	226.2	173.5
13	W 18	0.2	104.7	133.9	125.2	84.63	110.0
14		0.4	131.9	185.7	157.8	136.4	125.0
15		0.6	160.5	287.4	196.0	227.8	185.0
16		0.8	198.7	316.8	233.4	262.9	165.0
17	W 21	0.2	154.2	218.5	188.9	138.5	194.0
18		0.4	192.2	303.6	235.4	223.6	232.0
19		0.6	231.1	384.2	282.1	305.1	296.0
20		0.8	269.5	468.3	328.9	389.2	273.0

Table(4)-P_{uc} and P_{uy} for tests with load at supports.

(a)-Using nominal yield stress and cross-section dimensions.

No	Sect	N/d	P_{uc}	P_{uy}	P'_{uc}	P'_{uy}	P_{tst}
1	W 12	0.2	19.51	29.48	20.54	22.10	28.25
2		0.4	26.04	46.68	32.99	39.25	46.25
3		0.6	32.56	63.83	48.00	56.40	64.75
4	W 14	0.2	26.20	40.87	31.37	30.00	46.00
5		0.4	32.87	63.62	47.25	52.75	58.50
6		0.6	39.54	86.37	66.31	75.51	95.50
7	W 16	0.2	37.95	59.29	47.65	42.58	67.50
8		0.4	46.63	90.73	70.26	74.02	64.75
9		0.6	55.31	122.2	97.22	105.5	127.0
10	W 18	0.2	44.44	68.61	52.58	50.38	73.25
11		0.4	56.11	106.8	79.68	88.61	99.00
12	W 21	0.2	71.26	101.9	84.01	74.95	127.5
13		0.4	90.10	158.9	127.4	131.9	180.0

(b)-Using actual yield stress and cross-section dimensions.

No	Sect	N/d	P_{uc}	P_{uy}	P'_{uc}	P'_{uy}	P_{tst}
1	W 12	0.2	23.97	43.79	23.76	32.76	28.25
2		0.4	32.41	68.34	38.72	57.53	46.25
3		0.6	40.23	95.81	57.09	84.69	64.75
4	W 14	0.2	34.03	63.81	40.80	46.89	46.00
5		0.4	38.75	88.55	62.26	73.49	58.50
6		0.6	53.65	133.1	73.31	116.5	95.50
7	W 16	0.2	44.08	90.90	55.65	65.34	67.50
8		0.4	52.62	158.6	81.72	129.5	64.75
9		0.6	63.84	190.7	110.5	164.67	127.0
10	W 18	0.2	56.48	117.1	62.62	86.04	73.25
11		0.4	69.43	175.2	94.66	145.3	99.00
12	W 21	0.2	85.69	169.8	94.44	125.0	127.5
13		0.4	97.16	240.7	141.2	200.1	180.0

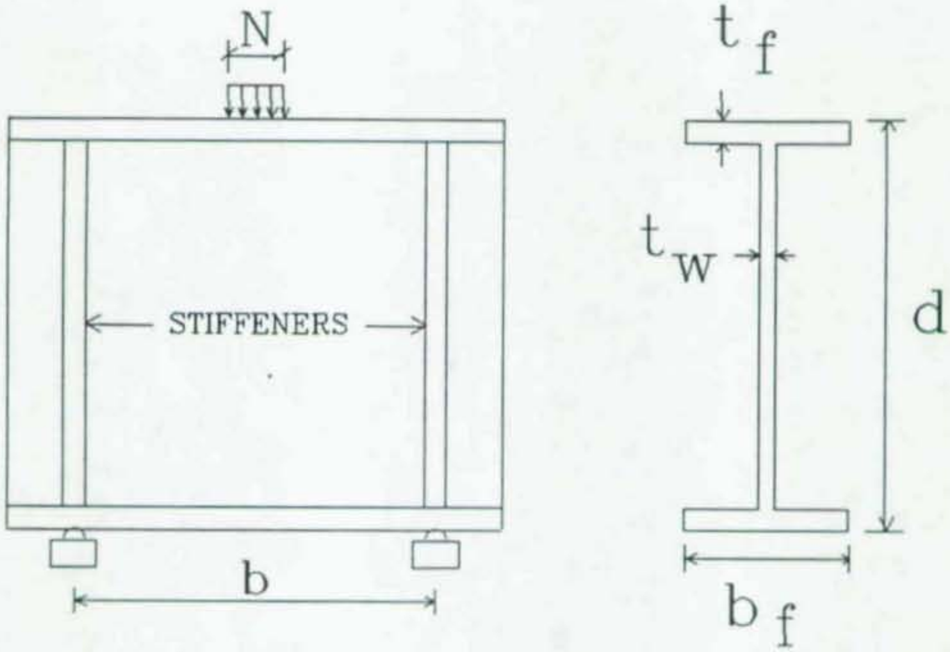


Fig. 1 : Load between supports

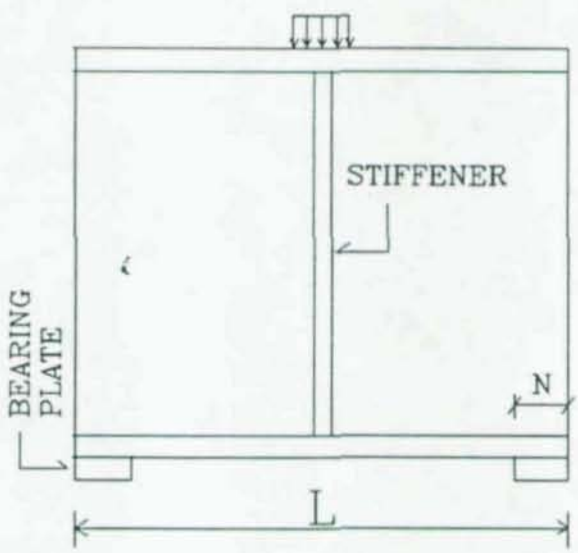


Fig. 2 : Load at supports

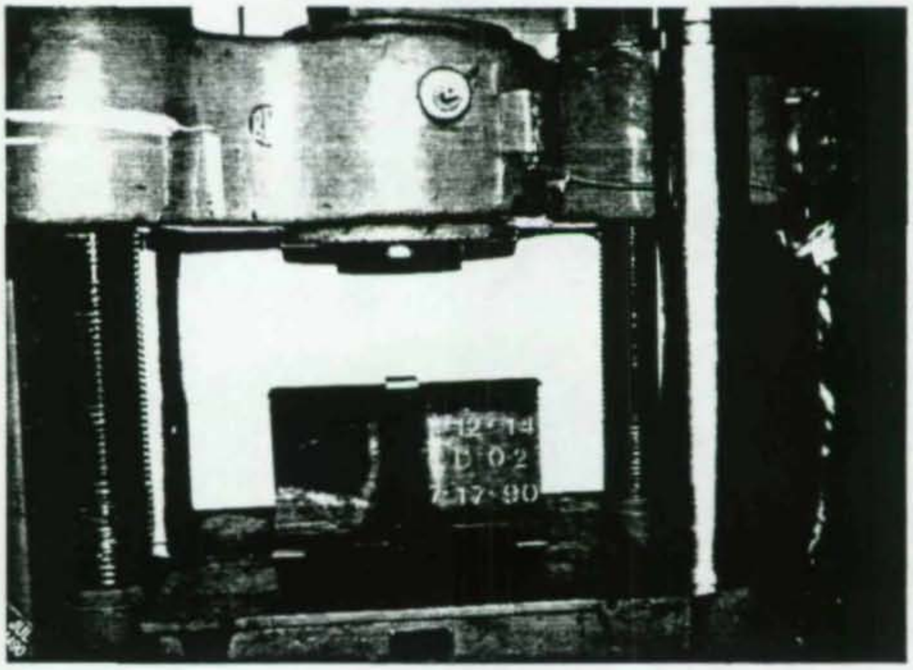


Figure (3) - TEST SET-UP

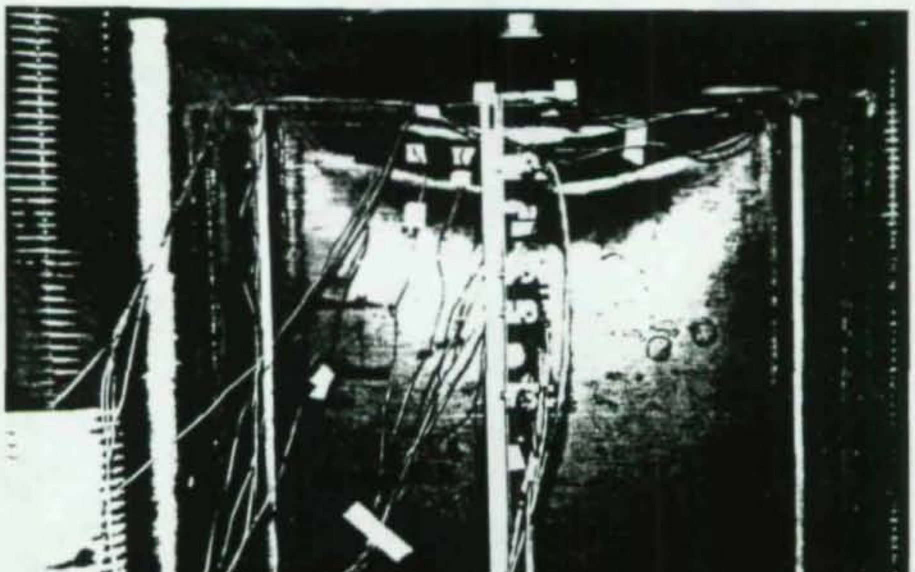


Figure (4) - CRIPPLING FAILURE BEFORE YIELDING

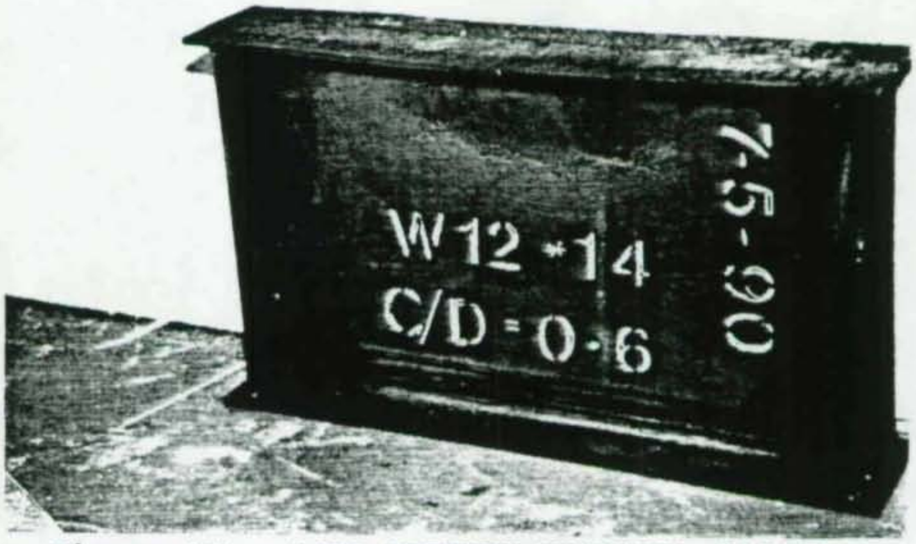


Figure (5) - LOAD BETWEEN SUPPORTS, W12x14
YIELDING BEFORE CRIPPLING

Figure (6) - LOAD BETWEEN SUPPORTS, W16x31
YIELDING BEFORE CRIPPLING

Figure (7) - LOAD AT SUPPORTS, W12x14
YIELDING BEFORE CRIPPLING

Figure (8) - LOAD AT SUPPORTS, W21x50
YIELDING BEFORE CRIPPLING

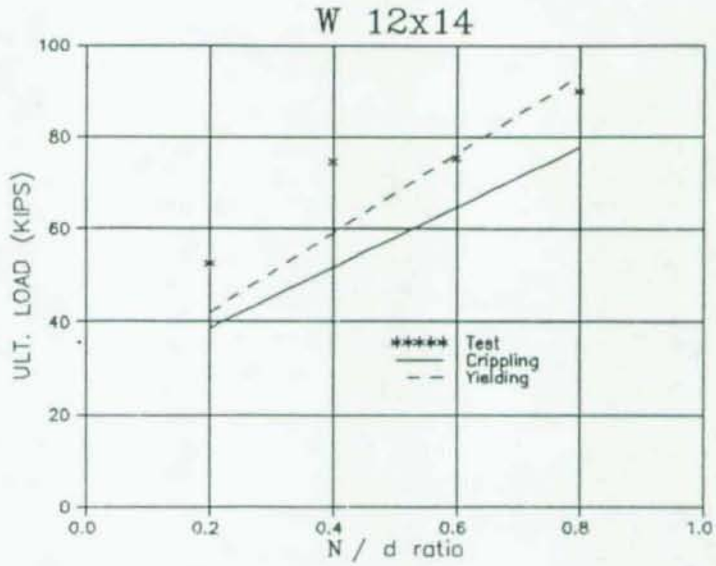


Fig. 9a : Test results v/s LRFD spec formulas (using nominal yield stress and cross-section dimensions)

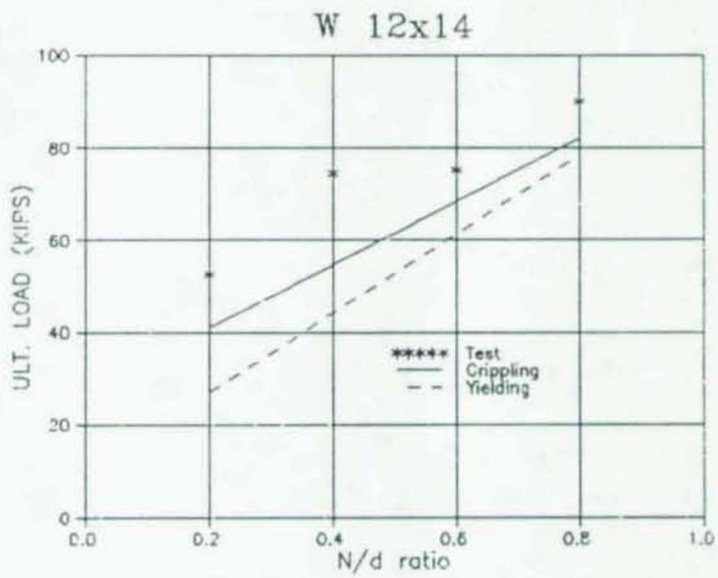


Fig. 9b : Test results v/s modified LRFD spec. formulas (using nominal yield stress and cross-section dimensions)

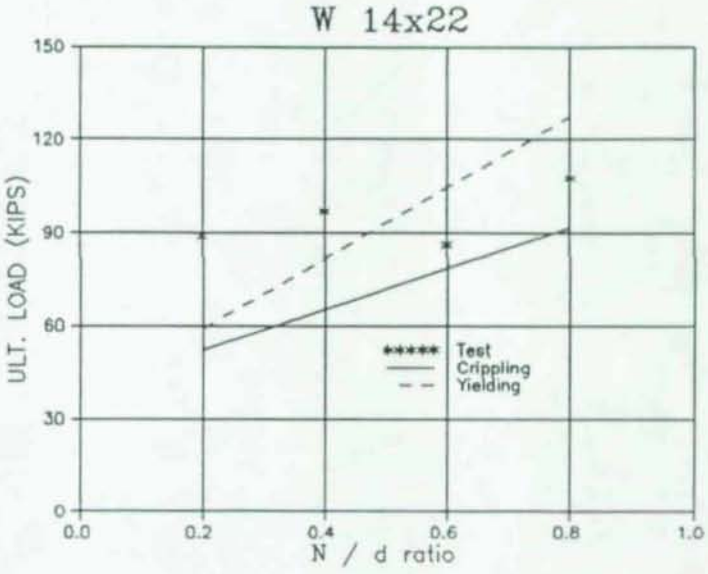


Fig. 10a : Test results v/s LRFD spec. formulas
(using nominal yield stress and cross-section dimensions)

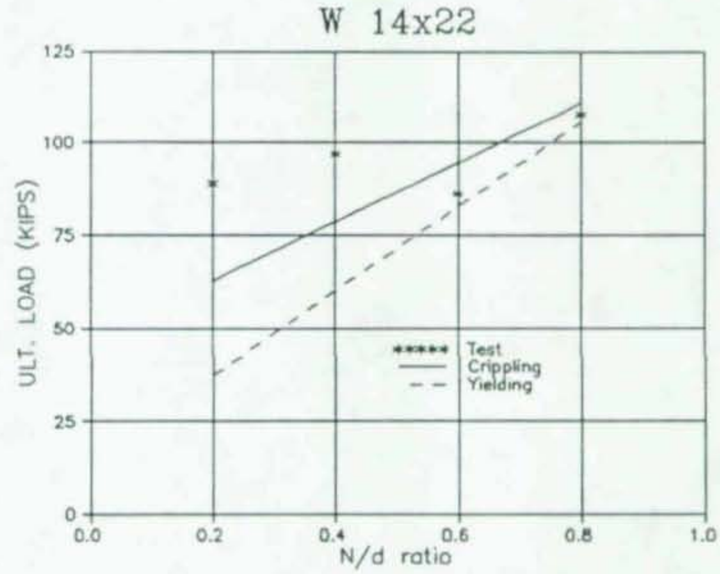


Fig. 10b : Test results v/s modified LRFD spec. formulas
(using nominal yield stress and cross-section dimensions)

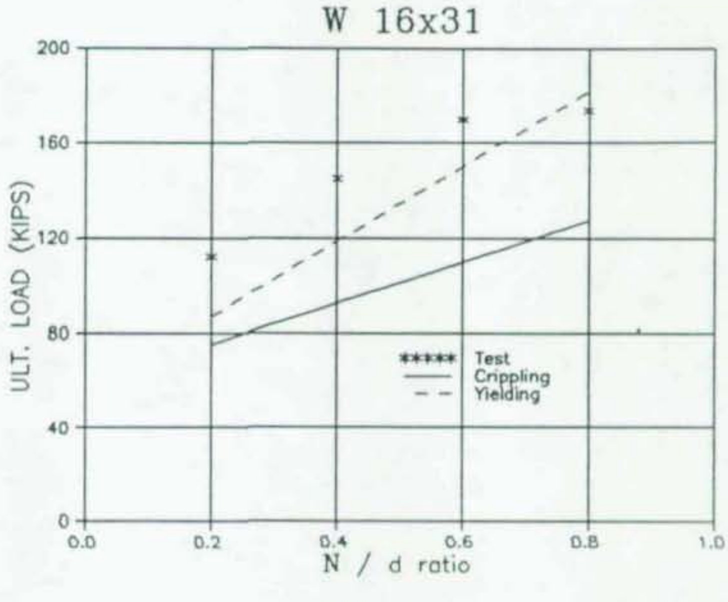


Fig. 11a : Test results v/s LRFD spec. formulas (using nominal yield stress and cross-section dimensions)

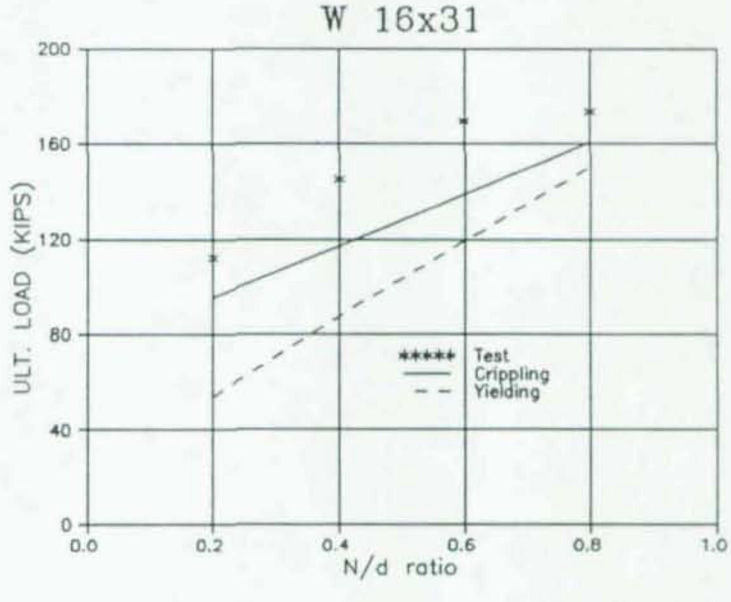


Fig. 11b : Test results v/s modified LRFD spec. formulas (using nominal yield stress and cross-section dimensions)

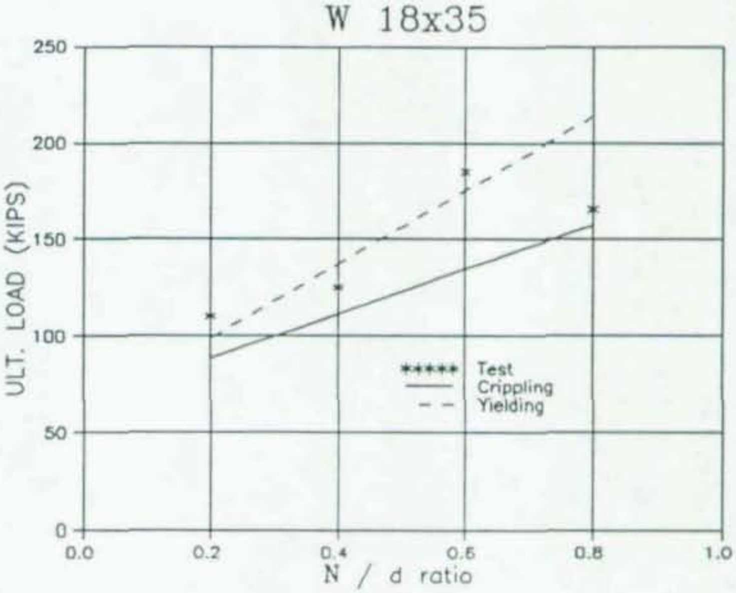


Fig. 12a : Test results v/s LRFD spec. formulas (using nominal yield stress and cross-section dimensions)

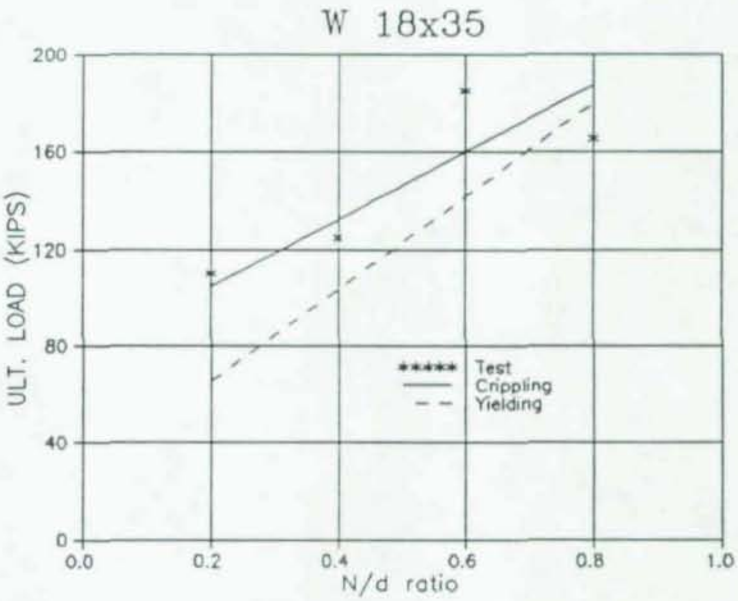


Fig. 12b : Test results v/s modified LRFD spec. formulas (using nominal yield stress and cross-section dimensions)

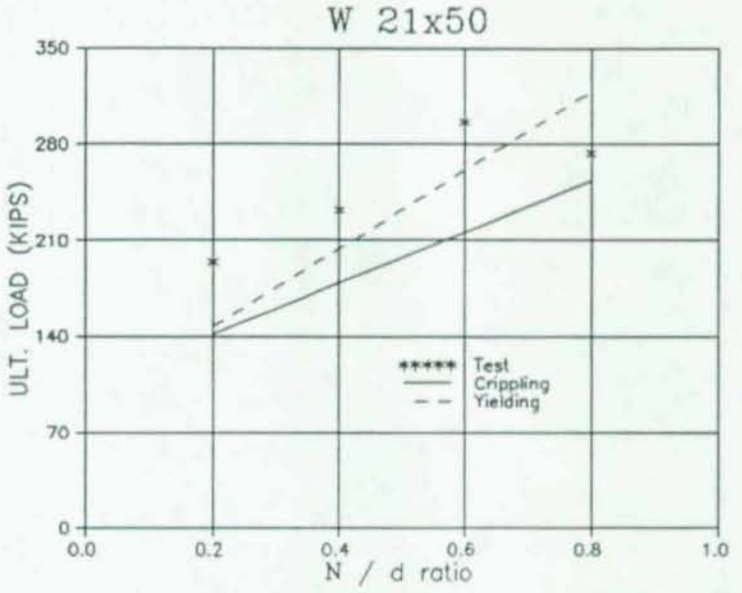


Fig. 13a : Test results v/s LRFD spec. formulas (using nominal yield stress and cross-section dimensions)

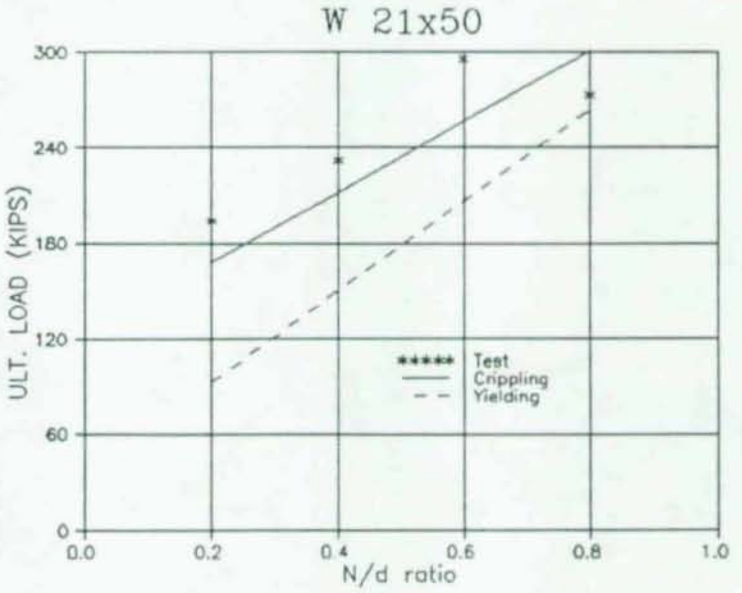
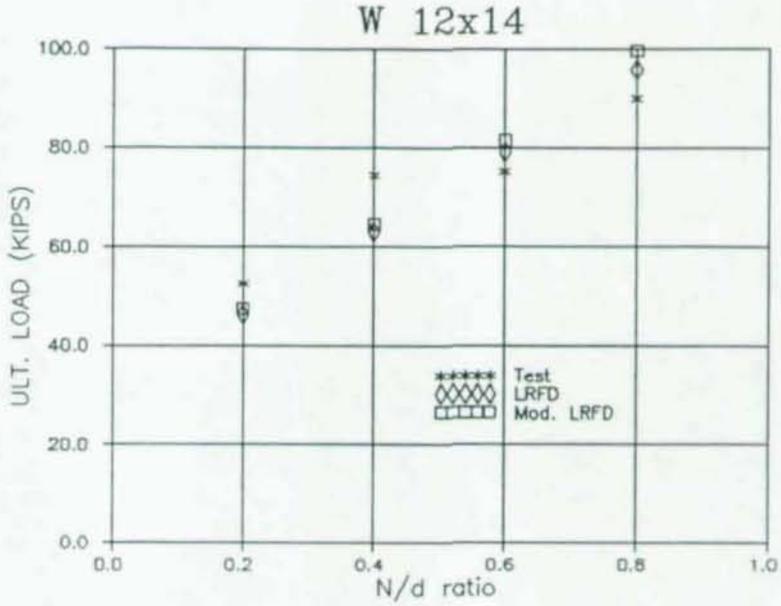
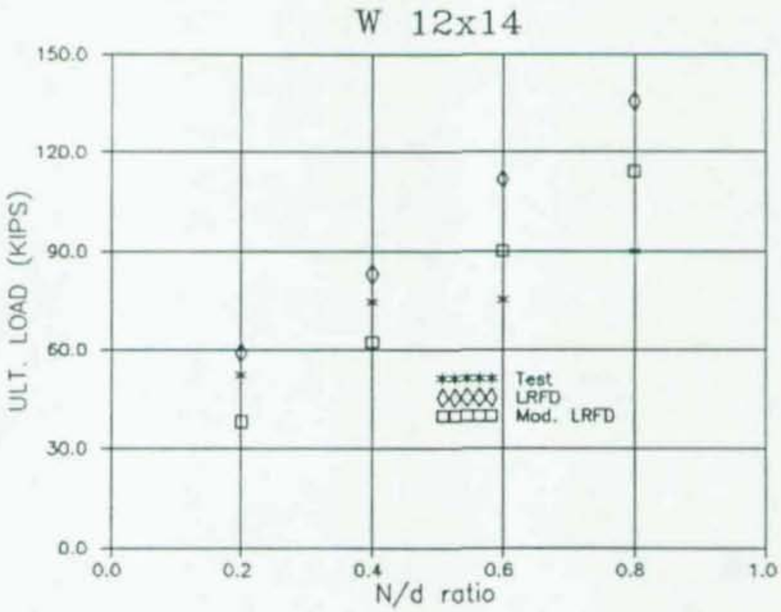


Fig. 13b : Test results v/s modified LRFD spec. formulas (using nominal yield stress and cross-section dimensions)

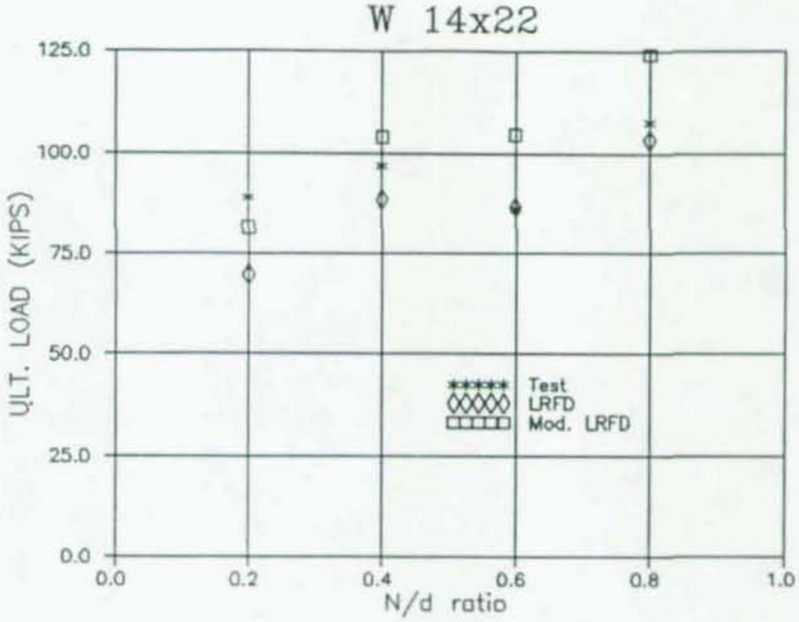


(a) - CRIPPLING

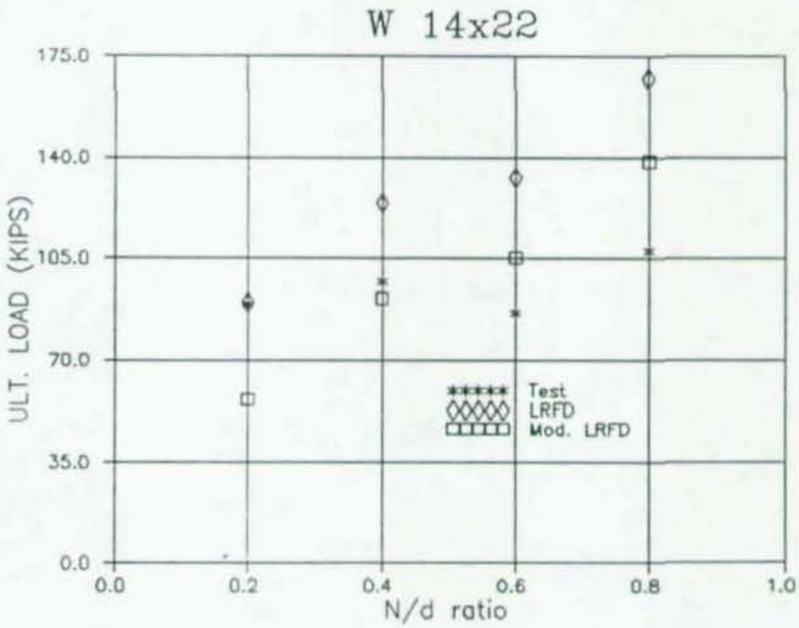


(b) - YIELDING

Fig. 14 : Test results v/s LRFD spec. formulas (using actual yield stress and cross-section dimensions)



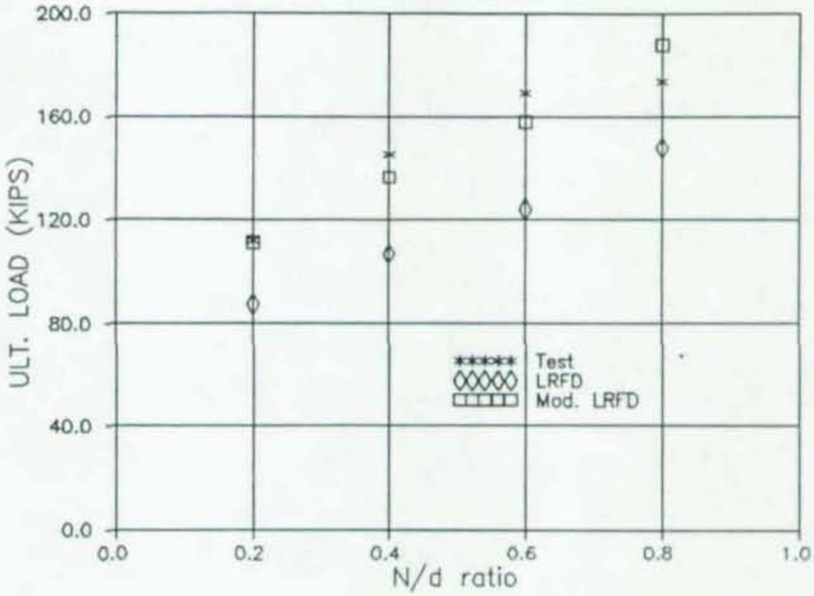
(a) - CRIPPLING



(b) - YIELDING

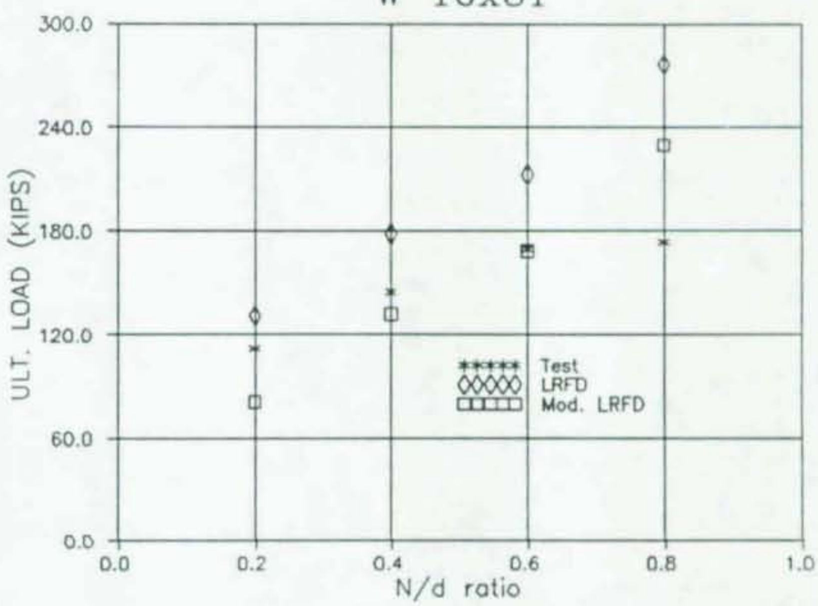
Fig. 15 : Test results v/s LRFD spec. formulas (using actual yield stress and cross-section dimensions)

W 16x31



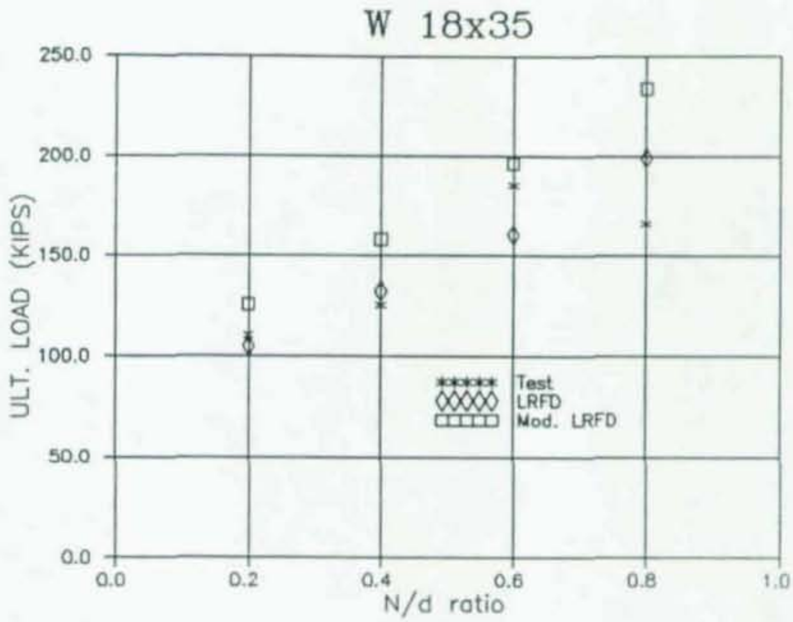
(a) – CRIPPLING

W 16x31

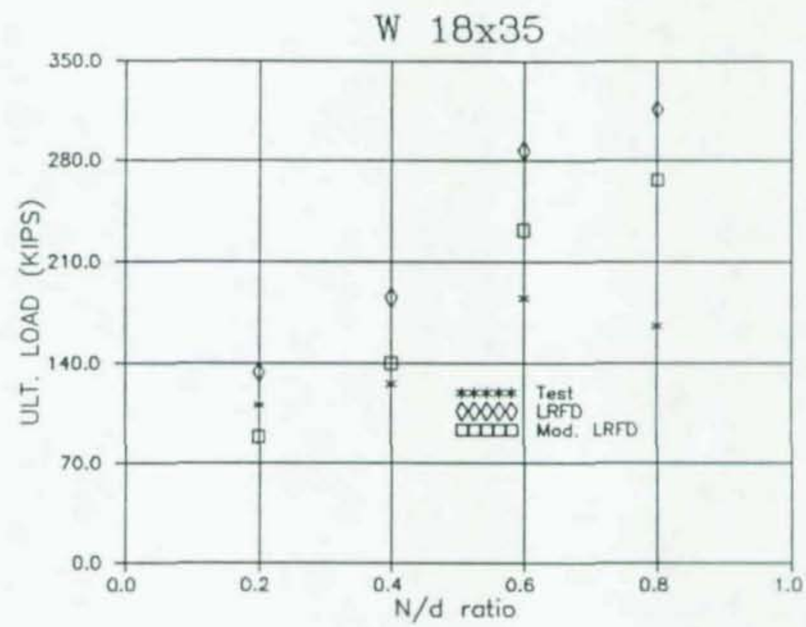


(b) – YIELDING

Fig. 16 : Test results v/s LRFD spec. formulas (using actual yield stress and cross-section dimensions)

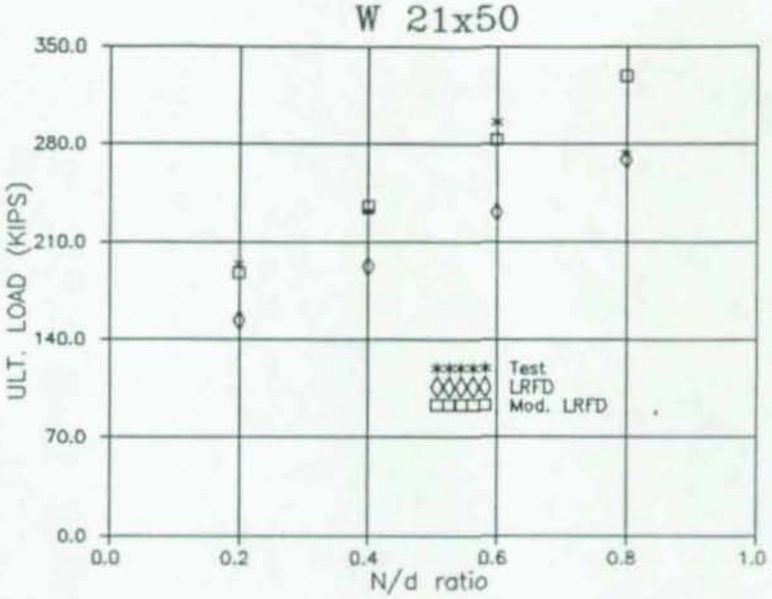


(a) - CRIPPLING

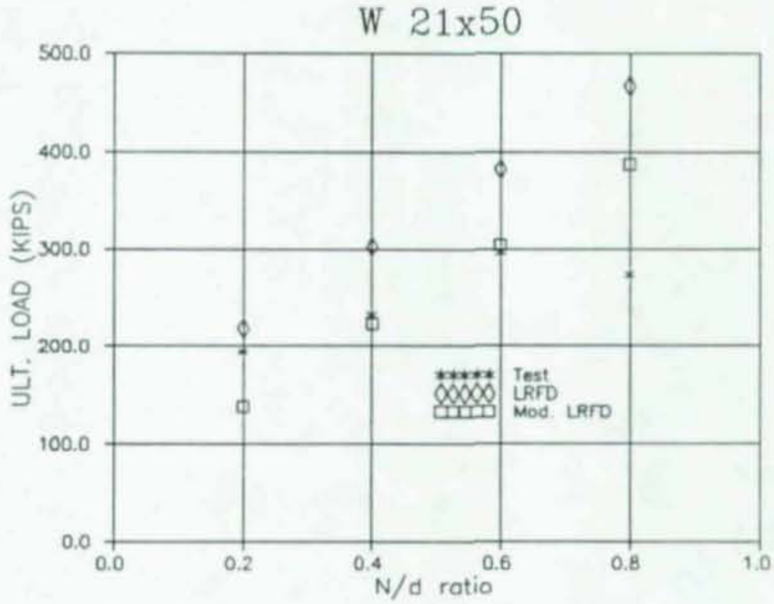


(b) - YIELDING

Fig. 17 : Test results v/s LRFD spec. formulas
(using actual yield stress and cross-section dimensions)



(a) - CRIPPLING



(b) - YIELDING

Fig. 18 : Test results v/s LRFD spec. formulas
(using actual yield stress and cross-section dimensions)

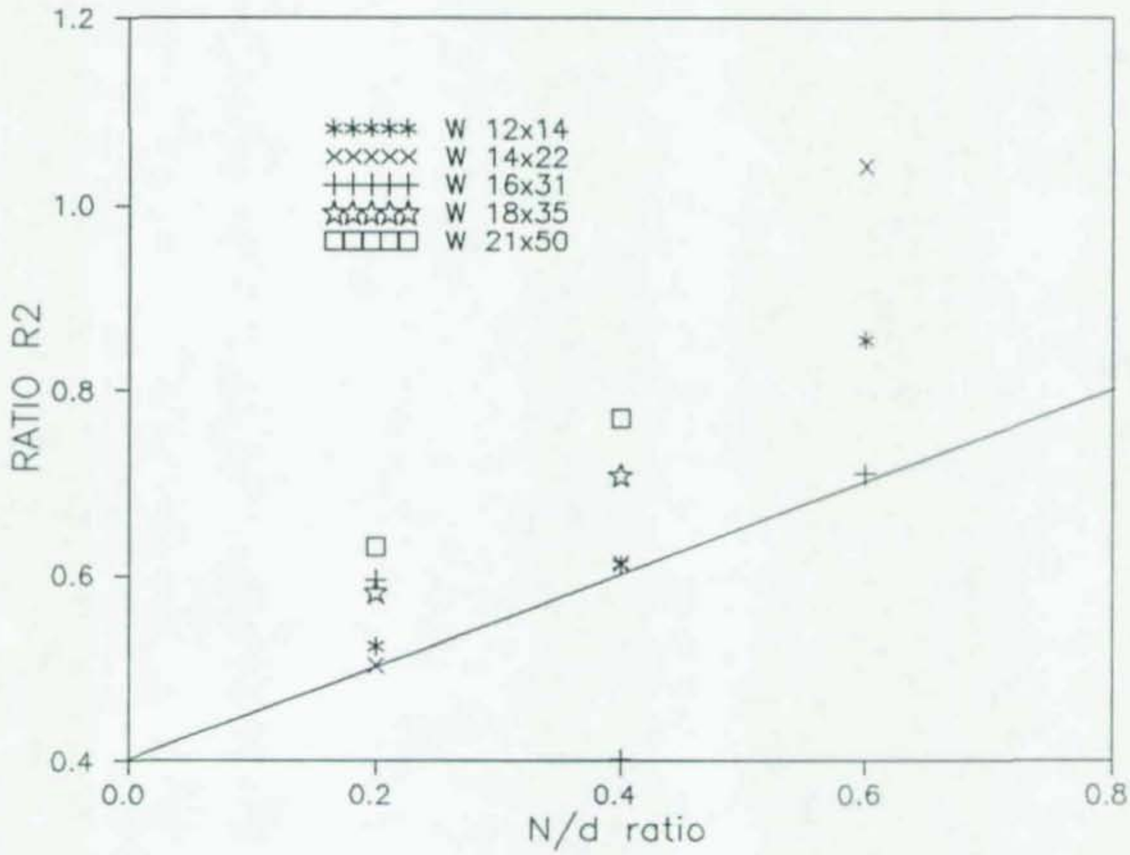
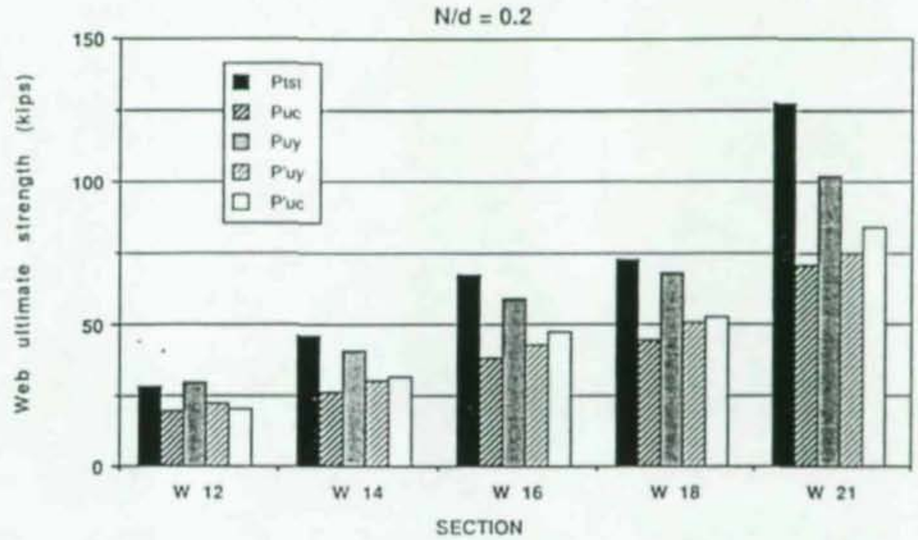
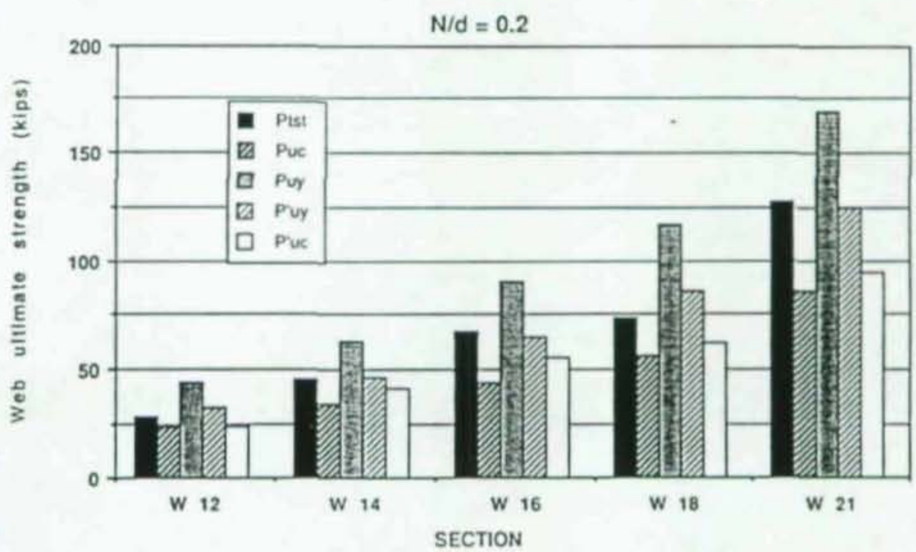


Fig. 19 : Ratio R2 v/s N/d ratio

(R2 = Ptst-Load at supports / Ptst-Load between supports)

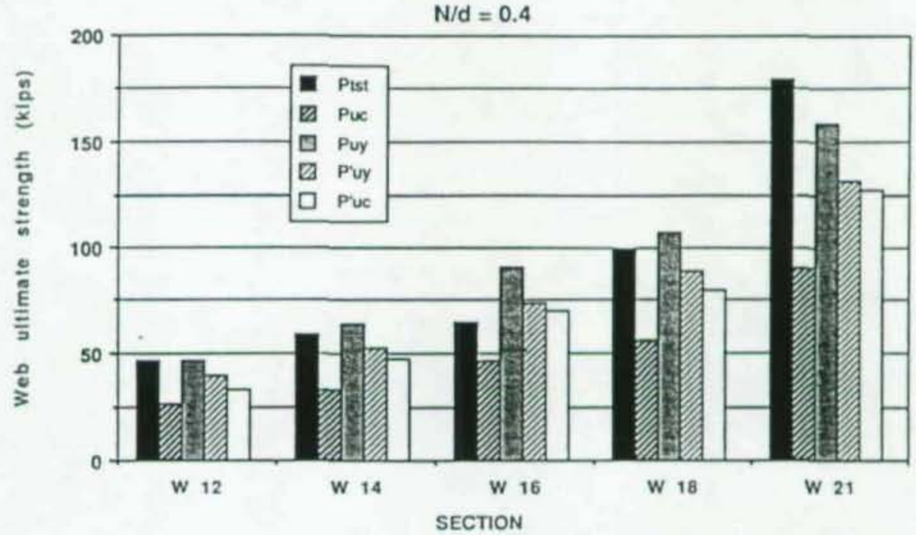


a - Based On Nominal Dimensions and Yield Stress

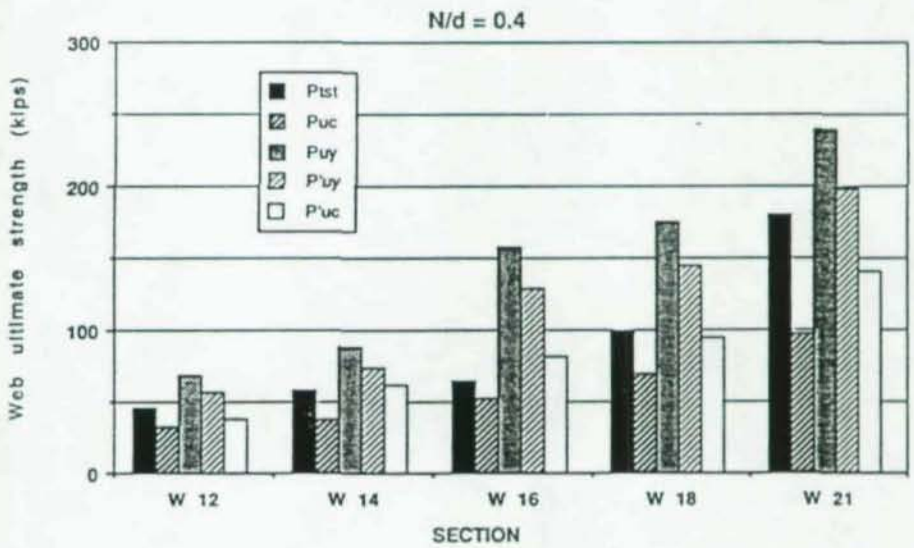


b - Based On Actual Dimensions And Yield Stress

Figure (20) - TEST RESULTS vs. AISC FORMULAS, (ORIGINAL AND MODIFIED) N/d = 0.2

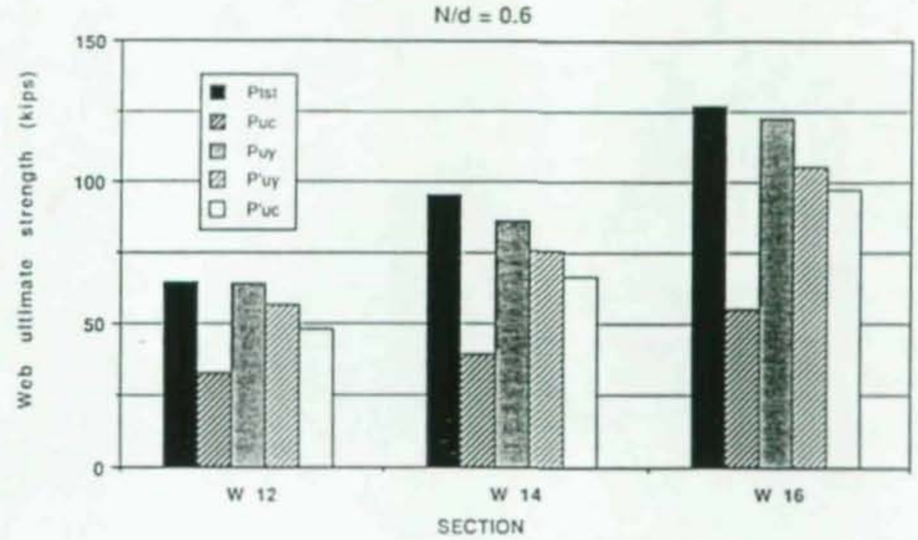


a - Based On Nominal Dimensions and Yield Stress

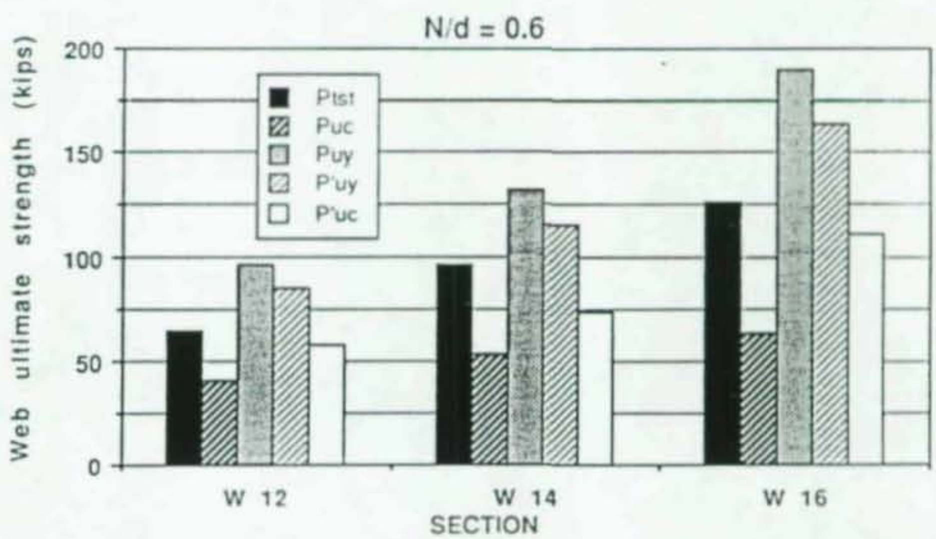


b - Based On Actual Dimensions And Yield Stress

Figure (21) - TEST RESULTS vs. AISC FORMULAS, (ORIGINAL AND MODIFIED) N/d = 0.4



a - Based On Nominal Dimensions and Yield Stress



b - Based On Actual Dimensions And Yield Stress

Figure (22) - TEST RESULTS vs. AISC FORMULAS,
(ORIGINAL AND MODIFIED)
N/d = 0.6

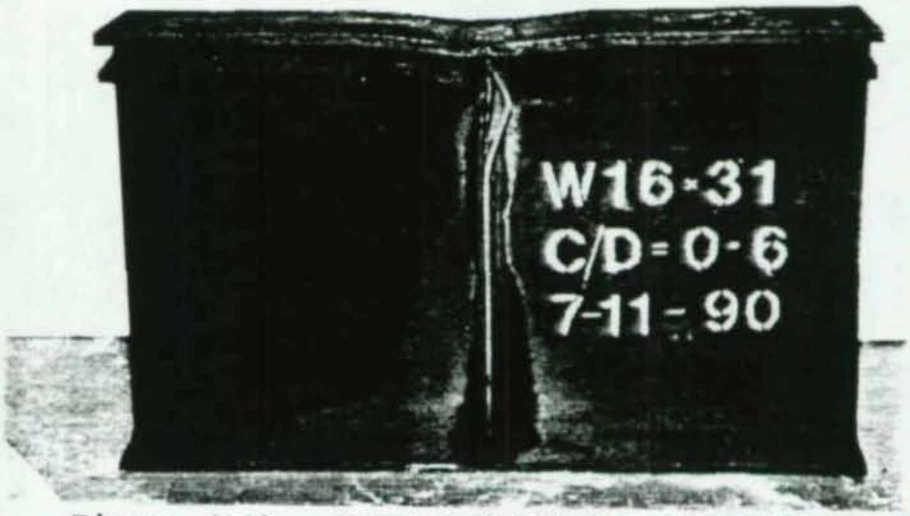


Figure (23) - CRIPPLING OF THE STIFFENERS UNDER THE LOAD.

Figure (24) - CRIPPLING OF THE STIFFENERS OVER THE BEARING PLATE.

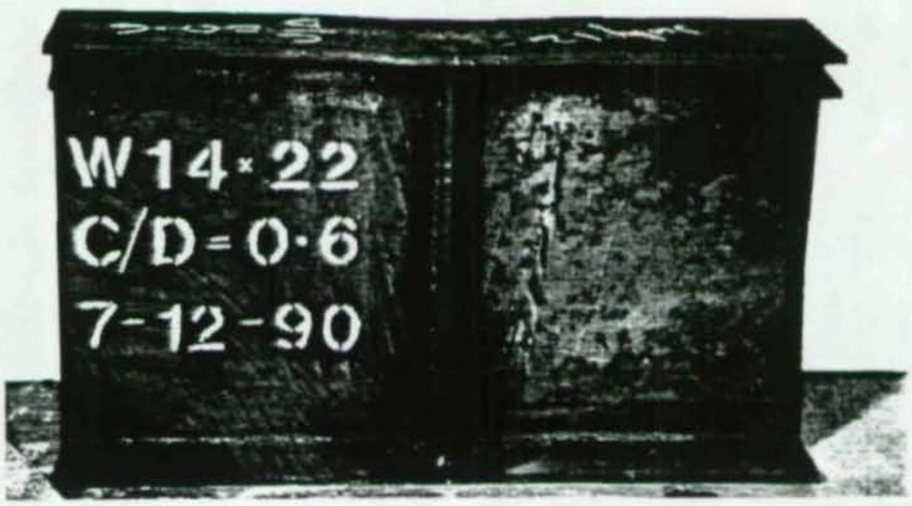


Figure (25) - YIELDING OF THE WEB PLATE WITHOUT FAILURE OF THE STIFFENERS