Web Crippling Under Edge Loading

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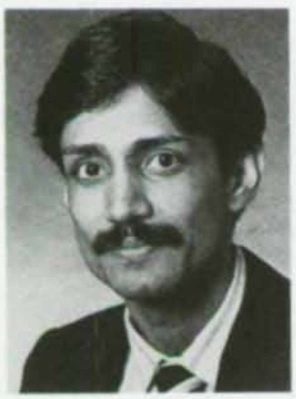

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Dr. Mohammed Elgaaly is professor of civil engineering at the University of Maine. He received a bachelor's degree in civil engineering from Cairo University, and a master's and doctorate from the University of Michigan.

Between his graduation in 1957 and 1974, Dr. Elgaaly taught, conducted research, and did consulting work at Cairo University, the University of Michigan, University of Libya and the University of Wales at Cardiff. Between 1974 and 1985, he held several positions with Bechtel Corporation including principal engineer in the Eastern Power Division.

His research has been primarily on the ultimate strength and postbuckling behavior of steel plate structures. He is the principal investigator on two research projects funded by the National Science Foundation. One project deals with the seismic behavior of steel plate shear walls, which has been recently funded by the National Science Foundation for two more years. The other National Science Foundation project addresses the behavior of web plates under discrete eccentric loads. Dr. Elgaaly received research funds from the American Institute of Steel Construction and the Structural Stability Research Council, to conduct research work on steel plate structures. He was able to secure funds of $100,000 per year for the duration of six years from Bath Iron Works in Maine to help establish the Research Center on Steel Plate Structures at the University of Maine.

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Summary

Webs of rolled and built-up sections can be subjected to local inplane edge loads. With the absence of a stiffener under the load, the web has to be designed so that local web yielding and/or crippling does not occur. Most of the research work conducted in the past was for thin webs, as in the case of built-up sections.

Currently, research work on web behavior under in-plane eccentric discrete compressive loading is in progress, at the University of Maine. The behavior of rolled beam webs under in-plane compressive edge loads was examined. Rolled shapes were tested, and the load was applied either on the top flange at the center of the beam or under the bottom flange at the end of the beam. The width of the loaded patch varied between 0.2 and 0.6 times the depth of the beam. The results were analyzed and compared with the current American Institute of

Steel Construction design requirements.

The effect of a small eccentricity of the load wit respect to the plane of the web was investigated. This effect was examined through testing and analysis. A Finite Element model was developed which can predict the test results with a high degree of accuracy. Another issue which is under investigation is the design of stiffeners for compressive edge loads. The effect of a small eccentricity of the load with respect to the stiffener is also being investigated.

The results of the research work at the University of Maine will be presented in this paper.

WEB CRIPPLING UNDER LOCAL COMPRESSIVE EDGE LOADING

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

Abstract : This paper addresses research work in progress at the University of Maine in the field of Web Crippling under local in-plane and eccentric compressive edge loads. The results of this research are compared with the AISC design requirements, and recommendations are made. Research dealing with the design of stiffeners, which is in its early stages at Maine, is discussed.

Introduction :

Webs of rolled and built-up beams can be subjected to local in-plane and eccentric compressive edge loads. For practical and/or economic reasons, transverse stiffeners are to be avoided or minimized. Most of the research to-date has addressed the web behavior under in-plane loads, mostly for built-up beams. Currently, research work on the behavior of webs of rolled as well as built-up beams, under local in-plane and eccentric compressive loading is in progress at the University of Maine.

The behavior of webs of rolled beams under local in-plane compressive edge loading was examined. Rolled shapes were tested under load which was applied either on the top flange at the center of the beam or under the bottom flange at the ends of the beam. The width of the loaded patch used in the tests varied between 0.2 and 0.6 times the beam depth. The results were analyzed and compared with the current AISC design requirements.

The effect of a small eccentricity of the load with respect to the plane of the web was investigated, through laboratory testing and computer analysis. A Finite Element model was developed which can predict the test results to a very good degree of accuracy.

Another issue which is under investigation is the design of stiffeners for compressive edge loads, with or without some eccentricity of the load in the longitudinal direction with respect to the stiffener vertical axis.

The results of the research work at the University of Maine will be presented in this paper.

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Webs Under In-plane Compressive Loading At The Supports :

Experimental Investigation : Early research in this area was done by Ketchum and Draffin, in the early 1930's. They tested 66 light I-beams, with depths of 6, 10 and 12 inches (1, 2). Recent tests at Maine were conducted on rolled shapes ranging from W 12 to W 21. The ratio of the load width to the beam depth (N/d), varied from 0.2 to 0.6. A description of the test specimens can be found in Tables (1a) and (1b). The former describes 13 tests done on specimens with length-to-depth ratio (L/d) ranging from 1.6 to 1.8, and the latter describes 14 tests done on W 12x16 sections, with L/d varying from 3 to 4. Two 0.5" thick plates were used as bearing supports, and vertical web stiffeners were provided under the load, as shown in Figure (1). All tests were carried out in a Baldwin Testing Machine, with a capacity of 400 kips. The load was applied to the specimens through 0.5" thick steel plates, placed symmetrically with respect to the plane of the web.

Test Results : Table (2a) shows the P_{uc} and P_{uy} values for all the tests described in Table (1a), calculated based on equations (K1-5) and (K1-3), of the LRFD specification, respectively, using actual values of web yield stress and cross-sectional dimensions. From this table, it can be seen that the values of P_{uy} are consistently higher than the test results, whereas the values of P_{uc} are generally in good agreement with the test results. Furthermore, it can be noted that the ratio between the test results and the calculated values (P_{tst}/P_{uc}) has the tendency of increasing with the increase in the N/d ratio. This could be due to the fact that for higher N/d ratio, the resultant of the reaction is applied at a longer distance from the free edge of the web.

Table (2b) shows the P_{uc} and P_{uy} values for all the tests described in Table (1b), calculated based on equations (K1-5) and (K1-3) of the LRFD specification, respectively. The Mill Certificate web yield stress and the nominal cross-sectional dimensions, were used in these calculations. As was seen before, the values of P_{uy} are consistently higher than the test results, whereas the values of P_{uc} are in close agreement. The increase in the ratio P_{tst}/P_{uc} with the increase in the ratio N/d which was observed before is noted here as well, as shown in Figure (2). Due to the higher L/d ratio of these specimens and since the compression flange was not laterally braced, lateral torsional buckling was observed particularly in the longer specimens, as can be seen in the photograph given in Figure (3). The low P_{tst}/P_{uc} ratios for tests 23 and 25 (less than 1.0) can be attributed to this effect; L/d for these two specimens was 4.0.

Webs Under In-plane Compressive Loading Between The Supports:

Experimental Investigation : Most of the experimental work to-date, in this area has been on built-up beams, where the web is slender. Recent work at the University of Maine has been mainly on rolled beams. The sections ranged from W 12 to W 21. The ratio N/d varied from 0.2 to 0.6. A description of the test specimens can be found in Table (3). As in the previous tests, the tests were carried out in a Baldwin Testing Machine, and the load was applied through thick steel plates. The plates were placed symmetrically with respect to the plane of the web. Two rollers were used as supports, and transverse web stiffeners were placed over them, as shown in Figure (4).

Test Results : Table (4) shows the P_{uc} and P_{uy} values for all the tests described in Table (3). Actual values of web yield stress and cross-sectional dimensions were used in the calculations. As can be seen, the average value of P_{tst}/P_{uc} is about 0.9. The values of P_{uy} were always higher than the test results, and the difference is large for higher values of N/d.

Tests on built-up beams with slender webs, subjected to in-plane compressive edge loads on the top flange between the supports have also been carried out at Maine. The results from these tests will not be reported in details in this paper.

Failure Mode Under Edge Loading :

There is a difference in the failure mode between stocky and slender webs, in that the former yields before crippling and the latter buckles before yielding. The latter failure mode is seen in the photograph given in Figure (5). In all the tests on rolled shapes , the former mode of failure was observed; yield lines (in the form of an arc of a circle) under the load or over the support were observed before crippling occurred. The out-of-plane deformations of the web were observed only near or at failure. The photographs given in Figures (6) and (7) show this mode of failure. As can be noted from Figure (7), the height of the circular yield line segment increases with the increase in the N/d ratio.

Evaluation of the AISC LRFD Specification :

As can be noted from Tables (2) and (4), P_{uy} calculated from equations k1-2 and k1-3 is almost always bigger than P_{uc} calculated from equations k1-4 and k1-5. During all the tests reported in Tables (2) and (4), web yielding occurred first followed by web crippling.

Based on observation of the behavior of the specimens near and at failure, for the tests reported herein and other tests conducted by the authors and not reported in details in this paper, one cannot justify the classification of web yielding and web crippling as two separate failure modes. Hence, only equations k1-4 and k1-5 for web crippling will be evaluated based on the test results reported in this paper.

The formulation of equation k1-4 is based on work conducted by Roberts (3). The constant of 135 was derived by Galambos, using some 89 test results from 122 reported by Elgaaly (2). In his derivation Galambos assumed that the dead and live loads are of the same magnitude. Based on the derivation by Galambos and assuming a strength reduction factor of 0.75, the corresponding reliability index can be calculated to be equal to 2.7. The 89 tests used by Galambos are mostly on built up sections with slender webs. The authors conducted a reliability analysis using their test results, which are reported herein, and the same aforementioned assumptions. The reliability index was found to be equal to 2.68. Hence it can be concluded that equation k1-4 can be applied to rolled shapes as well as built-up sections.

In built-up sections with slender webs, the common practice is to stiffen the web over the supports. Stiffeners over the supports can only be omitted for rolled shapes with relatively stocky webs. The constant of 68 in equation k1-5 was derived by Galambos using some 29 test results from 69 reported by Elgaaly (2), using the aforementioned assumptions. Based on the derivation by Galambos and assuming a strength reduction factor of 0.75, the corresponding reliability index can be calculated to be equal to 2.5. The 29 tests used by Galambos were conducted by Ketchum and Draffin (1) in the late 1920's. These tests were conducted on 6, 10, and 12 inch light I-sections which are not available today.

The authors conducted a reliability analysis using their test results which are reported in this paper. If the target reliability index is assumed to be 2.5, the corresponding strength reduction factor was calculated to be 0.94 using the 13 tests in Table (2a), 1.00 using the 14 tests in Table (2b), and 0.96 using all 27 tests. Hence it can be concluded that equation k1-5 is conservative, and should be modified. The modification can be achieved by increasing the constant from 68 and/or increasing the strength reduction factor from 0.75. It has to be noted that for the case where the load is between the supports, if the reliability index is 2.5 instead of 2.7, the corresponding capacity reduction factor will be equal to 0.786 and o.773 for the aforementioned 89 tests and the 15 tests reported in this paper, respectively.

Webs Under Eccentric Compressive Loading Between Supports :

Eccentricity of edge loads with respect to the plane of the web are unavoidable in practice. For this reason, the strength of webs under eccentric loads needs to be studied. Research in this area was started by Elgaaly and Nunan in 1988, at the University of Maine. Twenty-two W 12x19 rolled sections were tested to study the effect of eccentricity of the load. It was found that there was little reduction in the web ultimate strength P_u due to eccentricity , when the load was applied through a thick patch plate, placed eccentrically with respect to the plane of the web. However, reductions occurred when the load was applied through a cylindrical roller; the reduction being a function of the eccentricity (4). Further research was carried out by Elgaaly and Sturgis. Several rolled and built-up beams were tested. The parameters studied were the flange to web thickness ratio, "t_f/t_w", the eccentricity of the load "e" and the panel aspect ratio "b/d". The conclusions from this study were that P_u decreases with an increase in e, increases with an increase in t_f/t_w, and that the panel aspect ratio did not appreciably affect the web strength (5,6). A need for further investigation, to quantify the reduction in P_u due to the eccentricity of the load was established. Hence, effort in this direction was started by the authors in June 1989, with emphasis on experimental as well as analytical (F.E. analysis) investigation which is briefly described in the following.

Experimental Investigation : The tests were conducted for loads between the supports as illustrated in Figure (4). Table (5) describes the tests conducted by the authors (Tests S1 to S6) and gives the experimental and analytical ultimate (Failure) loads. P_{tst} refers to the test failure load, P_{anl} refers to the analytical failure load, and R is the ratio of the former to the latter. Tests J1 to J5 were done by Elgaaly and Sturgis (5), tests N1, and N2 by Elgaaly and Nunan (4,5), and tests T1 to T5 were conducted by others as reported by Elgaaly (2). All test specimens had an aspect ratio of 1, except in test T5, where it was 2.

Analytical Investigation : A nonlinear F. E. analysis program developed by Elgaaly, Caccese and Du (7), was used. The analysis takes into consideration both geometric and material nonlinearities. The validity of the finite element analysis was established by comparing the analytical and experimental loads as shown in Table (5). Using the program, parametric studies can be conducted to quantify the effect of the eccentricity on the failure load. Changes in parameters such as t_f/t_w, N/d, and d/t_w can be considered.

The results of the research conducted by the authors to-date indicate that this reduction is controlled mostly by the parameters t_f/t_w, and e/b_f, and is hardly controlled by the parameters b_f/t_f and N/d . For all practical purposes, the reduction in P_u for a given beam is directly proportional to the e/b_f ratio. Figure (8) shows straight line reductions in P_u as a function of e/b_f, for t_f/t_w equals 2 and 4; these were obtained from F.E. analyses. The scattered points shown in the figure are those obtained from the tests conducted by Elgaaly and Nunan (4); they are for a nominal t_f/t_w ratio of 1.5. As can be noted from Figure (8), a small eccentricity of $b_f/16$ for beams with t_f/t_w of 1.5 greatly reduce P_u by about 67%, while an eccentricity as high as $b_f/6$ for beams with t_f/t_w of 4.0 will reduce P_u by about only 20%.

Behavior Of Stiffeners Under Edge Compressive Loading :

During the course of their investigation the authors encountered some stiffeners' failure, as shown in Figure (9). As can be noted from the figure the failure is not a global column failure, but rather local crippling of the stiffener. Investigation of the stiffener behavior under edge compressive loading is in its early stages at Maine. The parameters under consideration in the experimental work are the ratio of web thickness to the stiffener thickness, the depth of the stiffener, and the longitudinal eccentricity of the load with respect to the stiffeners. The non-linear F.E. program will be verified for this application by comparing the analysis and the test results. Once the program has been verified analyses will be conducted to increase the parametric study data base. This will enable the investigators to make design recommendations.

Preliminary results indicate that the reduction in the stiffener's capacity due to the load eccentricity depends on the method of load application. If the load is applied through a plate, as shown in Figure (10), the reduction is not appreciable. On the other-hand if the load is applied through a roller, as shown in Figure (10), the capacity of the stiffener under eccentric load with 0.5" eccentricity is only 73% of the capacity under centric load. The specimen with the eccentric load at failure is shown in Figure (11).

Conclusions :

The material presented in this paper addresses three distinct issues. The first is the design of built-up and rolled sections under in-plane compressive edge loading. The second deals with the effect of the load eccentricity with respect to the plane of the web. The third issue address the behavior of stiffeners under compressive edge loads.

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, the limit state for yielding is not necessary. Based on the authors test results, it appears that the current AISC design for web crippling over the supports is conservative.

Eccentric loading can occur in practice, and can reduce the web ultimate strength by an amount that depends on various parameters. The results of the research conducted by the authors to-date indicate that this reduction is controlled mostly by the parameters t_f/t_w, and e/b_f, and is hardly controlled by the parameters b_f/t_f and N/d.

The research work on the stiffeners behavior under compressive edge loading has just started. The conclusions from the results to-date can be summarized in the following. The failure of the stiffener is not due to an overall column buckling but rather local crippling. Details of the stiffener design and the AISC design requirements will be evaluated when the study is completed.

Acknowledgements :

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References :

1. Ketchum, M. S., and Draffin, J. O., Strength of Light I-Beams, University of Illinois Experiment Station, Bulletin No. 24, February 1932.

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

3. Roberts, T. M., Slender Plate Girders Subjected to Edge Loading, Proceedings of the Institute of Civil Engineers, Part 2, 71, September 1981.

4. Elgaaly, M., Nunan, W., Behavior of rolled section web under eccentric edge compressive loads, Journal of Structural Engineering, 1561-1578, Vol. 115, No. 7, July 89.

5. Sturgis, J., Web behavior under eccentric edge loading, Master's thesis May 1989, University of Maine, Orono.

6. Elgaaly, M., Sturgis, J., Nunan, W., Stability of plates under eccentric edge loads, Proceedings of the American Society of Civil Engineers, Structural Congress, San Francisco, California, May 1989.

7. Elgaaly, M., Caccese, V., Du, C., Post-buckling strength of plates: Finite elements vs empirical models, Proceedings of the 4th International Colloquium, Structural Stability Research Council, 123-134, 1989.

8. Elgaaly, M., Salkar, R., Behavior of webs under eccentric compressive edge loads, Proceedings of the IUTAM Symposium, Prague, Czechoslovakia, Sept. 1990.

Table (1)
Test Program To Study Web Failure
Under Load At Supports

(a) - First Test Series.

No	Section	N/d	L/d	d/t_w	b_f/t_f	t_f/t_w	t_w	F_y
1	W 12x14	0.2	1.77	59.08	18.75	1.07	.201	53.2
2		0.4	1.75	59.41	18.90	1.06	.202	51.9
3		0.6	1.76	60.00	18.90	1.08	.199	54.2
4	W 14x22	0.2	1.74	58.28	15.53	1.39	.237	54.4
5		0.4	1.74	60.10	15.53	1.44	.230	49.9
6		0.6	1.74	57.10	15.30	1.38	.242	52.5
7	W 16x31	0.2	1.69	60.60	13.08	1.64	.263	57.6
8		0.4	1.69	64.26	13.25	1.67	.248	69.6
9		0.6	1.69	60.83	12.79	1.64	.262	58.8
10	W 18x35	0.2	1.69	60.37	14.10	1.46	.294	62.6
11		0.4	1.69	60.37	14.27	1.45	.294	60.1
12	W 21x50	0.2	1.58	57.84	12.61	1.45	.362	62.8
13		0.4	1.58	59.82	12.61	1.50	.350	59.0

(b) - Second Test Series.

All the tests in this series were done on W 12x16 rolled sections. The web material yield stress was obtained from the mill certificate as 43.2 ksi.

Test	14	15	16	17	18	19	20	21	22	23	24	25	26	27
N/d	0.2	0.2	.25	0.3	0.3	.35	0.4	0.4	.45	0.5	0.5	.55	0.6	0.6
L/d	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.5	4.0	3.5	4.0	3.5	3.5

For W12x16: d/t_w = 54.5, b_f/t_f = 15.06, t_f/t_w = 1.205, and t_w = 0.22.

Table (2)
Comparison Of Test Results With LRFD Equations (K1-5) And (K1-3)

(a) - For the tests in Table (1a).

No	Section	N/d	P_{uc}	P_{uy}	P_{tst}	P_{tst}/P_{uc}
1	W 12x14	0.2	31.96	43.79	28.25	0.884
2		0.4	43.21	68.34	46.25	1.070
3		0.6	53.64	95.81	64.75	1.207
4	W 14x22	0.2	45.37	63.81	46.00	1.014
5		0.4	51.67	88.55	58.50	1.132
6		0.6	71.53	133.1	95.50	1.335
7	W 16x31	0.2	58.77	90.90	67.50	1.149
8		0.4	70.16	158.6	64.75	0.923
9		0.6	85.12	190.7	127.0	1.492
10	W 18x35	0.2	75.31	117.1	73.25	0.973
11		0.4	92.57	175.2	99.00	1.070
12	W 21x50	0.2	114.3	169.8	127.5	1.116
13		0.4	129.6	240.7	180.0	1.389

(b) - For the tests in Table (1b).

No	Section	N/d	P_{uc}	P_{uy}	P_{tst}	P_{tst}/P_{uc}
14	W 12x16	0.2	34.52	40.61	36.52	1.058
15		0.2	34.52	40.61	35.02	1.014
16		.25	37.21	46.31	43.52	1.170
17		0.3	39.90	52.01	46.10	1.155
18		0.3	39.90	52.01	44.98	1.127
19		.35	42.60	57.70	52.30	1.228
20		0.4	45.29	63.40	50.60	1.117
21		0.4	45.29	63.40	55.05	1.216
22		.45	47.99	69.10	52.40	1.092
23		0.5	50.68	74.80	48.16	0.950
24		0.5	50.68	74.80	53.05	1.047
25		.55	53.37	80.49	49.90	0.935
26		0.6	56.07	86.19	56.70	1.011
27	W 12x16	0.6	56.07	86.19	57.60	1.027

Table (3)
Test Program To Study Web Failure Under Load Between Supports

No	Section	N/d	b/d	d/t_w	b_f/t_f	t_f/t_w	t_w	F_y
1	W 12x14	0.2	1.59	59.39	19.35	1.05	.201	50.4
2		0.4	1.59	59.39	19.35	1.05	.201	50.4
3		0.6	1.58	60.29	19.35	1.06	.198	53.4
4	W 14x22	0.2	1.61	56.35	15.30	1.37	.244	51.6
5		0.4	1.61	56.35	15.30	1.37	.244	51.6
6		0.6	1.60	60.57	15.53	1.45	.227	46.4
7	W 16x31	0.2	1.59	60.37	12.79	1.63	.264	56.4
8		0.4	1.59	60.37	12.79	1.63	.264	56.4
9		0.6	1.59	59.92	13.08	1.62	.266	52.7
10	W 18x35	0.2	1.59	58.39	13.94	1.43	.304	48.0
11		0.4	1.59	58.39	13.94	1.43	.304	48.0
12		0.6	1.60	61.42	14.10	1.49	.289	61.1
13	W 21x50	0.2	1.58	59.65	12.62	1.50	.351	57.9
14		0.4	1.58	59.65	12.62	1.50	.351	57.9
15		0.6	1.58	59.31	12.62	1.49	.353	56.9

Table (4)
Comparison Of Test Results With LRFD Equations (K1-4) and (K1-2) For The Tests in Table (3)

No	Section	N/d	P_{uc}	P_{uy}	P_{tst}	P_{tst}/P_{uc}
1	W 12x14	0.2	61.83	59.06	52.50	0.849
2		0.4	83.96	83.27	74.50	0.887
3		0.6	105.6	112.4	75.25	0.713
4	W 14x22	0.2	92.85	89.65	89.00	0.959
5		0.4	118.1	124.3	97.00	0.821
6		0.6	115.8	133.0	86.25	0.745
7	W 16x31	0.2	116.2	131.2	112.0	0.964
8		0.4	142.3	178.7	145.0	1.019
9		0.6	165.3	212.9	169.5	1.025
10	W 18x35	0.2	139.6	133.9	110.0	0.788
11		0.4	175.9	185.7	125.0	0.711
12		0.6	214.0	287.4	185.0	0.865
13	W 21x50	0.2	205.6	218.5	194.0	0.944
14		0.4	256.3	303.6	232.0	0.905
15		0.6	308.1	384.2	296.0	0.961

Table (5)
Web Crippling Under In-Plane and Eccentric Load
Test Results vs Analytical Results

No	N/d	d/t_w	b_f/t_f	t_f/t_w	t_w	e/b_f	F_y	P_{tst}	P_{anl}	R
J1	.2	208.3	24.3	2.1	.120	0	41	24.2	24.5	.988
J2	.2	208.3	23.8	2.1	.120	1/24	40	22.4	22.0	1.02
J3	.2	208.3	23.8	2.1	.120	1/12	40	19.0	17.5	1.09
J4	.2	208.3	23.8	2.1	.120	1/8	41	13.9	13.0	1.07
J5	.5	49.4	20.9	1.0	.200	0	51	58.8	55.5	1.06
S1	.2	213.7	12.1	4.24	.117	0	44	28.4	29.5	.96
S2	.2	208.3	12.1	4.13	.120	1/12	39	25.5	24.0	1.06
S3	.2	208.3	12.1	4.13	.120	1/12	39	26.0	24.0	1.08
S4	.2	213.7	12.1	4.24	.117	1/6	44	25.8	24.0	1.08
S5	.6	213.7	12.1	4.24	.117	1/6	44	37.0	34.5	1.07
S6	.6	213.7	24.0	2.14	.117	1/12	44	26.5	26.0	1.02
N1	.2	50.5	12.2	1.33	.241	0	51	66.0	67.0	0.99
N2	.2	49.2	11.2	1.45	.247	1/8	55	35.0	37.0	0.95
T1	.1	250.0	2.0	12.3	.079	0	35	13.2	14.5	0.91
T2	.1	165.0	4.9	2.78	.143	0	41	34.6	33.0	1.05
T3	.05	168.0	5.1	2.80	.141	0	37	28.0	27.0	1.04
T4	.2	250.0	16.7	3.00	.079	0	35	11.6	12.0	0.97
T5	.07	127.0	12.8	2.09	.118	0	36	23.3	22.2	1.06

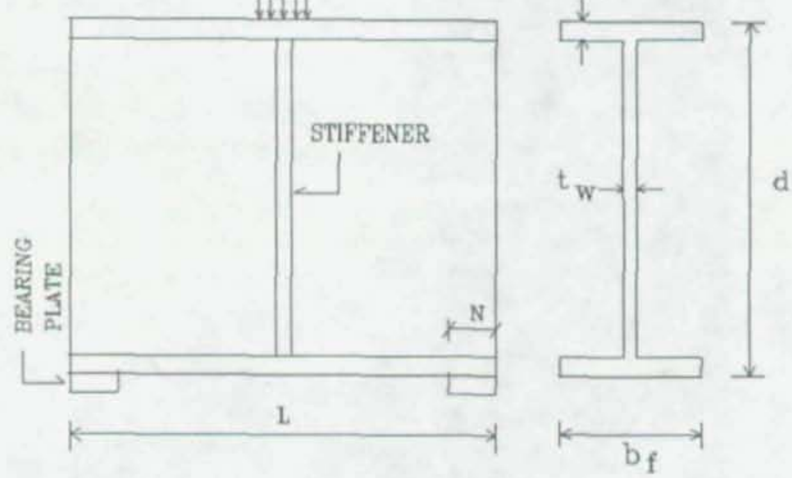


Figure (1) - Web Crippling Over The Supports

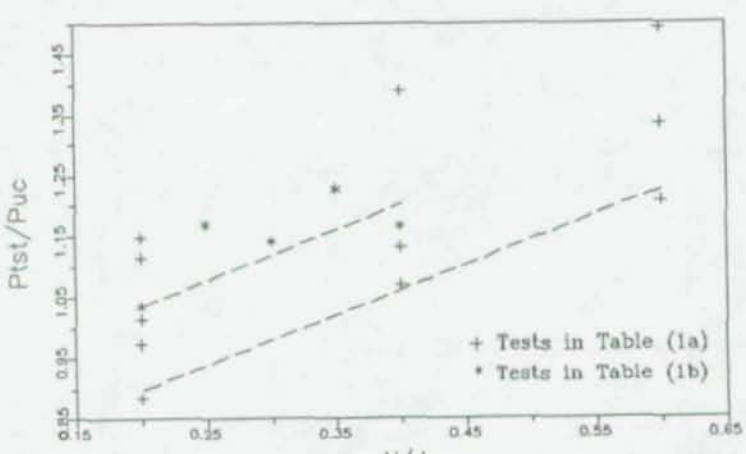


Figure (2) - P_{tst}/P_{uc} vs. N/d

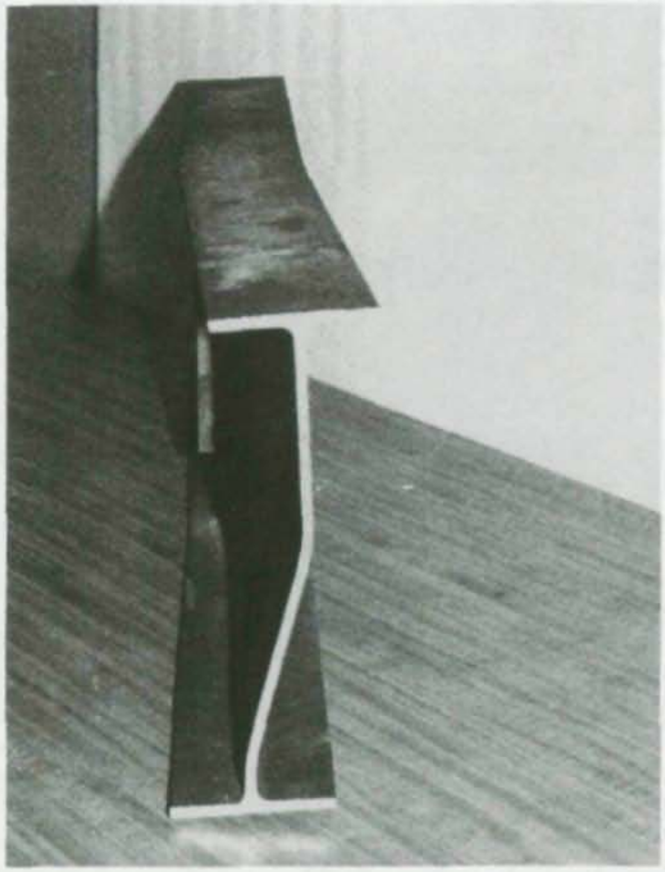


Figure (3) - Lateral-Torsional Buckling

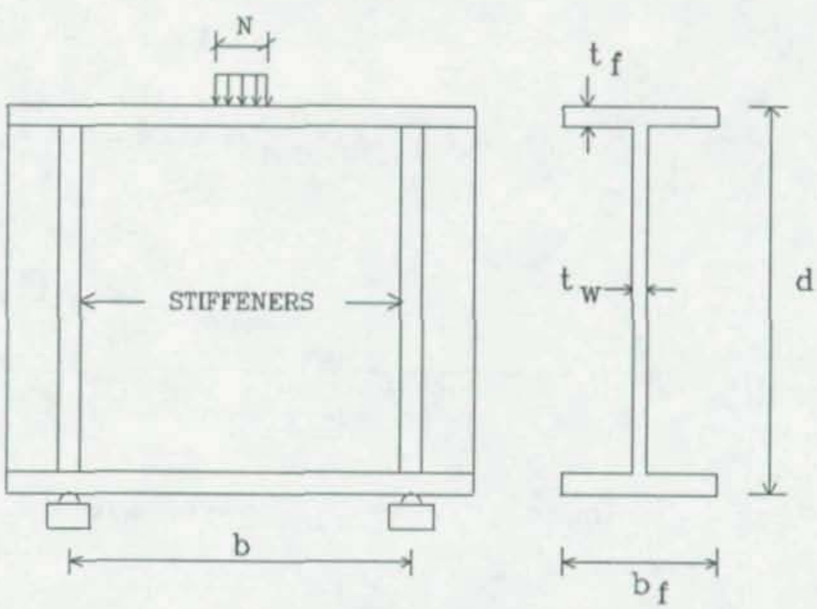


Figure (4) - Web Crippling Between Supports

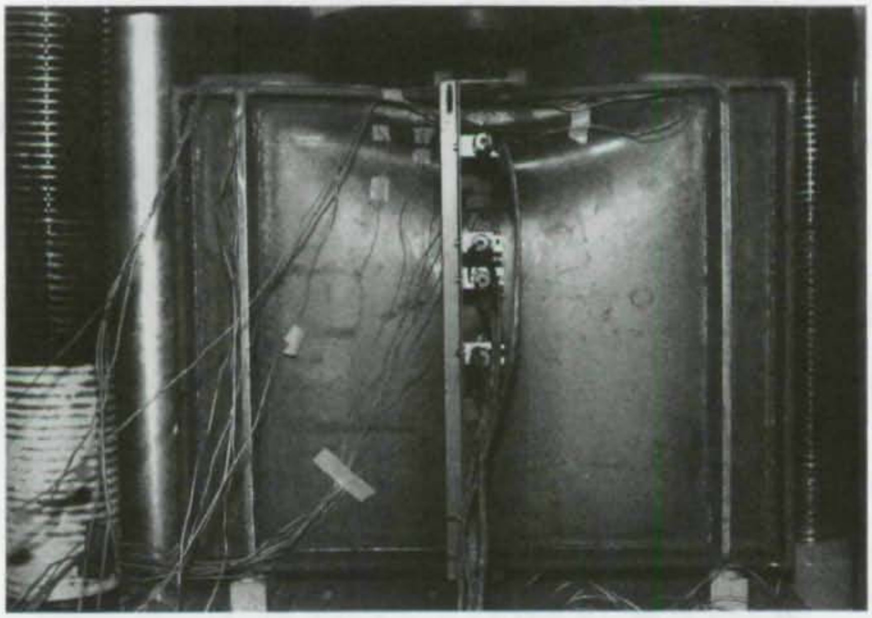
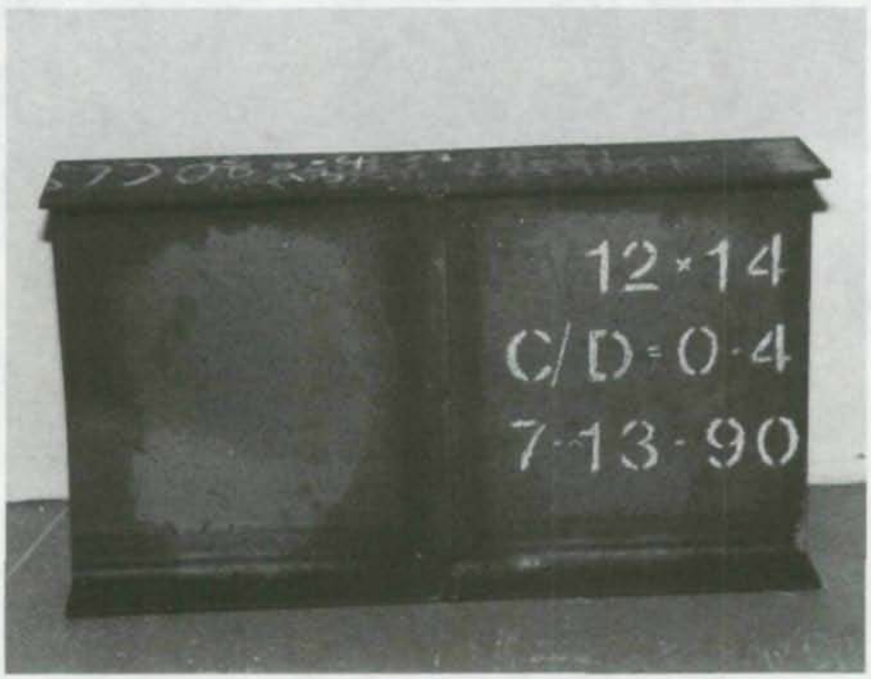


Figure (5) - Web Crippling Before Yielding
Slender Web, h/t = 200

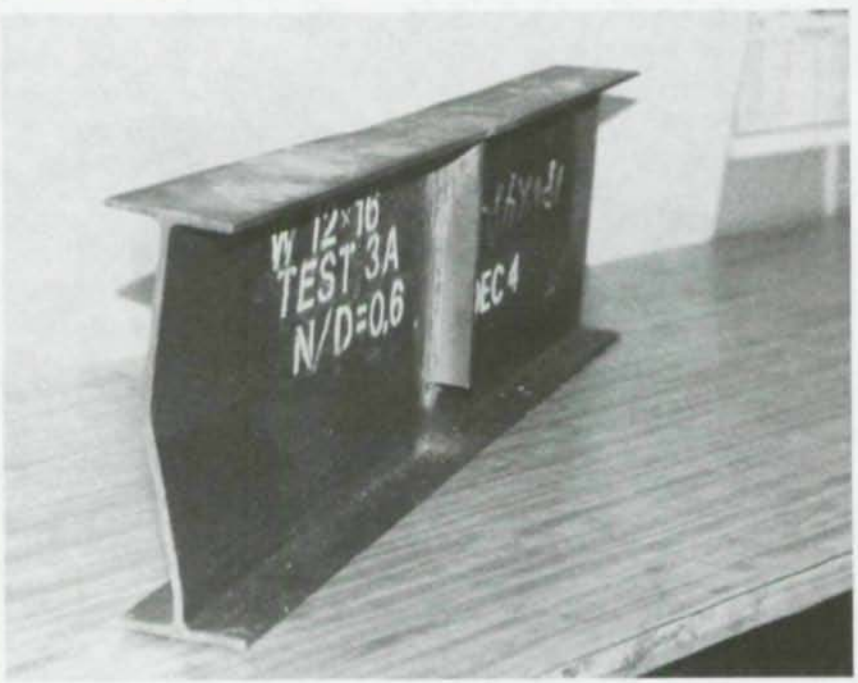
Crippling Between Supports



Crippling At Supports

Figure (6) - Web Yielding Before Crippling
Stocky Web, d/t =60

N/d = 0.2



N/d = 0.6

Figure (7) - Web Crippling Over Supports

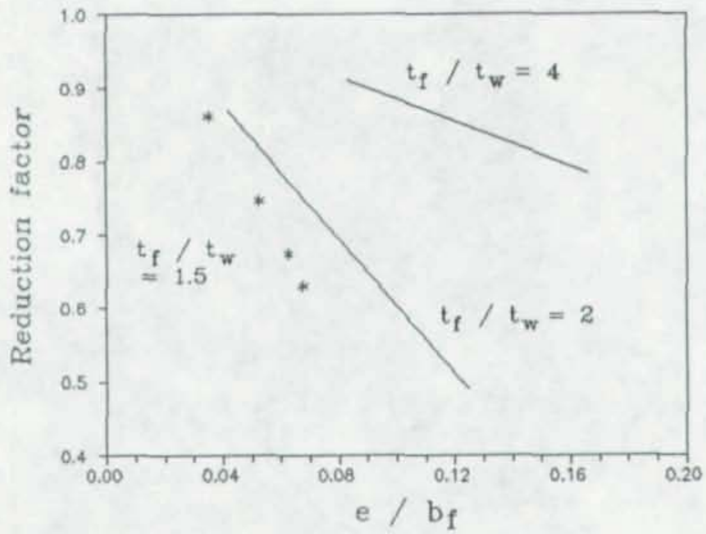


Figure (8) - Reduction in Ultimate Capacity Due to Load Eccentricity

Figure (9) - Stiffener Crippling Under Load

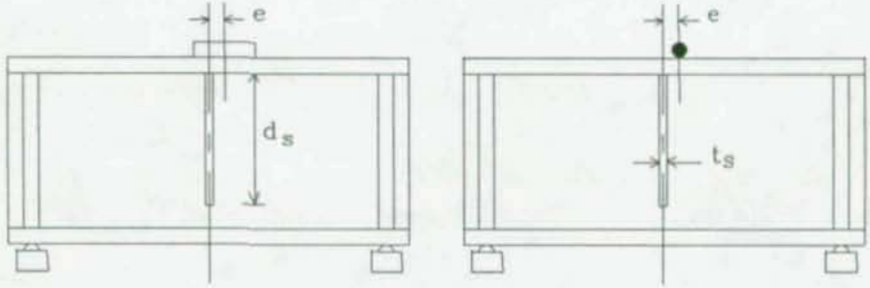


Figure (10) - Eccentric Loading On Stiffener

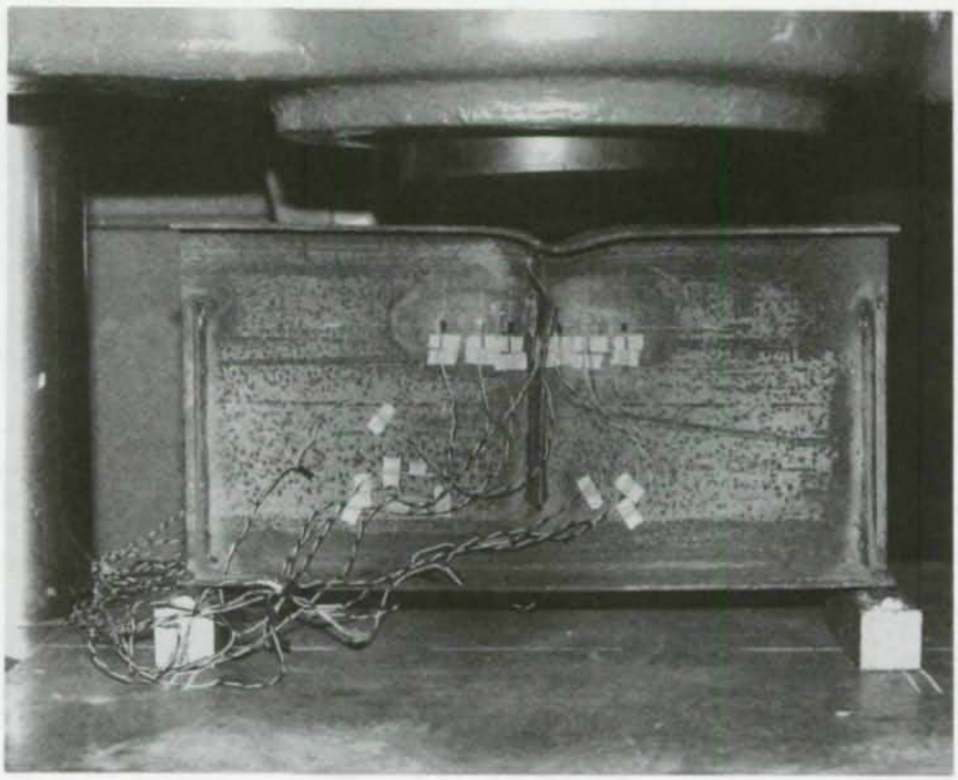


Figure (11) - Stiffener Crippling Under Eccentric Load