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

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

Twenty-Fifth Progress Report

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I. SCOPE OF THIS REPORT

All the beams heretofore tested in this program were furnished with web stiffeners in order to avoid crushing of the web at the load points and at the supports. In practical application the use of such stiffeners at points of concentrated loads would not only be uneconomical but also would impair the versatility of the elements, since stiffeners would have to be spaced on each individual beam according to the particular location and loading.

For this reason it seemed essential to investigate the resistance of unreinforced webs to concentrated loading. The tests reported herein are to be regarded as pilot tests designed to furnish some preliminary data on this question and to serve as a base for more detailed investigation on specially designed specimens. The specimens for this series of tests were cut from the beams A to G previously used for failure tests of different types. The range of dimensions so obtained was rather limited and, consequently, it is believed that more tests on shapes other than those tested will be necessary in order to widen the limits of the investigation.

23 tests were carried out, 10 of which were made on single web beams and 13 on double web beams.

II. METHOD OF TESTING

The specimens were cut from undamaged portions of beams A to G. With but one exception (B 2) the outside portions of these beams were used, i.e. the parts of the beams between the support and the load point. These parts, in the former tests, were stressed less than the center portion and showed no signs of local failure.

The short beams so obtained were supported on two rockers placed under the web stiffeners. Distributing plates were inserted between the edges of the rockers and the bottom flanges. This arrangement excluded local crushing at the supports as well as lateral motion of the beam.

The short beams were then loaded at the center of the span by a single concentrated load. Tests were carried out with different inserts between the head of the testing machine and the top flange of the beams: 1" rollers to simulate highly concentrated loads, and distributing plates with widths of 1 1/4", 2 1/2" and 3 1/2" were used to obtain loads of different concentrations.

The only data recorded in these pilot tests were the ultimate loads. In all but one case (D 2 a) failure occurred by local crushing of the top flange and the unreinforced web at the load point.

III. RESULTS

The results of this series of tests are given in table 1 below.

Table 1

Results of Local Crushing Tests on 23 Short Beams

Beam	web	gage	b		P_{ult}	P_{web}	
B 2	double	14	0	27	9200	4600	9900
B 3 a	"	"	1 1/4	36	11.400	5.700	16.700
A 3	"	"	2 1/2	36	13.500	6.750	15.400
B 3 b	"	"	3 1/2	36	15.600	7.800	22.700
D 2 a	"	16	0	36	5.050	2.525	8.600 *)
E 3	"	"	0	24	5.730	2.865	8.300
D 2 b	"	"	1 1/4	36	7.450	3.725	12.700
D 3 a	"	"	2 1/2	36	8.200	4.100	13.900
D 3 b	"	"	3 1/2	36	9.300	4.650	15.800
G 3 a	"	18	0	36	3.450	1.725	9.300
G 3 b	"	"	1 1/4	36	3.650	1.825	9.000
G 1 a	"	"	2 1/2	36	4.650	2.325	12.600
G 1 b	"	"	3 1/2	36	5.200	2.600	14.100
K 1 a	single	11	1 1/4	36	8.650	8.650	18.700
K 1 b	"	"	3 1/2	36	12.100	12.100	25.800

Beam	web	gage	b	l	P_{ult}	P_{web}	σ
N 1 a	single	14	0	36	4.870	4.870	12.000
N 2 a	"	"	1 1/4	36	5.830	5.830	14.400
N 1 b	"	"	2 1/2	36	7.630	7.630	18.800
N 2 b	"	"	3 1/2	36	7.240	7.240	18.000
O 1 a	"	18	0	33	2.170	2.170	9.100
O 2 a	"	18	1 1/2	33	2.245	2.245	9.500
O 1 b	"	"	2 1/2	33	2.800	2.800	11.100
O 2 b	"	"	3 1/2	33	3.250	3.250	13.800

*) Beam D 2 a failed in the welds before appreciable local crushing occurred at the load point.

In table 1 above

b = width of distributing plate under the center load (b = 0 indicates that a 1" roller was used instead of a plate, the theoretical width of the contact surface being zero in this case).

l = span of the beam

P_{ult} = failure load

P_{web} = failure load per web; i.e. $P_{web} = P_{ult}$ for the single web beams, and $P_{web} = 1/2\ P_{ult}$ for the double web beams

σ = bending stress in top flange as computed from the ordinary flexure formula.

Discussion:

It is seen from table 1 that, as would be expected, the crushing loads increase with increasing web thickness and with increasing width of the distributing plates. A comparison of the loads per web, P_{web}, for the single and double web specimens of 14 ga and 18 ga thickness reveals that these loads are essentially the same for both types of specimens. This is true especially for the 14 ga specimens. The 18 ga specimens, contrary to expectation, show a somewhat smaller P_{web} for the double web specimens as compared with the single web. It can be concluded from these results that, in local crushing, the two halves of double webs act individually rather than as a unit. ← Depend upon location of welds ?

The bending stresses in the last column of table 1 were computed in order to make sure that no yielding due to bending occurred in these tests. These stresses, because of the short spans used, are, indeed, sufficiently lower than the yield point to assure failure due to local crushing only. A comparison of these stresses with σ_1 of table 5 of the 21st Report shows that the maximum bending stresses at failure were consistently below those at which the first signs of distortions were observed on the local buckling tests of the same beams. It is thereby established that failure in this series was due in all cases to local crushing exclusively, except for the weld failure in beam D 2 a.

The external appearance of the beams failure was, in character, the same on all specimens, but changed in intensity depending on the width of the loading plate and the thickness of the web. Two zones were clearly discernable: a highly localized portion of the web directly below the load which was sharply bent out of its originally vertical plane; and a much wider zone characterized by gradual bulging of the web. The latter zone increased in width and depth with increasing width of the loading plane. This zone was of a semicircular or semielliptical form and, in some specimens, reached down almost to the toe of the web.

Inclined waves indicating shear-instability of the web, were observed only on beams O 1 b and O 2 b. They developed in these beams at or slightly above 2000 lb. As was noticed in other beams tests before, these inclined shear waves did not impair the bearing capacity of the beam which, in the case of O 2 b, reached a value about 50% above that at which such waves were first noticed.

Failure of a number of welds in the web at the top flange were noticed on D 2 a where they resulted in considerable spreading of the two halves of the flange and obviously contributed to a lowering of the failure load (compare loads of D 2 a and E 3). On beams D 2 b and D 3 a one weld failed in the web at the top flange in each of these specimens. These isolated weld failures, it is believed, did not affect the strength of the beams.

IV. EVALUATION OF DATA

The phenomenon of web crushing involves so many different elements (instability in compression and shear, plastic flow, elastic stress distribution, etc.) that a rigorous theoretical approach seems almost impossible. For this reason an attempt was made to establish, from the test data, a purely empirical formula. Since this formula is based on a rather limited and insufficient number of tests it should, at the present time, be regarded as a working hypothesis rather than a definite answer. It is believed that the formula gives at least the order of magnitude of the crushing strength and may be refined or improved by further tests.

It seems clear that the general type of such a formula should be as follows:

$$P_w = \left[A + B\, f(b,t)\right] t\, \sigma_{yp}$$

where

P_w = the crushing strength of a single web

b = the length of the loaded portion of the beam (width of distributing plate)

t = thickness of web

σ_{yp} = yield point

A, B = empirical constants

The physical meaning of a formula of this type is the following: The crushing strength can naturally be expected to increase with increasing thickness and yield point. The first term in the brackett represents the resistance of a load distributed over "zero width" (knife edge); the second term, involving some function f (b,t), gives the increase of the crushing strength with increasing width of load distribution.

By trial and error it was found that the formula most closely reproducing the test data is the following:

$$P_w = \left[0.36 + 4.4\sqrt{b\ t}\right]\ t\ \sigma_{yp}$$

Empirical Formula for Crushing strength of Web. (single web) (Double web = 2 × P_w)

In designing the tests it was hoped that the load applied through a 1" roller would give the first term of such an equation. However, because of plastic flow and elastic stress distribution, the load transmitted through a roller is actually distributed over a definite width. By substituting back into the formula this equivalent loading width for a 1" roller was found to be approximately 3/4". In the following table 2 the test data are compared with the results from the formula. The 1" roller tests have been included, in bracketts, in the table, with b = 0.75".

Table 2

Comparison of Test Data with Results of Empirical Formula

Beam	σ_{yp}	P_w from test	P_w from formula	% error
B 2	35.800	4.600	(3.720)	(-19)
B 3 a	"	5.700	4.550	-20
A 3	"	6.750	6.000	-11
B 3 b	"	7.800	6.930	-11
E 3	37.900	2.865	(3.000)	(+4)
D 2 b	"	3.725	3.640	-2
D 3 a	"	4.100	4.810	+17
D 3 b	"	4.650	5.520	+18
G 3 a	32.200	1.725	(1.750)	(+1)
G 3 b	"	1.825	2.100	+15
G 1 a	"	2.325	2.730	+17
G 1 b	"	2.600	3.100	+19
K 1 a	37.600	8.650	9.500	+9
K 1 b	"	12.100	14.600	+17
N 1 a	35.800	4.870	(3.730)	(-23)
N 2 a	"	5.830	4.560	-22
N 1 b	"	7.630	6.080	-20
N 1 b	"	7.240	6.970	-4
O 1 a	32.200	2.170	(1.750)	(-22)
O 2 a	"	2.245	2.100	-6
O 1 b	"	2.800	2.730	-2
O 2 b	"	3.250	3.100	-7

The deviations of the measured values from the computed ones are seen to range from +22% to -19%, the average error being -2%. Since, in design specifications, a safety factor of from 2 to 3 would probably be applied in this case, the above variation will amply be taken care of by the safety coefficient.

It should be emphasized again that (a) the value given by the formula applies to a single web; the crushing load of a double web is approximately double that of a single web, and (b) this formula is purely empirical and needs further verification and possibly improvement by additional tests.

Such tests, at least for double webs, can probably be carried out on cut of portions of the 84 beam and 84 stud specimens now on order after they have been tested for flange strength. These future tests should be carried out so that, in addition to the ultimate load, deflections will be measured at the load point independently for the top and the bottom flanges. This will give additional indication of incipient failure while in the present pilot tests only the ultimate failure load was observed.

V. SUMMARY

(1) 23 tests on the crushing strength of unreinforced webs under local load were carried out, 10 of them on single webs, and 13 on double webs.

(2) Except for one specimen which failed in the welds, all beams actually failed by crushing of the web.

(3) It was found that the crushing strength of a double web is about twice that of a single web of same sheet thickness, or, in other words, the two webs failed individually rather than as a composite unit.

(4) An empirical formula was developed which represents the test results with fair accuracy.

(5) This formula is as yet based on an insufficient number of tests and should be regarded as a working hypothesis rather than a final answer.

(6) Additional tests with a more elaborate set-up are contemplated, to be carried out on cut from portions of the beam and stud specimens now on order.

(7) Until the results of such tests are available, it is believed that the present findings could be recommended for practical use, if a safety factor of sufficient magnitude is applied to take care of the existing uncertainties.