Local Buckling of Cold Formed Steel Members

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LOCAL BUCKLING OF COLD-FORMED STEEL MEMBERS

by V. Kalyanaraman[1]

Thin walled stiffened and unstiffened compression elements, commonly encountered in cold-formed steel structural members often experience local buckling prior to member failure. The bifurcation type of local buckling indicated by small deformation theory is absent in commercially manufactured cold-formed members with their inevitable initial imperfections. However, the computation of the theoretical local buckling stress is necessary for calculation of the postbuckling effective width using the general form of the effective width equations (5). Furthermore, the compressive strain when local buckling occurs in the plastic range is needed, if inelastic reserve strength of steel structural members is to be fully utilized.

The local buckling is a function of the local buckling coefficient, and depends on the element dimensions, and material properties. The local buckling coefficient of compression elements with high aspect ratio is also a function of the rotational edge restraint of the adjoining elements.

The local buckling coefficient, assuming no rotational restraint, used in practice is conservative. Effective widths calculated using this approximation produce results as much as 20% conservative in stiffened elements and 35% conservative in unstiffened elements. The calculation of

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exact value of local buckling coefficient of elements in cold-formed steel members is difficult. In this paper an approximate analytical procedure for calculating a more realistic value of the local buckling coefficient of stiffened and unstiffened elements made of elastic plastic materials is presented. Charts, tables and equations will be presented to facilitate computation of more realistic local buckling coefficients for design. The results of the proposed analytical procedure are compared with some test results.

Many authors (1, 2, 4, 8, 10, 12, 13) have presented theoretical and analytical procedures, charts, and tables for calculating the local buckling coefficients of plate elements and members with plate elements. All the procedures disregard the out of plane deformation due to initial imperfection and the consequent partial plastification of elements which occurs prior to the theoretical local buckling. In the procedure presented, the effect of partial plastification is considered in an empirical way.

LOCAL BUCKLING

The elastic local buckling stress of stiffened and unstiffened elements can be calculated using the following equation.

$$(\sigma_{cr})_e = K_e \frac{\pi^2 E}{12(1 - \mu^2)(w/t)^2} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

in which E = Young's modulus; μ = Poisson's ration; w = element flat width; t = element thickness and K_e = elastic local buckling coefficient.

Stowell (11) derived and expression for calculating the local buckling stress in the inelastic range, by modifying earlier works in this area and using Shanley's concept of non-reversal of stress during inelastic buckling. Stowell presented the following equation for local buckling stress in the inelastic range.

$$(\sigma_{cr})_p = \eta(\sigma_{cr})_e \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

in which $(\sigma_{cr})_p$ = local buckling stress in the inelastic range and η = plasticity index applied to local buckling stress in the elastic range. The plasticity index of stiffened and unstiffened elements have been shown by Stowell to be functions of material properties, element dimensions and rotational restraint of adjoining elements.

The following equations for the strain at local buckling follow from equations 1 and 2 for local buckling stresses.

$$(e_{cr})_e = \frac{K_e \pi^2}{12(1 - \mu^2)(w/t)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3a)$$

and

$$(e_{cr})_p = \frac{K_p \pi^2}{12(1 - \mu^2)(w/t)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3b)$$

In Eqs. 3a and 3b $(e_{cr})_e$ and $(e_{cr})_p$ are the elastic and inelastic local buckling strains; K_p = inelastic local buckling coefficient as follows:

$$K_p = \frac{E}{E_s} \eta K_e = \eta' K_e \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

in which E_s = secant modulus and η' = modified plasticity index.

In the case of cold-formed structural members of elastic plastic steel treated in this paper, η', the modified plasticity index for stiffened and unstiffened elements is given by the following equations in which subscripts s and u denote the stiffened and unstiffened elements respectively. These equations are derived from the Stowell's (11) more general equations.

$$\eta'_s = \frac{f_1(\varepsilon) + \sqrt{f_2(\varepsilon)}}{f_1(\varepsilon) + 2\sqrt{f_2(\varepsilon)}} \quad \ldots\ldots \quad (5a)$$

and

$$\eta'_u = \frac{f_3(\varepsilon) + \sqrt{f_4(\varepsilon)}}{f_3(\varepsilon) + 2\sqrt{f_4(\varepsilon)}} \quad \ldots\ldots \quad (5b)$$

in which $f_1(\varepsilon)$, $f_2(\varepsilon)$, $f_3(\varepsilon)$, and $f_4(\varepsilon)$ are functions of the rotational edge restraint factor ε and are given by

$$f_1(\varepsilon) = \frac{1.0 + 0.1894\varepsilon + 0.0114\,\varepsilon^2}{0.5 + 0.0947\varepsilon + 0.00461\,\varepsilon^2} \quad \ldots\ldots \quad (5c)$$

$$f_2(\varepsilon) = \frac{0.5 + 0.297\varepsilon + 0.0237\,\varepsilon^2}{0.5 + 0.0947\varepsilon + 0.00461\,\varepsilon^2} \quad \ldots\ldots \quad (5d)$$

$$f_3(\varepsilon) = 0.5 + 0.1742\varepsilon + 0.0192\,\varepsilon^2 \quad \ldots\ldots \quad (5e)$$

$$f_4(\varepsilon) = 0.0834\varepsilon + 0.0414\,\varepsilon^2 + 0.00688\,\varepsilon^3 + 0.00038\,\varepsilon^4 \quad \ldots\ldots \quad (5f)$$

The rotational edge restraint factor ε is defined as

$$\varepsilon = \frac{B_b}{D_b} \cdot S_r \quad \ldots\ldots \quad (5g)$$

in which B_b and D_b = the buckling element's width and flexural rigidity respectively, and S_r = rotational stiffness of the restraining element.

The elastic local buckling coefficient K_e and the plastic local buckling coefficient K_p of plates having high aspect ratios are functions of the rotational edge restraint factor, ε, alone, (5, 7). The equations for K_e and K_p

of stiffened and unstiffened elements are plotted in Figs. 1 and 2. These curves can also be represented by the following parametric equations with a maximum error of 2.6%

$$K_{e,s} = 5.485 + 1.485\ (\varepsilon^{0.94}-7.47)/(\varepsilon^{0.94}+7.47) \quad (6a)$$

$$K_{p,s} = 3.858 + 0.858\ (\varepsilon^{1.03}-10.5)/(\varepsilon^{1.03}+10.5) \quad (6b)$$

$$K_{e,u} = 0.851 + 0.426\ (\varepsilon^{0.7}-1.5)/(\varepsilon^{0.7}+1.5) \quad (6c)$$

$$K_{p,u} = 0.637 + 0.212(\varepsilon^{0.74}-2.04)/(\varepsilon^{0.74}+2.04) \quad (6d)$$

In the above equations, the subscripts s and u indicate the expressions for stiffened and unstiffened elements respectively.

Eqs. 6a through 6d plotted in Figs. 1 and 2, give local buckling coefficient of stiffened and unstiffened elements in cold-formed structural members of elastic plastic material if the rotational edge restraint factor ε is known.

ROTATIONAL EDGE RESTRAINT FACTOR (ε)

The cross sections of common types of cold-formed structural members are shown in Fig. 3. Local buckling is often initiated in slender elements of compressed members but adjacent elements restrain the edge rotation of buckling elements at the common edge. Consequently, once the rotational stiffness S_r of the restraining elements at the common edge is known the rotational edge restraint factor ε of buckling elements can be calculated using Eq. 5g.

In Fig. 4 the buckling and restraining elements of the common structural members are shown by the light and heavy lines respectively. The buckling and restraining roles of stiffened and unstiffened elements is apparent in these members. The boundary conditions of the restraining elements in these members can be classified into three categories as shown in Fig. 5.

Obviously all cases of local buckling of cold-formed structural members do not fall into the categories shown in Figs. 4 and 5. But it is almost always possible to conservatively model the actual members into one of the categories without unacceptable loss of accuracy for design purposes. Consequently, the problem reduces to the calculation of the rotational stiffness at the edge of the three cases of restraining elements shown in Fig. 5.

The rotational edge stiffness S_r of a restraining element is influenced by the compressive stress in the longitudinal direction. Bleich (1) has shown that the influence of the longitudinal compression can be incorporated through a correction factor to the rotational stiffness calculated for the case of the sinusoidally varying edge moment as shown in Fig. 5 without considering longitudinal compression.

Using the differential equation of plate bending, the rotational edge stiffness S_r' neglecting the longitudinal compression can be derived. The equations for S_r' for the three cases in Figs. 5a, 5b, and 5c are respectively

$$S'_{r,I} = (D_r/B_r)\ 4\alpha \cosh^2(\alpha/2)/(\alpha + \sinh\alpha) \qquad (7a)$$

$$S'_{r,II} = (D_r/B_r)\ 2\alpha \sinh^2\alpha\ /(0.5 \sinh 2\alpha - \alpha) \qquad (7b)$$

$$S'_{r,III} = (D_r/B_r)\ 2\alpha\ (\alpha + 3 \sinh\alpha \cdot \cosh\alpha)/(1 + \alpha^2 + 3\cosh^2\alpha). \qquad (7c)$$

in which B_r, D_r = restraining element's width and flexural rigidity respectively; and $\alpha = \pi B_r/\lambda$ in which λ = one half of the buckling wave length. Eqs. 7a, 7b, and 7c are plotted in Fig. 6 for the most common values of B_r/λ. Eqs. 7a, 7b, and 7c and Fig. 6 can be represented by the following easy to use parametric equations with only a little error.

$$S'_{r,I} = \sqrt{118.8 + 84.6(B_r/\lambda)^2} - 8.9 \quad \ldots\ldots\ldots\ldots (8a)$$

$$S'_{r,II} = \sqrt{33.4 + 50.7(B_r/\lambda)^2} - 7.12 \quad \ldots\ldots\ldots\ldots (8b)$$

$$S'_{r,III} = \sqrt{0.533 + 44.9(B_r/\lambda)^2} - 0.73 \quad \ldots\ldots\ldots\ldots (8c)$$

In Eqs. 7 and 8 and Fig. 6, the half wave length λ is unknown. However, they can be assumed conservatively as follows:

stiffened buckling element: $\lambda = B_b$ . . . . (9a)

unstiffened buckling element: $\lambda = \infty$ . . . . (9b)

The rotational edge stiffness S_r including the effect of longitudinal compression can be written as

$$S_r = C_f \, S_r' \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

in which C_f = correction factor. If the buckling stress of restraining element is equal to that of buckling element, then the rotational restraint is zero and if the buckling stress of the restraining element is much higher than that of the buckling element then the effect of the longitudinal stress on the restraining element's rotational edge stiffness is negligible. The following equation for correction factor suggested by Bleich (1) satisfies the enumerated requirements.

$$C_f = 1.0 - \frac{(\sigma_{cr})_b}{(\sigma_{cr})_r} = 1.0 - (K_b/K_r)(B_r/B_b)^2(t_b/t_r)^2 \quad \ldots\ldots (11)$$

In the above equation K_b, K_r = the buckling coefficients of buckling and restraining element corresponding to the hinged edge condition and t_b, t_r = thicknesses of the buckling and restraining elements respectively. In Fig. 4

the ratio K_b/K_r for commonly encountered sections is given. The values of K_b and K_r used for axially compressed members is self explanatory. In flexural members the compressive stress on restraining web element is linearly distributed. The buckling coefficient corresponding to a linear compressive stress distribution changing from the maximum value at the extreme compression fiber to zero stress at the extreme tension fiber of the web is assumed for the restraining element buckling coefficient (K_r). This assumption yields a simple and conservative expression for the correction factor C_f of restraining elements in flexural members. The curves in Fig. 7a show the variation of the correction factor C_f with reference to the parameter $(B_r/B_b)/(t_r/t_b)$ for different values of K_b/K_r. In Figs. 7b through 7h the same curves are drawn for the most common values of t_b/t_r = 0.5, 1.0, and 2.0.

Substituting Eqs. 9, 10, and 11 in Eq. 5g an expression for the rotational edge restraint factor ε is obtained in which N_b = number of buckling elements at the junction.

$$\varepsilon = \frac{B_b}{B_r} \cdot \frac{D_r}{D_b} \cdot \frac{s'}{(D_r/B_r)} \cdot \frac{C_f}{N_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

Using Eqs. 6 through 12 or Figs. 1 through 7, the elastic and plastic buckling coefficients K_e and K_p of elements in cold-formed members can be determined. In the process, the expressions for the rotational edge restraint factor derived using elastic assumptions have been extended to plastic range also. Plasticity influences the parameters D_r, D_b, and λ. The influence of plasticity in D_b and D_r cancel in Eq. 12. The half wave length λ tends to reduce in the plastic range, hence using the λ corresponding to elastic range is conservative.

The actual buckling coefficient K of a compression element can vary between K_e and K_p depending upon yield stress σ_y and element dimensions. Theoretically the buckling coefficient K varies as follows.

$$\text{If} \quad K_y \geq K_e \geq K_p \quad \text{then} \quad K = K_e \qquad (13a)$$

$$\text{If} \quad K_e \geq K_y \geq K_p \quad \text{then} \quad K_e \geq K \geq K_y \qquad (13b)$$

$$\text{If} \quad K_e \geq K_p \geq K_y \quad \text{then} \quad K \geq K_y \qquad (13c)$$

In which K_y is a hypothetical buckling coefficient that will cause the buckling stress of element to equal its yield stress and is given by

$$K_y = \frac{\sigma_y \, 12(1 - \mu^2) \, (w/t)^2}{\pi^2 E} \qquad (14)$$

However, in practice the buckling coefficient K reduces below the elastic buckling coefficient K_e even before K_y K_e, due to a combination of the following reasons: 1. Non-linearity of stress strain relationship near the yield stress even in the elastic-plastic materials, 2. increase in out of plane deformation even before local buckling caused by initial imperfections, and the consequent partial yielding of elements on the concave side of the waves.

On the basis of comparison with many test results the following equations are deduced for calculating the actual buckling coefficient K.

$$K = K_o \quad \text{if} \quad K_y \geq 1.25\, K_e \qquad (15a)$$

$$K = K_e - (K_e - K_p)\,(1.25K_e - K_y)/(1.25K_e - K_p) \ \text{if} \ 1.25K_e \geq K \geq K_p \qquad (15b)$$

and

$$K = K_p \quad \text{if} \quad K_y \leq K_p \qquad (15c)$$

COMPARISON WITH TEST RESULTS

The analytical values obtained following the procedure outlined in the preceeding section are compared with some test results. The details of the specimens and relevant test results are presented in Fig. 8 and Tables 1 and 2. All the tests were conducted using cold-formed steel specimens of elastic plastic material. Both stiffened and unstiffened compression elements are included in the comparison. Additional information regarding these tests may be obtained from references 3, 6 and 9.

In Table 1 the local buckling coefficient K obtained from analysis are compared with measured values from tests. The analytical values compare well with the test results excepting a few cases. The mean error is 5 percent and the standard deviation is 11 percent. Considering the approximations involved in the analytical method and in the measurement of buckling stresses experimentally, this margin of error is acceptable. The errors in postbuckling effective widths calculated using analytical values of the local buckling coefficient would be smaller, because of the form of effective width equations for stiffened and unstiffened elements.

In Table 2 strains corresponding to local buckling in the plastic range, calculated analytically, are compared with ultimate strains found from test results. It has been commonly observed by many that if local buckling occurs in the elastic range, failure occurs at a strain nearly equal to yield strain. However, if the local buckling occurs well into the plastic range the failure almost immediately follows local buckling. In the intermediate range, where the local buckling strain is around the yield strain, the failure strain is higher than the local buckling strain. The same type of behavior can be observed by comparing analytical buckling strain in the inelastic range and failure strain measured in tests, shown in Table 2. Especially for compression elements which remain fully effective up to and beyond yielding (i.e. elements with $(w/t) \geq (w/t)_{lim.}$) the buckling strain (e_{cr}) calculated analytically seems to give a good estimate of the compressive strain capacity (e_u). Consequently the analytical buckling strain could be used as an estimate of the ultimate strain prior to failure. Although this could be conservative in the intermediate range, the large scatter in test values caused by the initial imperfection renders such a conservative approximation desirable in this range.

SUMMARY AND CONCLUSIONS

An approximate analytical procedure for calculating the local buckling coefficient of stiffened and unstiffened compression elements in cold-formed elastic-plastic structural members was presented. Parametric equations and charts were given for use in design offices.

Although some conservative approximations were made to simplify the analytical procedure, the procedure compared well with test results. The analytical method could be used to calculate the local buckling stress, required in the general form of the effective width equations. A conservative estimate of the plastic strain capacity of thin walled elements, prior to failure could also be obtained from the analytical procedure.

Extension of the analytical procedure to include members made of non-linear materials such as aluminum and stainless steel, is being investigated.

APPENDIX I. - REFERENCES

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APPENDIX II.- NOTATION

The following symbols are used in this paper

B = width of plate element;

C_f = correction factor to account for compressive stress;

D = flexural rigidity, depth of member;

E = Young's modulus;

E_s = secant modulus;

E_t = tangent modulus;

e = strain;

K = local buckling coefficient;

S = edge rotational stiffness;

t = thickness of plate element;

w = flat width of locally buckling plate;

η = plasticity index;

η' = modified plasticity index ($= \eta E/E_s$);

ε = rotational edge restraint factor

μ = Poisson's ratio;

σ = stress;

and the subscripts are

b = buckling element;

cr = critical value;

e = elastic value;

p = plastic value;

r = restraining element;

s = stiffened element;

u = unstiffened element.

Table 1 - ANALYTICAL AND EXPERIMENTAL LOCAL BUCKLING COEFFICIENTS

Spec.	w/t	BC (in.)	D (in.)	t (in.)	σ_y (ksi)	K_y	L	K_c	K_p	$K_{exp.}$	K_{th}	%err.
SC11	56.6	2.873	4.031	0.049	31.59	3.80	5.37	1.01	0.69	1.04	1.01	3.1
SC12	56.7	2.871	4.032	0.049	30.73	3.71	5.37	1.01	0.69	0.96	1.01	-4.5
SC21	50.5	2.505	3.988	0.048	25.68	2.46	4.65	0.99	0.68	0.95	0.99	-4.2
SC22	49.1	2.498	4.009	0.049	30.26	2.73	4.60	0.99	0.68	0.91	0.99	-8.3
SC31	41.9	2.126	3.998	0.048	31.29	2.06	3.80	0.96	0.67	0.95	0.96	-1.4
SC32	41.9	2.127	4.000	0.048	31.11	2.05	3.80	0.96	0.67	0.95	0.96	-0.7
SC41	34.3	1.751	2.997	0.048	31.29	1.38	4.25	0.98	0.67	0.99	0.98	0.9
SC42	34.0	1.727	3.034	0.048	30.50	1.32	4.12	0.97	0.67	0.99	0.97	1.4
SC51	28.7	1.497	3.011	0.049	33.18	1.03	3.48	0.95	0.66	0.88	0.86	1.6
SC52	28.8	1.501	3.003	0.049	31.05	0.96	3.50	0.95	0.66	0.85	0.83	2.5
UD2	19.6	1.250	3.000	0.058	41.90	0.60	2.72	0.91	0.64	0.79	0.64	18.7
UD3	23.9	1.500	3.000	0.058	41.90	0.89	3.49	0.95	0.66	0.82	0.79	4.4
UD4	28.2	1.750	3.000	0.058	41.90	1.25	4.23	0.98	0.67	0.86	0.98	-13.7
S1	57.3	3.558	2.058	0.058	41.90	5.17	40.83	6.42	4.40	4.85	4.83	0.5
S2	83.2	5.058	2.058	0.058	41.90	10.88	49.63	6.50	4.44	5.37	6.50	-21.0
S3	117.7	7.058	2.058	0.058	41.90	21.77	63.00	6.58	4.50	6.11	6.58	-7.7
S4	152.2	9.058	2.058	0.058	41.90	36.39	77.42	6.64	4.53	6.90	6.64	3.8
B1	60.6	4.360	4.047	0.071	51.00	7.02	3.11	0.93	0.65	0.96	0.93	2.9
B2	53.1	3.847	4.023	0.071	53.80	5.69	2.72	0.91	0.64	0.93	0.91	2.2
B3	44.5	3.410	4.198	0.075	53.80	3.99	2.25	0.89	0.63	0.83	0.89	-6.6
B4	36.9	2.840	3.189	0.075	51.00	2.60	2.52	0.90	0.63	0.79	0.90	-14.0
B5	29.8	2.278	3.272	0.074	51.30	1.71	1.87	0.86	0.61	0.80	0.86	-7.5
UP9	26.0	1.680	3.978	0.060	42.00	1.06	4.56	0.99	0.68	0.75	0.89	-19.6
UP10	32.9	1.220	4.013	0.035	36.00	1.46	3.02	0.93	0.65	0.67	0.93	-39.4
UP11	38.8	1.417	4.005	0.035	36.00	2.04	3.70	0.96	0.66	0.80	0.96	-19.1

Note: SC,B,UP specimens Ref. 6;S,UD specimens Ref. 3

1 inch= 25.4 mm; 1 ksi = 6.9 mN/mm^2

Table 2 - ULTIMATE COMPRESSIVE STRAIN AND PLASTIC BUCKLING STRAIN

Spec.	w/t	BC (in.)	D (in.)	t (in.)	σ_y (ksi)	K_y	ε	K_c	K_p	K	e_u	e_{cr}	$-l_{diff.}$
B7*	19.4	1.53	2.18	0.075	51.3	0.73	1.89	0.86	0.61	0.67	3.16	1.611	45
B8*	16.8	1.31	2.19	0.073	50.2	0.53	1.53	0.83	0.60	0.60	3.82	1.902	50
B9*	13.3	1.07	2.18	0.075	50.2	0.33	1.14	0.78	0.57	0.57	4.50	2.948	34
B12*	21.2	2.21	3.00	0.099	35.9	0.61	2.02	0.87	0.62	0.62	2.78	1.235	55
B13*	19.5	2.04	3.00	0.100	35.9	0.51	1.82	0.85	0.61	0.61	2.83	1.446	51
B14*	16.7	1.76	2.50	0.100	35.9	0.37	1.85	0.86	0.61	0.61	3.78	1.987	47
B15*	14.1	1.51	2.50	0.100	33.8	0.25	1.55	0.83	0.60	0.60	3.84	2.723	29
B16	12.7	1.36	2.00	0.099	33.8	0.21	1.84	0.86	0.61	0.61	4.59	3.396	26
B17	10.3	1.13	1.99	0.100	33.8	0.14	1.42	0.82	0.59	0.59	5.85	5.002	15
B18	7.9	0.89	2.00	0.100	33.8	0.08	0.95	0.76	0.56	0.56	8.60	8.201	5
HA1*	34.8	5.08	3.24	0.138	36.0	1.63	5.76	5.22	3.63	3.63	4.00	2.712	32
HA2*	43.0	4.73	3.25	0.105	37.0	2.57	5.34	5.17	3.60	3.60	1.26	1.759	-39
HA3*	43.6	4.70	3.25	0.103	36.0	2.57	5.31	5.16	3.60	3.60	2.18	1.707	22
HB1*	35.3	5.15	3.16	0.138	36.0	1.68	5.96	5.24	3.64	3.64	4.15	2.638	36
HB2*	43.9	4.73	3.34	0.103	36.0	2.60	5.18	5.15	3.59	3.59	1.57	1.684	12
HL1*	36.2	4.78	3.29	0.125	37.4	1.84	5.35	5.17	3.60	3.60	4.12	2.476	39
HL2*	40.7	5.34	3.62	0.125	37.4	2.33	5.41	5.18	3.60	3.60	2.99	1.964	34
HL3*	43.8	5.73	3.98	0.125	36.0	2.59	5.28	5.16	3.59	3.59	2.61	1.693	35
HL4*	42.4	4.44	3.01	0.100	36.4	2.45	5.41	5.18	3.60	3.60	1.82	1.814	1
HL5*	41.7	4.38	3.27	0.100	37.4	2.45	4.89	5.11	3.56	3.56	1.45	1.847	28

Note: B specimens Ref. 6; HA, HB, HL specimens Ref. 9.

1 in. = 25.4 mm; 1 ksi = 6.9 mN/mm^2

*specimens with $w/t \geq (w/t)_{lim.}$ (i.e., effective width reduces before yielding)

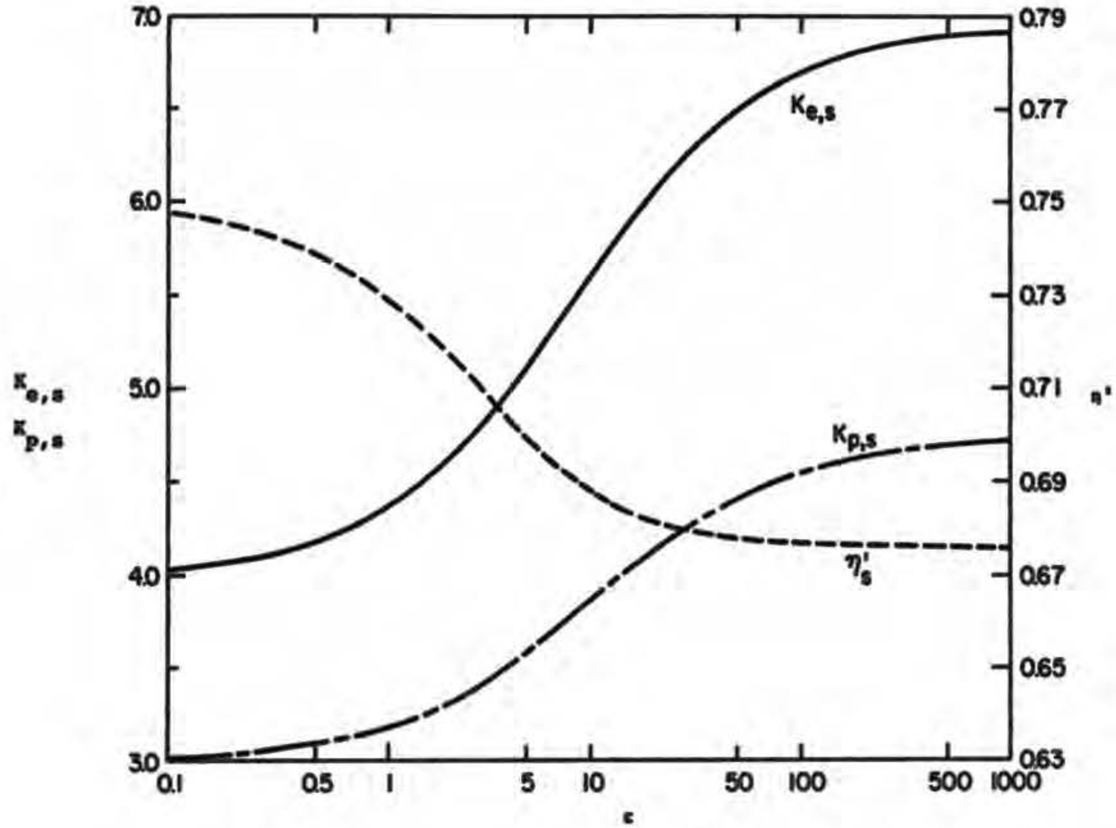


Fig. 1.- LOCAL BUCKLING COEFFICIENT .VS. ROTATIONAL EDGE RESTRAINT
(STIFFENED ELEMENT)

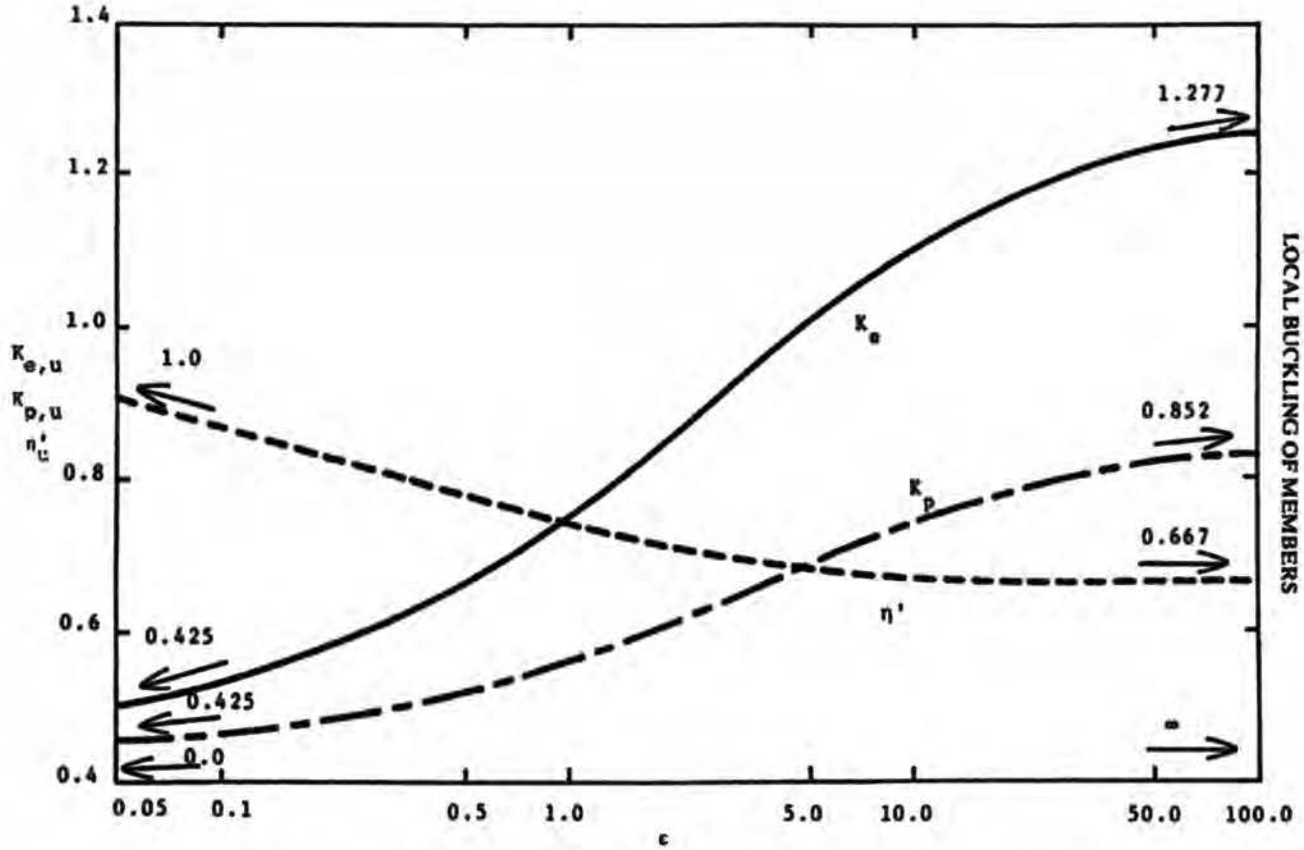
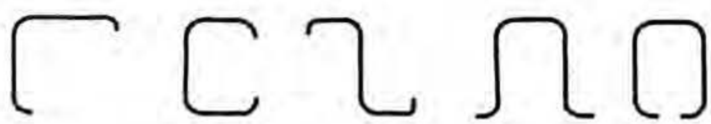
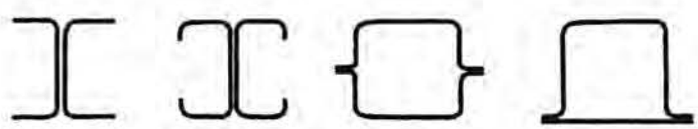


Fig. 2.- LOCAL BUCKLING COEFFICIENT .VS. ROTATIONAL EDGE RESTRAINT (UNSTIFFENED ELEMENT)

Open Sections

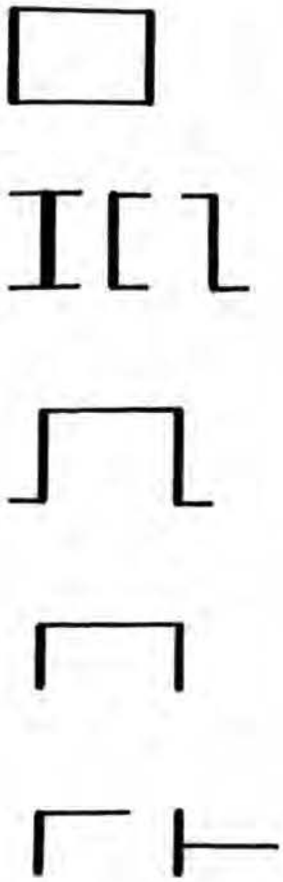


Lipped Sections



Built-up Sections

Fig.3.- COMMON COLD-FORMED STRUCTURAL SHAPES



	Axial Compression	Pure Bending (conservative values)
1	$\frac{4.0}{4.0} = 1.0$	$\frac{4.0}{7.8} = 0.513$
2	$\frac{0.425}{4.0} = 0.106$	$\frac{0.425}{7.8} = 0.055$
3	$\frac{4.0}{4.0} = 1.0$ $\frac{0.425}{4.0} = 0.106$	$\frac{4.0}{7.8} = 0.513$ $\frac{0.425}{7.8} = 0.055$
4	$\frac{4.0}{0.425} = 9.41$	$\frac{4.0}{2.0} = 2.0$
5	$\frac{0.425}{0.425} = 1.0$	$\frac{0.425}{2.0} = 0.213$

Fig. 4.- BUCKLING COEFFICIENT RATIO OF BUCKLING AND RESTRAINING ELEMENTS IN COMMON COLD-FORMED MEMBERS (K_b/K_r)

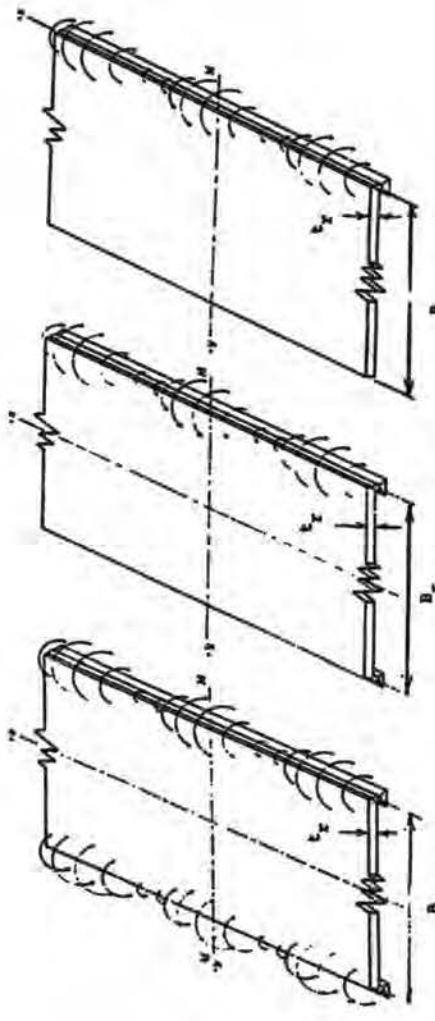


Fig. 5. COMMON BOUNDARY CONDITIONS OF RESTRAINING ELEMENTS

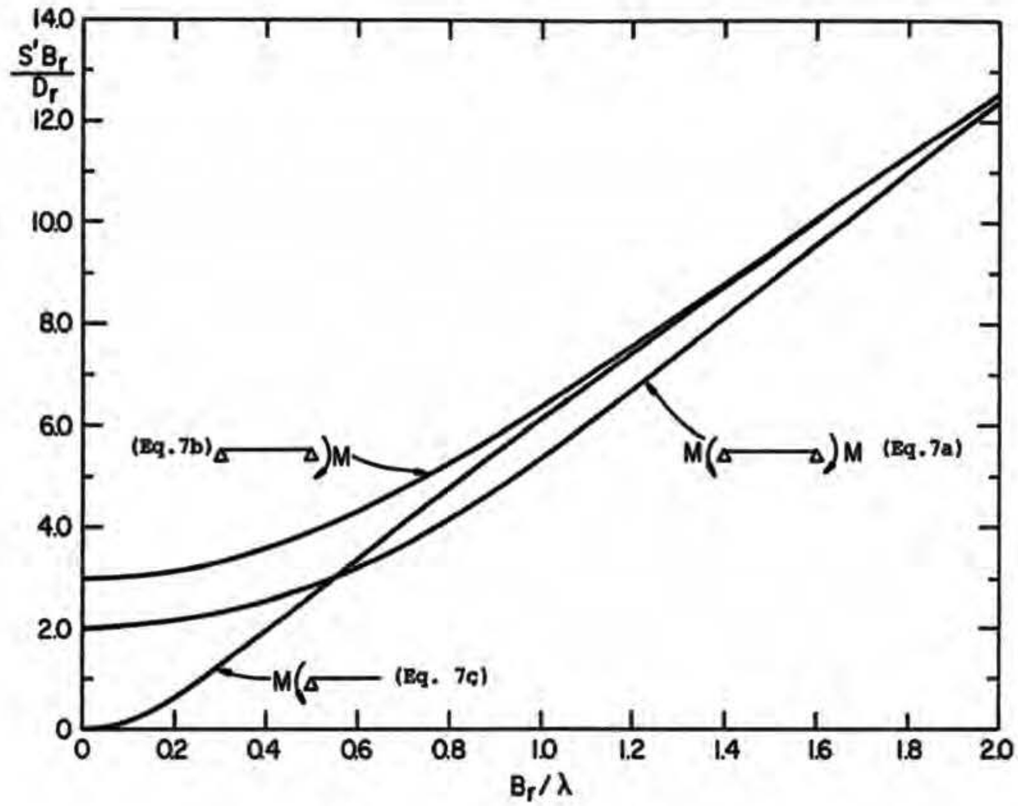


Fig. 6. RESTRAINING ELEMENT'S ROTATIONAL EDGE RESTRAINT

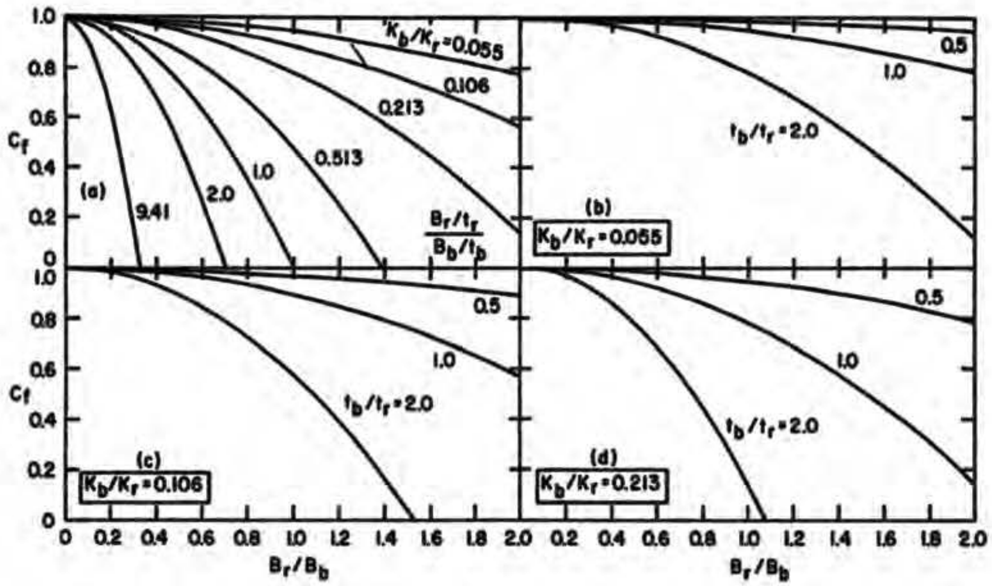


Fig. 7.- CORRECTION FACTOR FOR ROTATIONAL EDGE RESTRAINT

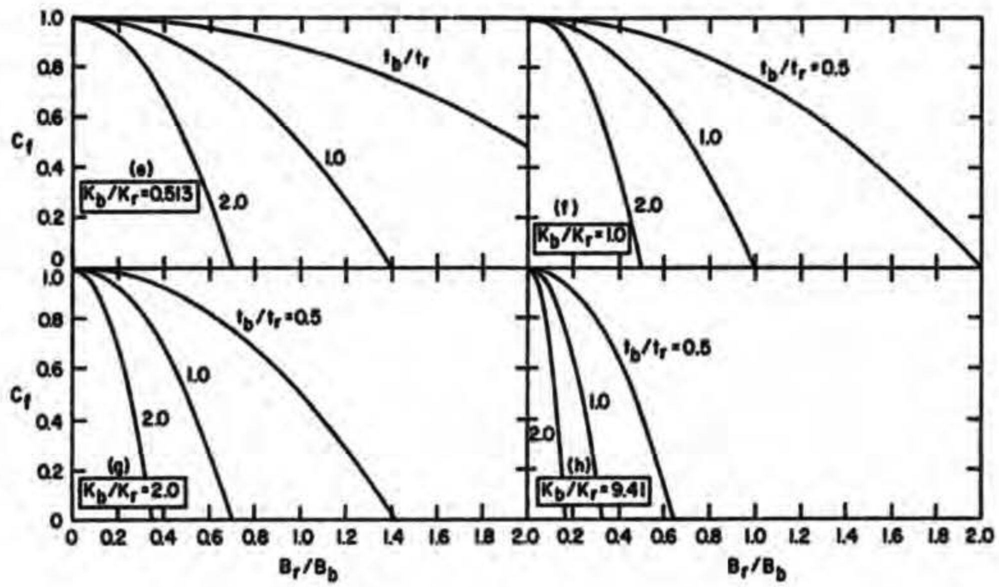
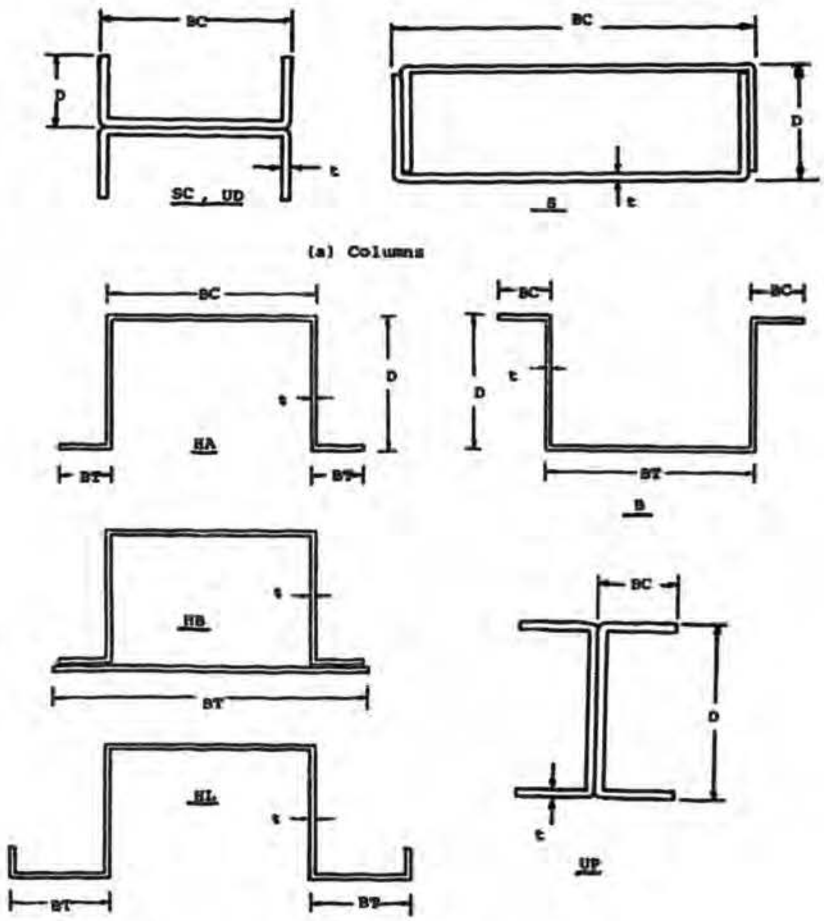


Fig. 7- CORRECTION FACTOR FOR ROTATIONAL EDGE RESTRAINT (contd.)



(b) Beams

Fig. 8. - CROSS-SECTION OF TEST SPECIMENS