Compression Tests of Cold-Formed Steel Columns

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Abstract: This paper presents a detailed description of an experimental study of the flexural buckling strength of cold-formed steel columns. A total of 68 columns and 25 stub columns are tested. It is observed that some types of columns show lower strength than the value predicted by the American Iron and Steel Institute column design formulas. In some cases, the differences between the test results and the AISI predictions are found to be larger than 15%. From the experimental findings, the cross-sectional dimensions and the magnitude of the residual stresses are found to have a consistent correlation with the weakening of the column strength. Other parameters, such as the stress-strain curve (sharp or gradual yielding) obtained from tensile coupon tests and the method used to form the sections (press-braked or roll-formed), are not found to have a definite influence on the strength of the columns.

Introduction

A study conducted by Karren and Winter (1967) on the flexural buckling strength of cold-formed steel columns indicated that the use of the Column Research Council's column curve (Johnston 1966), which was developed for hot-rolled steel columns, gave close estimations of the strength of the fully effective cold-formed steel columns. Since then, the CRC column curve has been used as the basis of the column design formulas of the AISI ("Specification" 1980). However, a recent study performed by Dat (1980) showed that the AISI column design formulas overestimate the strength of some types of cold-formed steel columns.

Fig. 1 shows the column test results of the 14-gauge channel sections obtained by Dat (1980). It is seen that the AISI column formulas overestimates the strengths of these columns. In some cases, the differences between the test results and the AISI predictions were found to be quite significant. However, for some other types of columns tested by Dat, including hat and channel sections, the values predicted by the AISI column formulas were found to be satisfactory.

The objective of this study was to perform more column tests to check whether the problem of unconservative predictions by the AISI formulas occurs only to certain types of columns. The main focus of the study was on the 14-gauge channel sections. It was noted that the 14-gauge columns tested by Dat (1980) were all from the same manufacturer and produced in the same roll-forming line. Thus, it was desirable to conduct some tests on similar sections of similar thickness produced elsewhere. In addition, columns with different thicknesses and other configurations were also tested for a further understanding of their behavior.

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Residual Stresses in Cold-Formed Steel Sections

A detailed description of the residual stresses measured from the columns tested in this investigation is to be presented in a subsequent paper. The following is a brief summary of the observed experimental results:

1. In the longitudinal direction, compression residual stresses were found on the inside surface of the sections, and tension residual stresses on the outside surface.
2. The magnitudes of the surface residual stresses of the section were found to be 25–70% of the yield stress of the material.
3. The magnitudes of the residual stresses on the flat portions of the section were approximately uniform along the perimeter of the section.
4. At the same location, the magnitudes of the residual stresses on the inside and outside surfaces of the flat portions of the section were found to be quite close.
5. The general shape of the distribution of residual stress followed a consistent pattern for all sections.

Test Specimens

The cross sections of the test specimens are shown in Fig. 2. The dimensions and material properties are given in Table 1. These specimens were

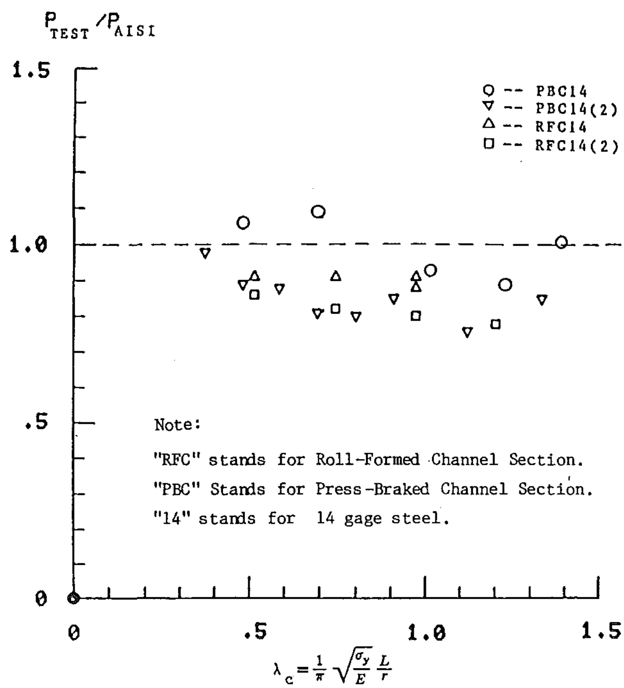

FIG. 1. Test Results of Dat (1980) versus AISI Predictions: Sections Showing Unconservative Predictions

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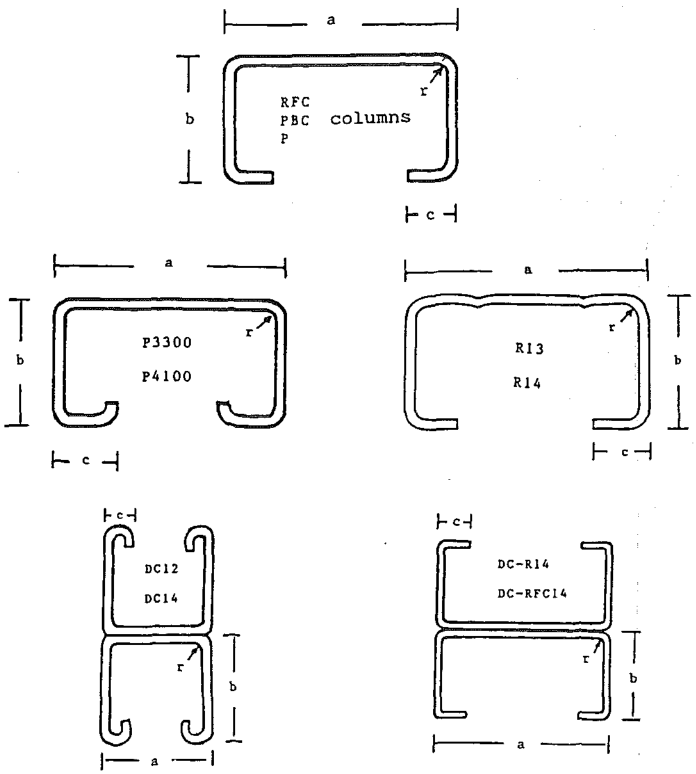


FIG. 2. Cross Section Geometries of Specimens

obtained from four different manufacturers and included both roll-formed and press-braked sections. The thickness of the specimens ranged from 0.064–0.121 in., including 11, 12, 13, 14, and 16 gauge steel.

The material properties of the specimens were determined according to the procedure of the standard tension tests recommended by the American Society for Testing and Materials ("Standard" 1975). The yield stress and the percentage of elongation in a 2 in. gauge length were obtained from the uniaxial tension coupon tests. For gradual yielding material, the yield stress was determined by the 0.2% offset method.

In the design of the test specimens, it was intended to have sections that were fully effective, and all column failures were due to flexural buckling around the weak axis of the sections. According to the AISI, the maximum flat width ratio, $(w/t)_{\mathrm{lim}}$, of a fully effective stiffened plate element is

$$\left(\frac{W}{t}\right)_{\mathrm{lim}} = \frac{221}{\sqrt{F_y}} \quad (1)$$

where W is the flat width of the plate element, t is the plate thickness, and F_y is the yield stress of the material. Based on this criterion, all specimens used in this investigation were proportioned so that the W/t ratio of the

TABLE 1. Cross-Sectional Dimensions and Material Properties

Type of column (1)	t (in.) (2)	A (in.) (3)	a (in.) (4)	b (in.) (5)	c (in.) (6)	r (in.) (7)	F_y (ksi) (8)	F_u (ksi) (9)	2 in. elongation (%) (10)
RFC11	0.119	0.835	3.152	1.648	0.706	0.156	40.38	53.12	34
RFC13	0.096	0.674	3.067	1.629	0.715	0.156	51.85	62.21	33
RFC14	0.075	0.533	2.998	1.756	0.694	0.219	55.09	76.55	30
R13	0.086	0.573	3.010	1.635	0.605	0.219	50.15	70.63	27
R14	0.075	0.511	3.015	1.658	0.610	0.219	49.73	69.32	30
PBC13	0.087	0.596	3.025	1.620	0.610	0.156	38.40	50.56	38
PBC14	0.071	0.493	3.001	1.632	0.605	0.156	36.30	50.07	33
P11(1)	0.118	1.296	5.037	2.491	0.878	0.125	30.59	50.95	35
P11(2)	0.121	1.328	5.037	2.491	0.878	0.125	33.60	51.91	34
P16(1)	0.064	0.395	2.645	1.377	0.623	0.094	33.45	40.13	31
P16(2)	0.064	0.395	2.645	1.377	0.623	0.094	32.06	45.09	32
P3300	0.105	0.397	1.625	0.875	0.375	0.156	55.89	65.04	23
P4100	0.075	0.285	1.625	0.813	0.375	0.156	51.65	59.81	25
DC12	0.105	1.110	1.625	1.625	0.375	0.156	44.31	53.12	36
DC14	0.075	0.610	1.250	1.250	0.281	0.156	44.95	59.20	35
DC-R14	0.075	1.014	3.015	1.658	0.610	0.219	49.73	69.32	30
DC-RFC14	0.075	1.066	2.998	1.756	0.694	0.219	55.09	76.55	30

Note: RFC and R both stand for roll-formed channel; PBC and P both stand for press-braked channel; DC stands for double channel section; 11, 12, 13, 14, and 16, are gauge numbers of steel; DC12 and DC14 are roll-formed 12 and 14 gauge double channels; and P3300 and P4100 are roll-formed 12 and 14 gauge channel sections (1 in. = 25.4 mm, 1 ksi = 6.89 N/mm^2).

component plate elements of the section were smaller than the limiting value, $(W/t)_{\text{lim}}$. It was also assumed that the edge stiffeners were adequate by the AISI criteria for all elements to be fully effective in all of the test specimens.

Stub Column Tests

In the stub column tests, the recommendations of Technical Memorandum No. 3 of the Structural Stability Research Council Guide (Johnston 1976) were utilized for the determination of the length of the stub column. In the memorandum, it is suggested that the length of a stub column should be no less than three times the largest dimension of the section, nor greater than 20 times the radius of gyration about the weak axis of the section. The objective of choosing a proper length is to ensure that the stub column is short enough so that the influence of overall buckling is minimized, but long enough so that the end effects can be neglected. Through the test of a stub column, the average stress-strain relationship over the complete cross section, with its locked-in residual stresses, can be studied.

The stub columns were cut with a saw from members at least 6 in. from the flame-cut ends. The ends of the stub columns were machined (ground) plane to within 0.0005 in. The parallelism of the two ends is desirable, since it facilitates alignment during the testing of the columns. Three strain gauges were mounted at the midheight of the specimen with one at the center of the web and two near the junctions of the flanges and lips. The F-400 foil

TABLE 2. Stub Column Test Results

Type of column (1)		L (in.) (2)	P_y (kip) (3)	P_u (kip) (4)	P_u/P_y (5)
RFC14	#1	10.0	29.36	29.4	1.00
	#2	10.0	29.36	29.9	1.02
	#3	10.0	29.36	29.6	1.01
RFC13	#1	10.0	34.95	35.0	1.00
	#2	10.0	34.95	36.4	1.04
RFC11	#1	10.0	33.71	37.4	1.11
R14	#1	10.0	25.41	26.1	1.02
	#2	10.0	25.41	26.6	1.03
R13	#1	10.0	28.74	29.2	1.02
	#2	10.0	28.74	29.5	1.03
PBC14	#1	10.0	17.90	18.5	1.03
	#2	10.0	17.90	17.7	0.99
	#3	10.0	17.90	17.8	0.99
PBC13	#1	10.0	23.18	23.5	1.01
	#2	10.0	23.18	23.5	1.01
P16	#1	10.0	12.66	13.2	1.04
P11	#1	17.0	44.62	45.3	1.02
P3300	#1	6.0	22.19	25.7	1.16
	#2	6.0	22.19	26.0	1.17
P4100	#1	6.0	14.72	17.2	1.17
	#2	6.0	14.72	17.1	1.16
DC12	#1	12.0	49.18	59.2	1.20
	#2	12.0	49.18	59.5	1.21
DC14	#1	10.0	27.42	36.5	1.33
	#2	10.0	27.42	36.7	1.34

Note: 1 in. = 25.4 mm, 1 kip = 4.45 kN.

strain gauges were used to measure the strains in the stub columns at each load level. They also served as an indication of uniformly distributed loading when the three gauges' readings were within 5% difference.

A Southwark-Emery (300-kip capacity) hydraulic testing machine was used for stub column tests. Two precisely ground end plates (planed to within 0.0005 in.) of high-strength steel were used. Hydrostone bedding was applied between the bearing plate and machine head. The end plates and the Hydrostone help ensure uniformity of load and adjust for any out-of-parallelism of the specimen ends.

The axial load was applied slowly with an increment of about one-tenth of the expected ultimate capacity of the stub column. Smaller increments were used near the failure load of the specimen. Readings were taken after the load was stabilized at each increment. During the test, all strain gauges were connected to a Hewlett Packard data acquisition system, and the strains at each load level were recorded with the computer.

Stub Column Test Results

A total of 25 stub columns were tested. The test results are given in Table 2. Some typical stress-strain curves obtained from the tests are shown in Figs. 3(*a*)–(*d*). The ratios of the ultimate capacity of the stub columns to

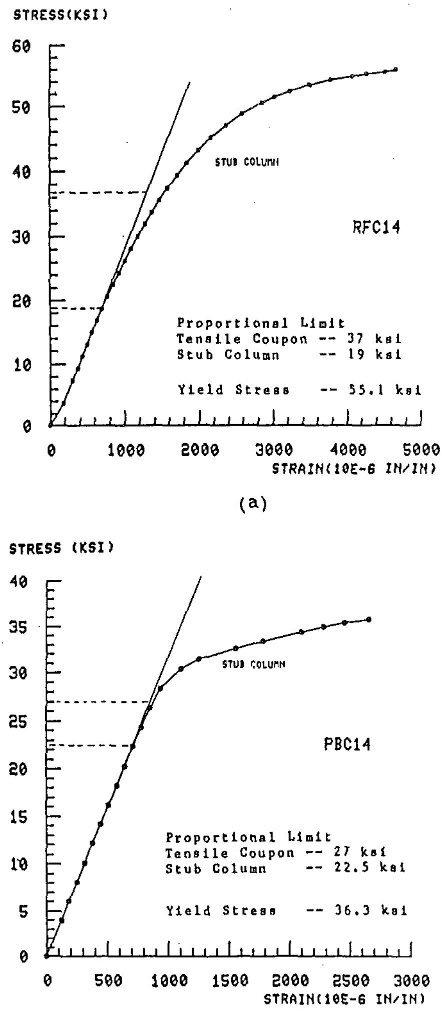
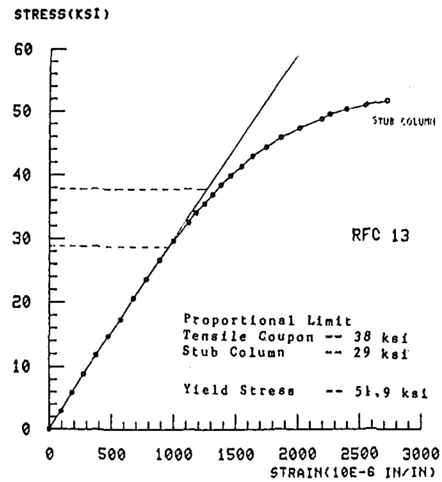


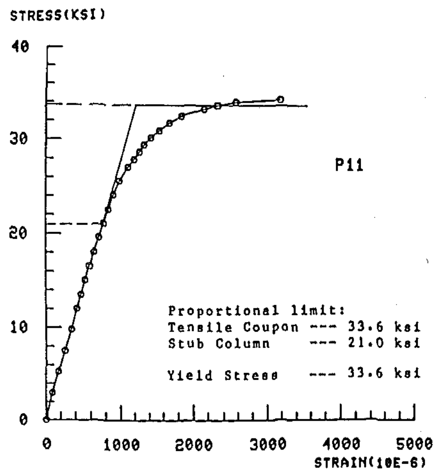
FIG. 3. Stub Column Stress-Strain Curves

the yield load of the sections, P_u/P_y, as shown in Table 2, are all equal to or greater than unity, except two of the PBC14 sections, which are 0.99. For the thinner sections of gauges 14 and 16, the yield load obtained by multiplying the gross area to the yield stress was found to be a good estimation of the ultimate capacity of the stub columns. However, for the thicker sections of gauges 11 and 13, the ultimate capacity is significantly larger than the yield load of the section due to the effect of strain hardening.

Another important factor studied from the stub column tests is the comparison of the stress-strain relationship between results of stub column and uniaxial tensile coupon tests. For this purpose, the proportional limits ob-



(c)



(d)

FIG. 3. ***(Continued)***

tained from the tensile coupon tests are indicated in the figures.

Since the residual stresses are typically low in coupons removed from flat sheet or strip steel, it was observed that the proportional limits obtained from the stub column tests are all lower than those from the tensile coupon tests. In some cases, the difference was found to be quite significant. The most severe case was found in the roll-formed 14 gauge section, RFC14, as shown in Fig. 3(*a*). The yield stress and proportional limit stress of this section obtained from the tensile coupon test are 55 ksi and 37 ksi, respectively. The figure shows that the proportional limit of the stub column is 19 ksi. This means that the stub column starts to behave nonlinearly when the stress is larger than about one-third of the yield stress of the material. In other

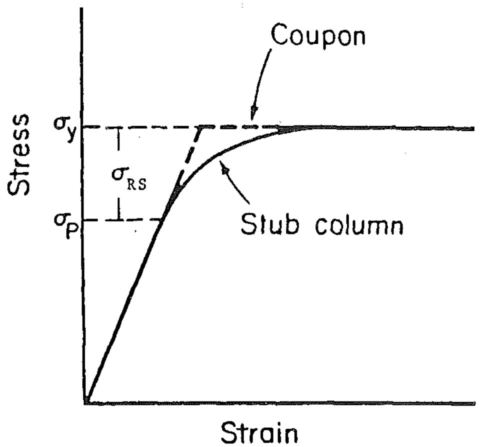


FIG. 4. Stub Column Proportional Limit versus Residual Stress

words, the Young's modulus, E, is valid only when the stress is less than one-third of the yield stress. For other sections, the proportional limits of the stub columns ranged approximately from 40–80% of the yield stress of the materials.

Since the reduction of the proportional limit is mainly due to the presence of the compression residual stress in the section, it is interesting to compare the proportional limits obtained from the stub column tests with the compression residual strains measured from these sections. In the typical stub column stress-strain curve, shown in Fig. 4, the sum of the proportional limit stress, σ_p, and the maximum residual stress, $(\sigma_{rs})_{\max}$ is equal to the yield stress of the material. That is,

$$\sigma_p + (\sigma_{rs})_{\max} = \sigma_y \quad \text{(2)}$$

or

$$\frac{\sigma_p}{\sigma_y} + \frac{(\sigma_{rs})_{\max}}{\sigma_y} = 1 \quad \text{(3)}$$

Eq. 3 can be written in terms of the residual strain $(\epsilon_{rs})_{\max}$, and the yield strain ϵ_y, as follows

$$\frac{(\epsilon_{rs})_{max}}{\epsilon_y} = 1 - \frac{\sigma_p}{\sigma_y} \quad \text{(4)}$$

By using Eq. 4, the correlations between the stub column proportional limits and the maximum residual strains measured from the flat portions of the sections are shown in Table 3. The yield stress of the flat portion of the section was used in the calculation. The differences between A and B, as shown in Table 3, are less than 10%, except for the roll-formed 13 gauge section, RFC13. It is apparent that the magnitude of the residual stress has a significant effect on the stress-strain relationship of the stub columns.

TABLE 3. Stub Column Proportional Limits versus Measured Residual Stresses

Type of column (1)	σ_y (ksi) (2)	σ_p (ksi) (3)	$1 - (\sigma_p/\sigma_y)$ (*A*) (4)	ϵ_y ($\mu\epsilon$) (5)	ϵ_{rs} ($\mu\epsilon$) (6)	ϵ_{rs}/ϵ_y (*B*) (7)	Difference (*A*) − (*B*) (%) (8)
RFC14	55.09	19.0	0.655	1,867	1,044	0.559	9.6
PBC14	36.30	22.5	0.380	1,231	404	0.328	5.2
R14	49.73	31.7	0.363	1,686	758	0.450	8.7
R13	50.15	27.5	0.452	1,700	857	0.504	5.2
RFC13	51.85	29.0	0.441	1,758	428	0.243	19.8
P11	33.60	21.0	0.375	1,139	458	0.402	2.7
P16	33.45	20.2	0.396	1,134	458	0.404	0.8
DC12	44.31	34.2	0.228	1,502	405	0.270	4.2
DC14	44.95	33.0	0.266	1,524	496	0.325	5.9
P3300	55.89	45.6	0.184	1,895	402	0.212	2.8
P4100	51.65	42.0	0.187	1,751	314	0.179	0.8

Note: 1 ksi = 6.89 N/mm^2.

Column Tests

Columns were cut with a saw to the desired lengths from specimens provided by the manufacturers. Two pieces of hot-rolled steel plates (3/4 × 6 × 6 in.) were welded to the ends of the column. To minimize weld-induced distortion, sequential, intermittent fillet welds were symmetrically applied on both sides of the section.

To measure the initial deflections, the column was placed horizontally on a plane surface and a dial gauge was used to measure the elevation of various points along the length of the column. For columns not longer than 4 ft, a ground table was used as the plane surface. For longer columns, a long precision ruler was used as the reference plane.

The columns were checked for three possible buckling modes: Flexural, torsional, and torsional-flexural buckling. The flexural buckling load near the weak axis was found to always be lower than the torsional or torsional-flexural buckling load. Thus, the failure of the columns due to flexural buckling was ensured.

Three F-400 foil strain gauges were mounted at mid-height of the column at the locations shown in Fig. 5. The strain gauges were used for alignment as well as measurement of the strains at each load level. A set of special end fixtures, which provided a pinned-end condition about one direction by knife edges and wedges, were used. The fixtures at Cornell University were used successfully by Pekoz (1967), DeWolf (1974), Kalyanaraman (1977), Mulligan (1984), and Loh (1985).

The same hydraulic testing machine and data acquisition system used for stub column tests were used for the column tests. During the tests, the displacements of the columns were measured using linear variable differential transformers (LVDT). Four LVDTs were used to measure the displacements in the column tests. The arrangement of the LVDTs is shown in Fig. 6. Since no movement of the end fixture was detected, the use of LVDT No. 4 was abandoned in the later tests.

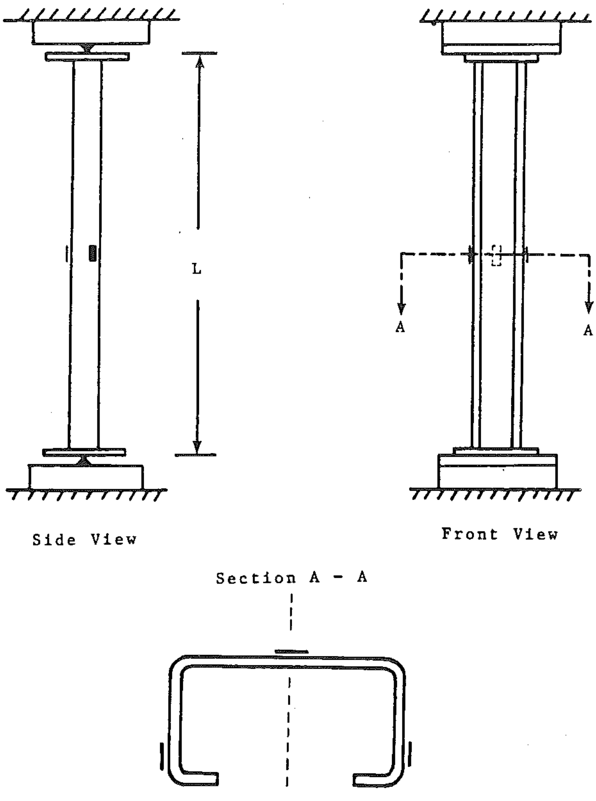


FIG. 5. Strain Gage Locations in Column Tests

Alignment

The alignment of the column is an important step to be carried out before testing a centrally loaded column. There are two approaches for aligning pinned-end columns. The first method is called "alignment under load," which is based on a uniform strain condition at mid-height of the column. The second method is called "geometric alignment," which is to align the column geometrically with respect to some reference points of the cross section.

In the first method, the condition of the alignment is judged from the readings obtained from the strain gauges applied on the column. The alignment is considered satisfactory when strains are uniform to within 5% for loads of approximately one-third of the expected column strength.

In the second method, the geometric alignment consists of centering the specimen in the testing machine at its gross centroid. Due to the unavoidable dimensional imperfections and the practical difficulty of precisely aligning the centroid of the specimen to the center of the machine table, this procedure rarely results in an exact alignment. In addition, an undesirable eccentricity may be introduced by the improper alignment, which results in a reduction of the strength of the column. Test results obtained using this alignment method usually contain higher degrees of uncertainty, and show

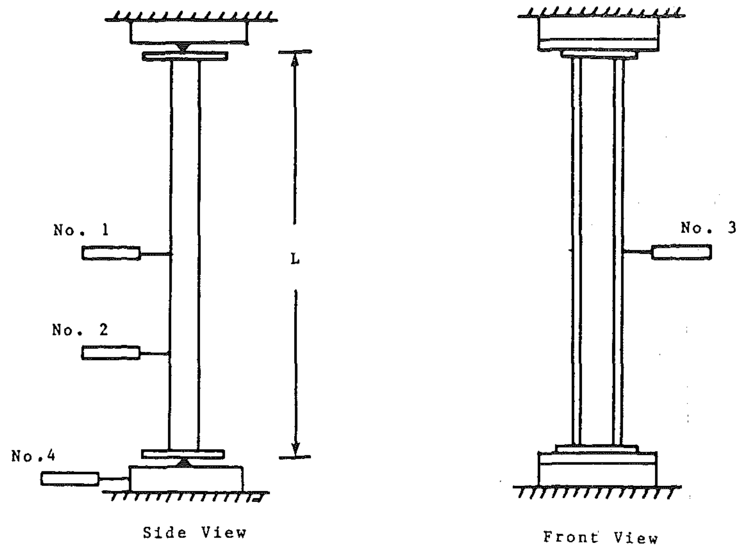


FIG. 6. LVDT Locations in Column Tests

larger scatter. However, this method has been used successfully by several researchers in the testing of hot-rolled steel columns where the effect of the cross-sectional imperfections may not be as significant as those in cold-formed steel members.

In cold-formed steel sections the cross-sectional dimensions are usually not as close tolerance as they are in hot-rolled sections. The calculated centroid may vary along the length of the column due to cross-sectional imperfections. The imperfections include the lengths of the stiffening lips, corner radii, thickness, etc. Because of these variations in this investigation, the method of alignment under load was used for all column tests. By using this method, the influence of the misalignment can be minimized, and the behavior of a centrally loaded straight column can be studied more closely. Also, the column test results obtained using this alignment method provide a better basis for comparison with equations in the AISI specifications ("Specification" 1980), which are intended for straight columns. The effects of initial imperfections are accounted for by the use of a factor of safety in the specifications.

The alignment of the column was done by adjusting the wedges and positioning screws of the end fixtures. Once the distribution of the strains at the mid-height of the column met the aforementioned criterion, the alignment was then completed.

After completion of the alignment, LVDTs were placed at the desired locations for measuring displacements during the test. Then, the strain gauges and LVDTs were connected to the data acquisition system. A loading procedure, identical to that described for stub column tests, was employed.

Column Test Results

A total of 68 columns were tested. Table 4 gives the results of the column tests and the comparison of the observed ultimate load, P_u, and the value

TABLE 4. Column Test Results

Type of column (1)		L (in.) (2)	KL/r (3)	P_u (kip) (4)	P_{AISI} (kip) (5)	P_u/P_{AISI} (5)
RFC14	#1	27.0	40.5	25.3	27.10	0.93
	#2	38.7	58.0	22.3	24.70	0.90
	#3	51.0	76.5	16.4	21.25	0.77
	#4	63.0	94.5	12.7	16.97	0.75
	#5	75.5	112.4	9.7	12.28	0.79
RFC13	#1	27.0	43.7	30.2	30.25	1.00
	#2	39.0	63.1	29.2	27.97	1.04
	#3	51.0	82.5	23.8	24.15	0.99
	#4	63.0	101.9	17.0	18.80	0.90
RFC11	#1	27.0	44.0	32.3	29.52	1.09
	#2	39.0	63.5	30.3	27.96	1.08
	#3	51.0	83.1	28.5	25.23	1.13
	#4	63.0	102.6	19.7	21.34	0.92
R14	#1	27.0	43.6	23.2	23.36	0.99
	#2	39.0	62.9	19.4	21.13	0.92
	#3	51.0	82.3	15.4	18.07	0.85
	#4	63.0	101.6	11.6	14.22	0.82
	#5	75.0	121.0	8.5	10.16	0.84
R13	#1	27.0	44.7	26.2	26.28	1.00
	#2	39.0	64.6	23.8	23.59	1.01
	#3	51.0	84.4	17.8	19.94	0.89
	#4	63.0	104.3	13.2	15.29	0.86
	#5	73.0	120.9	10.1	11.42	0.88
PCB14	#1	27.0	43.6	16.1	16.84	0.96
	#2	39.0	63.0	15.6	15.69	0.99
	#3	51.0	82.4	13.0	14.12	0.92
	#4	63.0	101.8	11.2	12.12	0.92
	#5	75.0	121.2	9.7	9.71	1.00
PBC13	#1	26.8	44.1	18.0	21.43	0.84
	#2	39.0	64.1	17.5	19.80	0.88
	#3	51.0	83.9	16.0	17.59	0.91
P11	#1a	55.0	58.8	34.2	36.07	0.95
	#2a	75.0	80.1	30.4	32.98	0.92
	#3b	90.0	96.4	27.8	32.69	0.85
	#4b	110.0	117.8	22.3	26.79	0.83
P16	#1a	31.0	58.1	11.2	11.94	0.94
	#2a	41.0	76.8	10.4	10.98	0.95
	#3b	52.0	97.4	8.0	9.36	0.86
	#4b	62.0	116.1	6.9	7.97	0.87
	#5b	69.0	129.2	6.2	6.85	0.91
P3300	#1	14.5	45.6	21.4	19.01	1.13
	#2	22.8	71.7	17.1	16.46	1.04
	#3	30.5	95.9	12.0	12.39	0.97
	#4	38.5	121.1	7.5	7.89	0.95
	#5	46.4	145.9	5.3	5.43	0.97
P4100	#1	14.5	47.1	14.8	13.28	1.11
	#2	22.5	73.1	12.3	11.24	1.09
	#3	30.5	99.0	7.7	8.32	0.93
	#4	38.5	125.0	5.2	5.31	0.97
	#5	46.5	151.0	3.6	3.64	0.98

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TABLE 4. (Continued)

(1)		(2)	(3)	(4)	(5)	(6)
DC12	#1	27.0	41.2	51.8	43.13	1.20
	#2	39.0	59.5	46.6	40.97	1.14
	#3	51.0	77.7	42.2	37.21	1.14
	#4	63.0	96.0	33.8	31.79	1.06
	#5	75.0	114.3	25.0	24.75	1.01
DC14	#1	27.0	53.2	30.1	24.44	1.23
	#2	39.0	76.8	22.2	21.20	1.05
	#3	51.0	100.4	16.5	16.77	0.98
	#4	63.0	124.0	11.8	11.55	1.02
	#5	75.0	147.6	8.4	8.15	1.03
DC-RFC14	#1	34.0	28.9	55.8	56.43	0.99
	#2	46.0	39.2	51.5	54.50	0.94
	#3	57.5	48.9	46.6	52.10	0.89
	#4	69.7	59.3	41.8	48.98	0.85
DC-R14	#1	39.9	33.6	48.5	48.02	1.01
	#2	60.3	50.8	44.2	44.91	0.98
	#3	88.1	74.2	34.8	38.61	0.90

Note: 1 in. = 25.4 mm, 1 kip = 4.45 kN.

predicted by the AISI column equations, P_{AISI}. The test results are also plotted in Figs. 7 and 8. Fig. 7 includes the columns showing lower strength than the AISI predictions. For other columns, the test results are plotted in Fig. 8. For comparison, the AISI column curve is also shown in the figures.

As shown in Table 4, it was observed that not only the 14 gauge columns, but also the 11, 13, and 16 gauge columns showed significant understrength when compared with the AISI predictions. Thus, the problem of understrength of cold-formed steel columns is not a matter related only to the 14

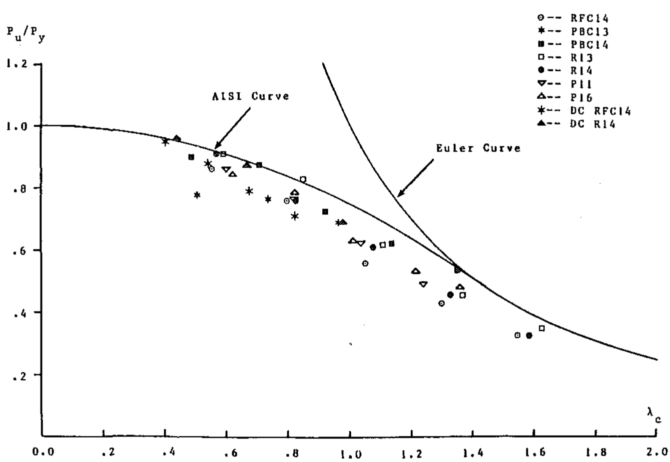

FIG. 7. Column Test Results versus AISI Column Curve: Sections Showing Unconservative Predictions

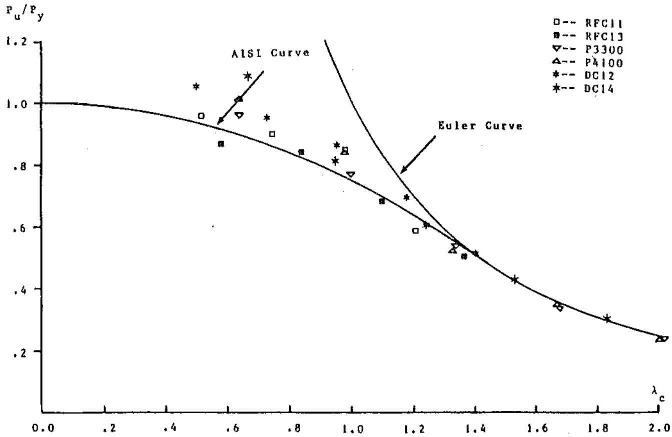

FIG. 8. Column Test Results versus AISI Column Curve: Sections Showing Conservative Predictions

gauge sections. This is easily understood by observing the test results of the columns RFC14 (roll-formed 14 gauge), R14, R13 (roll-formed 13 gauge), P11 (press-braked 11 gauge) and P16. These columns all showed lower strength than the AISI predictions. For the RFC14 columns, significant understrength was observed when the slenderness ratio of the column becomes larger than about 60. The differences between the test results and the AISI predictions can be as great as 25%.

On the other hand, the test results of another set of roll-formed 14 gauge sections, P4100, which have a different proportioning of the cross section dimensions as compared to the RFC14 and R14 sections, showed a better agreement between the test results and the AISI predictions. This observation indicates that the roll-formed 14 gauge columns are not necessarily weak if the cross-sectional dimensions of the sections are changed.

It was also found that the strengths of the double symmetric roll-formed 14 gauge columns, DC-R14 and DC-RFC14 (made from two R14 or RFC14 sections), were still weaker than the AISI predictions. The test results showed as much as 15% understrength when compared with the values predicted by the AISI column formulas. However, the other set of double symmetric columns, DC14, which are also roll-formed 14 gauge sections, but with different cross-sectional dimensions, showed good agreement with the AISI predictions. These observations suggest that the proportioning of the cross-sectional dimensions of the column, rather than the shape of the section, have a direct relation to the weakening of the column strength. Various parameters and their effect on the performance of the columns are discussed in a separate paper by the writer ("Effect of Residual Stresses on Cold-Formed Steel Column Strength," submitted to the ASCE Journal of Structural Engineering).

The test results also showed that the strength of the press-braked columns does not always have a better agreement with the AISI predictions than those of the rolled-formed ones. This was easily understood by observing the test results of two sets of press-braked columns, P11 and P16. As shown in Table

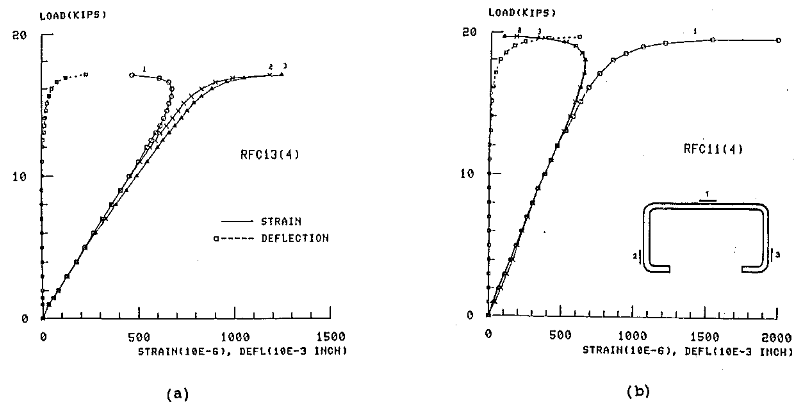

FIG. 9. Load-Deflection and Load-Strain Curves

4, P11 and P16 columns both showed apparent understrength when compared with the AISI predictions ("Specification" 1980). The ratios of P_U/P_{AISI} are 0.83–0.95.

It was also noted that, for those columns showing lower strength than the AISI predictions, two types of tensile coupon stress-strain curves were observed. Some of them have sharp-yielding stress-strain curves, such as sections P11, R14, and P16. Others have gradual-yielding stress-strain curves, such as sections R13 and RFC14. These observations indicate that the yielding type of the stress-strain curve obtained from the tensile coupon tests does not have a definite influence on the problem of the understrength of the columns.

It is interesting to compare the column test results with the residual stresses measured in the sections. As shown in Table 4, the press-braked 14 gauge columns, PBC14, indicate a better agreement with the AISI predictions than those of the roll-formed 14 gauge columns, RFC14. Table 3 also shows that the residual strains measured in the PBC14 sections are much smaller than those in the RFC14 sections. Furthermore, the magnitude of reduction of the proportional limit observed from the stub column tests of the PBC14 section is also much smaller than that of the RFC14 sections, as shown in Figs. 3(*a*) and (*b*).

Similarly, as indicated in Table 3, higher residual stresses were observed for sections R13, R14, P11, and P16. The ratio of the measured residual strain to the yield strain of the material, ϵ_{rs}/ϵ_y, are all higher than 40%. These columns also showed apparent understrength when compared with predictions derived from the AISI ("Specification" 1980). Based on these observations, it can be concluded that the higher the residual stresses in the sections, the worse the agreement between the column test results and the AISI predictions.

The press-braked 13 gauge section, PBC13, showed an understrength up to 16% of the AISI predictions. However, it was noted that some initial waves on the web and flanges of the sections were observed before the columns were tested, which may weaken column strength.

A typical load-deflection and load-strain curves obtained from the column tests are shown in Figs. 9(*a*) and (*b*).

Summary and Conclusions

The flexural buckling strength of cold-formed steel columns was investigated. A total of 93 columns were tested, including 68 columns and 25 stub columns. Attention was given to the influence of some important parameters on the column strength, which include the residual stress, the cross-sectional dimension, the yielding type (gradual or sharp yielding) of the stress-strain curve, and the forming method (press-braked or roll-formed) used to form the section.

From the stub column tests, the amount of reduction of the proportional limit was found to be in good agreement with the magnitude of the compression residual stress measured in the section. The results of the column tests showed that the column formulas used in the AISI Specification (1980) give unconservative predictions for some types of columns. The test results also showed that the problem of understrength was observed not only for the 14 gauge columns, but also for columns with different thicknesses.

The experimental results obtained from this investigation provide a good basis for comparison with theoretical predictions. An approach for predicting column strengths developed on the basis of this experimental evidence will be reported in a future paper.

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Appendix II. Notation

The following symbols are used in this paper:

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A = gross section area;
F_u = tensile strength;
F_y = yield stress;
L = column length;
P_u = ultimate column strength;
P_y = column yield load;
P_{AISI} = column strength predicted by AISI equations;
P_{TEST} = column strength obtained from the test;
t = plate thickness;
W = flat width;
ϵ_{rs} = residual strain;
ϵ_y = yield strain;
$\mu\epsilon$ = micro strain;
σ_p = proportional limit stress;
σ_{rs} = residual stress; and
σ_y = yield stress.

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