THE BEHAVIOR OF STRUCTURAL FRP COLUMNS AND A DESIGN GUIDE FOR PRACTICAL APPLICATIONS

Prepared for

Creative Pultrusions, Inc.

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I. INTRODUCTION

The research work presented in this report represents an experimental investigation on the behavior of pultruded glass-fiber reinforced polymer composite columns produced by Creative Pultrusions, Inc. to be used as a supporting member for civil engineering structures.

The pultruded FRP composite columns studied in this research have five section configurations as shown in Figure 1. Two sections have closed configurations; square tube and round tube, the other three are thin-walled open sections; they are wide-flange, I, and angle sections. More than 300 column members were tested with two or three specimens for each group.

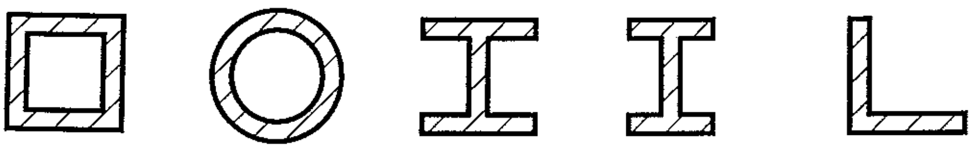


FIGURE 1 - COLUMN SECTION CONFIGURATIONS

For box sections, the thicknesses are 1/8 in. (3 mm) and 1/4 in. (6 mm). The dimensions of square tube varies from 1.5 in. (38 mm) to 4 in. (100 mm). For round sections, the thicknesses are 1/8 in. (3 mm) and 1/4 in. (6 mm). The diameters of the round tube are 1.5 in. (38 mm) and 2 in. (50 mm). For wide-flange sections, the thicknesses of flange and web are 1/4 in. (6 mm) and 3/8 in. (9.5 mm). The dimension of the W-section varies from 4 in. (100 mm) to 10 in. (254 mm). For I-sections, the thicknesses of flange and web are 1/4 in. (6 mm) and 3/8 in. (9.5 mm). The dimensions of I-section are 4 x 2 in. (100 x 50 mm) and 8 x 4 in. (200 x 100 mm). For angle sections, the thicknesses of the flange are 1/4 in. (6 mm), 3/8 in. (9.5 mm), and 1/2 in. (13 mm). The dimensions of the angle section are 3 x 3 in. (76 x 76 mm), 4 x 4 in. (100 x 100 mm), and 6 x 6 in. (152 x 152 mm).

The objectives of this research are:

1. To provide the column load data for five section configurations, taking into consideration the length of the column and the effective length factor "k,"
2. To provide in the tables the allowable compressive stresses,
3. To provide in the tables the allowable axial compressive loads,
4. To provide software and/or design equations for predicting load capacity of columns with various section configurations and for possible future structural profiles, and
5. To provide written explanations to relate experimental data with the design equations and procedures.

II. FRP COLUMN TEST PROGRAM

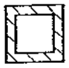
The length of the composite column varies from 1 ft. (0.3 m) to 20 ft. (6 m) to include short, intermediate, and long column members. Full scale column tests are performed by an axial compressive load in a vertical position as shown in Figure 2.

FIGURE 2 - COLUMN LOAD TEST SETUP

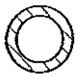
Short column members were tested on a MTS machine, long column members were tested in a 30-ft. reaction frame. During the test, a microprofiler was used to generate the displacement rate of loading at a 0.1 in./min. (2.5 mm/min.). The measurements included strains, ultimate loads, axial displacements, and lateral deflections.

The composite materials for the column members are made of polyester-based and vinylester-based resin matrix, with and without fire retardant, reinforced with continuous strand mats and continuous roving E-glass fibers.

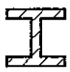
The test matrix for the program is presented in the following:

(A) Square Tube 

Dimension (in.)	Thickness (in.)	Length (ft.)
1 3/4 (1525)	1/4	1, 2, 3, 5, 7, 9
2 (1525)	1/4	1, 2, 3, 5, 7, 9, 12
3 (1525)	1/4	2, 3, 5, 7, 9, 12, 16
4 (1525)	1/4	5, 7, 9, 12, 16

(B) Round Tube 

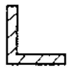
Dimension (in.)	Thickness (in.)	Length (ft.)
1 1/2 (1525)	1/8	1, 2, 3, 5, 7
2 (1525)	1/4	1, 2, 3, 5, 7, 9

(C) Wide Flange (W-section) 

Dimension (in.)	Thickness (in.)	Length (ft.)
4 x 4 (1500)	1/4	3, 4, 5, 7, 9, 12, 16
6 x 6 (1525)	3/8	5, 7, 9, 12, 16, 19
6 x 6 (special)	3/8	5, 7, 9, 12, 16, 19
8 x 8 (1525)	3/8	5, 7, 9, 12, 16, 19
8 x 8 (1625)	3/8	5, 7, 9, 12, 16, 19
10 x 10 (1625)	1/2	7, 9, 12, 16, 19

(D) I-Section 

Dimension (in.)	Thickness (in.)	Length (ft.)
4 x 2 (1525)	1/4	1, 1.5, 2, 3, 5, 7, 10
6 x 3 (1525)	3/8	2, 3, 4, 5, 7, 9, 12
8 x 4 (1525)	3/8	2, 3, 4, 5, 7, 9, 12

(E) Angle Section 

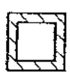
Dimension (in.)	Thickness (in.)	Length (ft.)
3 x 3 (1525)	3/8	1, 3, 5, 7, 9
4 x 4 (1525)	1/4	1, 2, 3, 5, 7, 9, 13
6 x 6 (1525)	1/2	1, 2, 3, 5, 9, 12, 13, 19

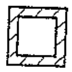
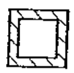
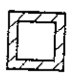
III. PHYSICAL LOAD TEST RESULTS

3.1 Closed Sections

3.1.1 Box Section

The average ultimate load capacity from load test for box section columns is presented in the following:

Section Dimension (in.)	Length (ft.)	Avg. Ult. Load (kips)
 (a) 1 3/4 x 1 3/4 x 1/4 (1525)	1	50.9
	2	39.2
	3	17.8
	5	5.8
	7	3.6
	9	1.5

Section Dimension (in.)	Length (ft.)	Avg. Ult. Load (kips)
 (b) 2 x 2 x 1/4 (1525)	1	71.1
	2	58.2
	3	28.7
	5	11.1
	7	5.4
	9	3.1
	12	1.3
 (c) 3 x 3 x 1/4 (1525)	2	87.8
	3	80.1
	5	33.1
	7	18.1
	9	12.7
	12	4.9
	16	2.8
 (d) 4 x 4 x 1/4 (1525)	5	74.3
	7	44.8
	9	29.8
	12	14.5
	16	9.7
	20	4.5

The typical axial load versus axial displacement relations for box section columns with various dimensions and lengths are shown in Figures 3 and 4.

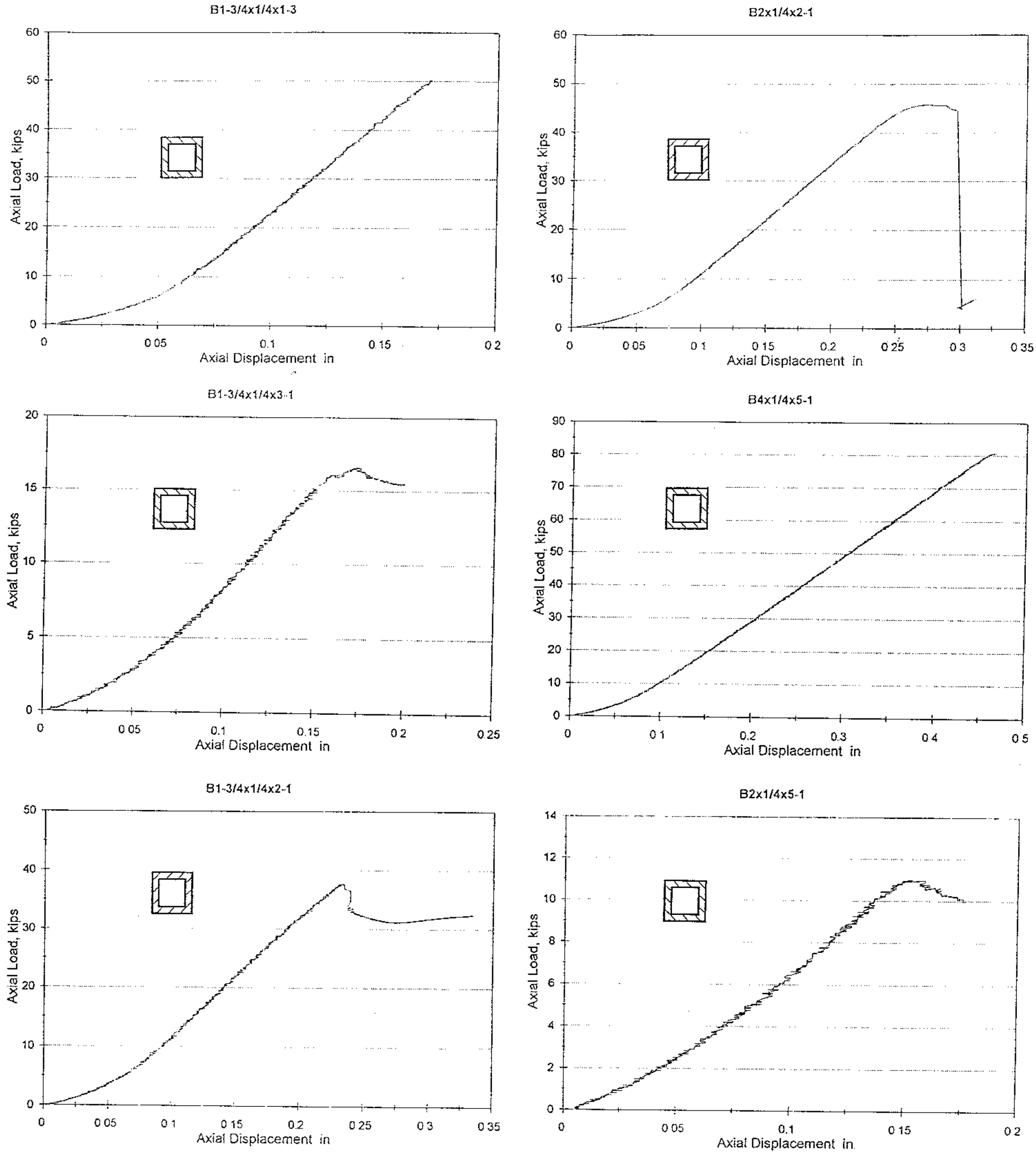


FIGURE 3 - TYPICAL AXIAL LOAD VERSUS AXIAL DISPLACEMENT RELATIONS FOR BOX SECTION COLUMNS WITH VARIOUS DIMENSIONS AND LENGTHS

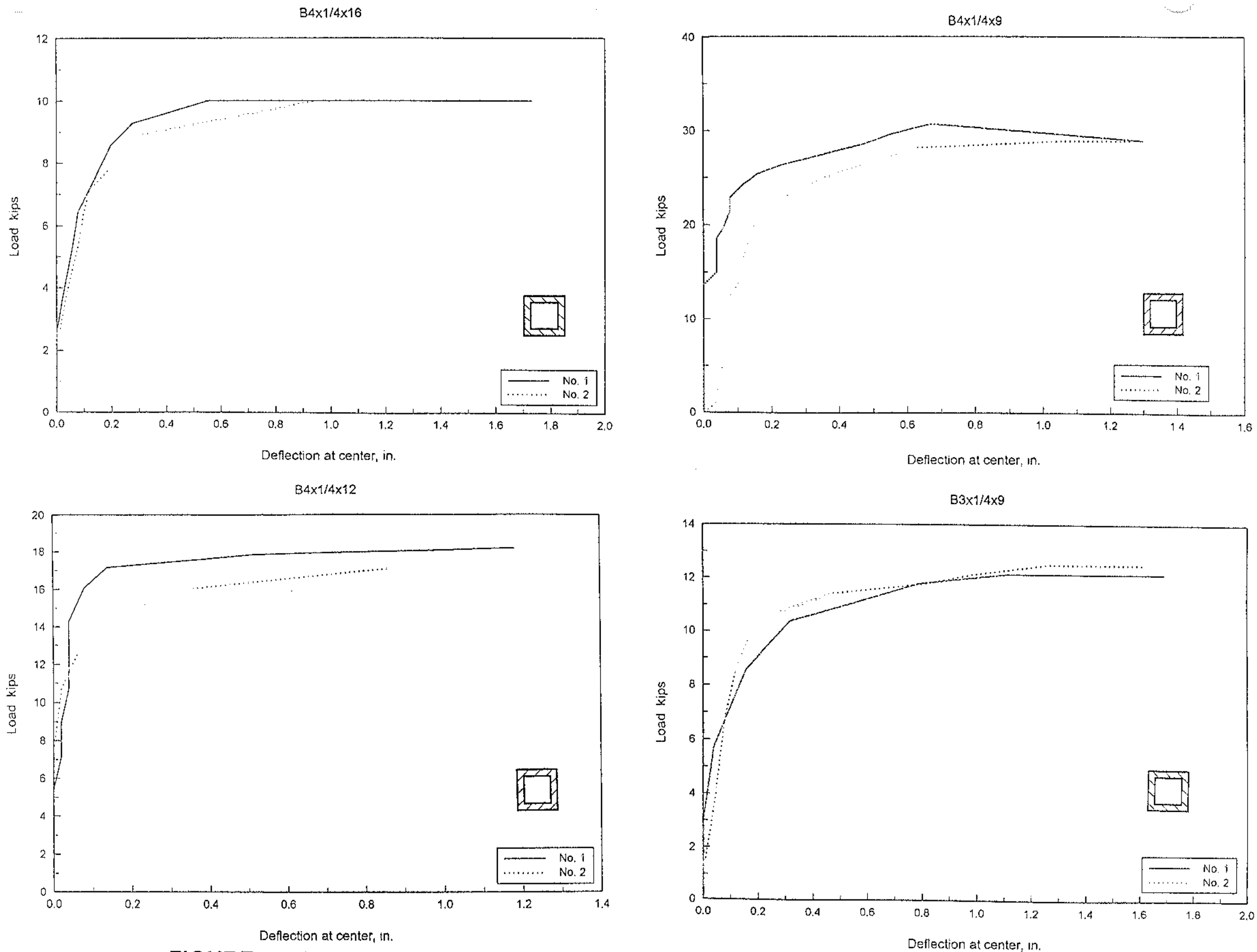
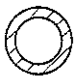
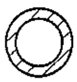


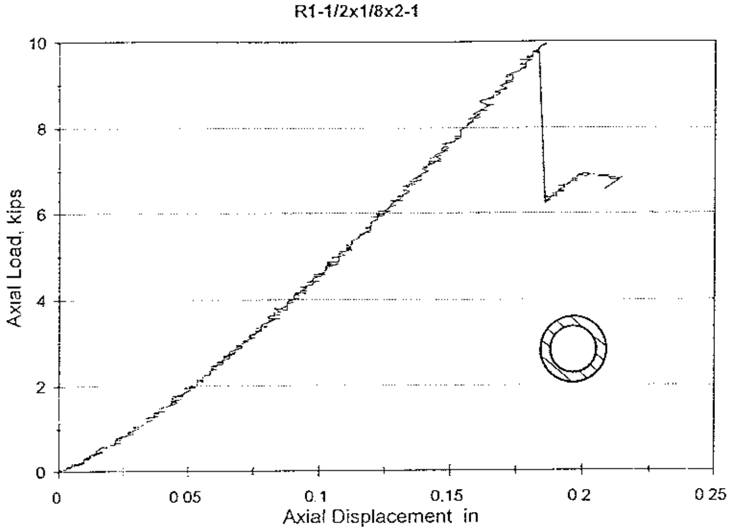
FIGURE 4 - TYPICAL AXIAL LOAD VERSUS LATERAL CENTER DISPLACEMENT RELATIONS FOR BOX SECTION WITH VARIOUS DIMENSIONS AND LENGTHS

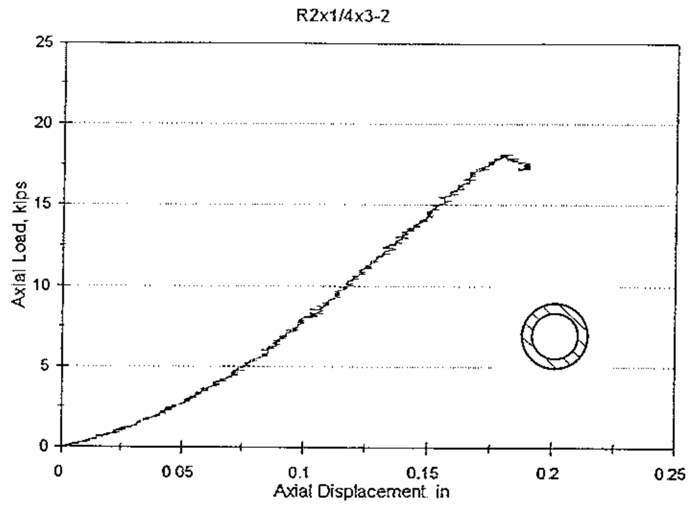
3.1.2 Round Section

The average ultimate load capacity from load test for round section columns is presented in the following:

Section Dimension (in.)	Length (ft.)	Avg. Ult. Load (kips)
 (a) 1 1/2 x 1/8 (1525)	1	14.1
	2	9.8
	3	4.6
	5	1.05
	7	0.54
 (b) 2 x 1/4 (1525)	1	45.7
	2	44.5
	3	19.5
	5	7.4
	7	3.4
	9	1.36

The typical axial load versus axial displacement relations for round section columns with various dimensions and lengths are shown in Figure 5





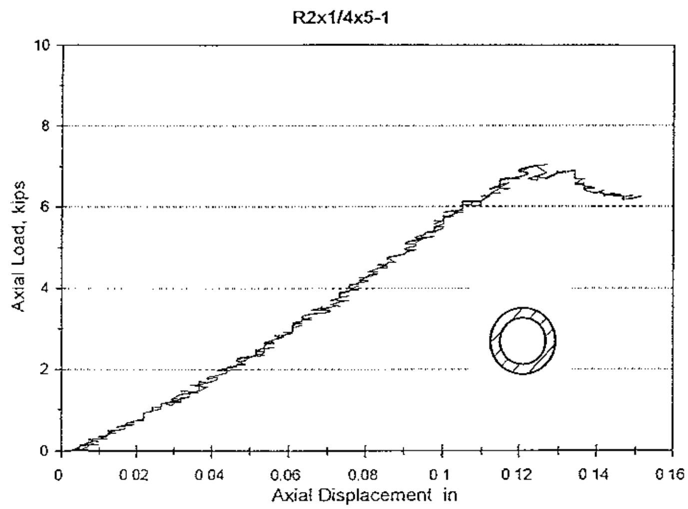
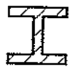
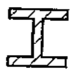
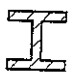


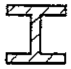
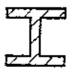
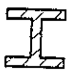
FIGURE 5 - TYPICAL AXIAL LOAD VERSUS AXIAL DISPLACEMENT RELATIONS FOR ROUND SECTION COLUMNS WITH VARIOUS DIMENSIONS AND LENGTHS

3.2 Open Sections

3.2.1 Wide Flange W-Section

The average ultimate load capacity from load test for W-section columns is presented in the following:

Section Dimension (in.)	Length (ft.)	Avg. Ult. Load (kips)
 (a) 4 x 4 x 1/4 (1525)	3	48
	4	39
	5	22.5
	7	11.8
	9	8.1
	12	3.8
	16	2.2
 (b) 6 x 6 x 3/8 (1525)	5	101.8
	7	70.8
	9	47.3
	12	33.0
	16	10.8
	19	7.7
 (c) 6 x 6 x 3/8 (special construction)	5	123.0
	7	52.3
	9	37.1
	12	22.0
	16	7.2
	19	5.1

Section Dimension (in.)	Length (ft.)	Avg. Ult. Load (kips)
 (d) 8 x 8 x 3/8 (1525)	5	85.8
	7	85.0
	9	82.4
	12	58.1
	16	29.4
	19	20.9
 (e) 8 x 8 x 3/8 (1625)	7	85.3
	9	83.2
	12	50.7
	16	25.7
	19	18.9
 (f) 10 x 10 x 1/2 (1625)	7	155.0
	9	162.7
	12	92.32
	16	52.1
	19	36.8

The typical axial load versus axial displacement relations for W-section columns with various dimensions and lengths are shown in Figure 6.

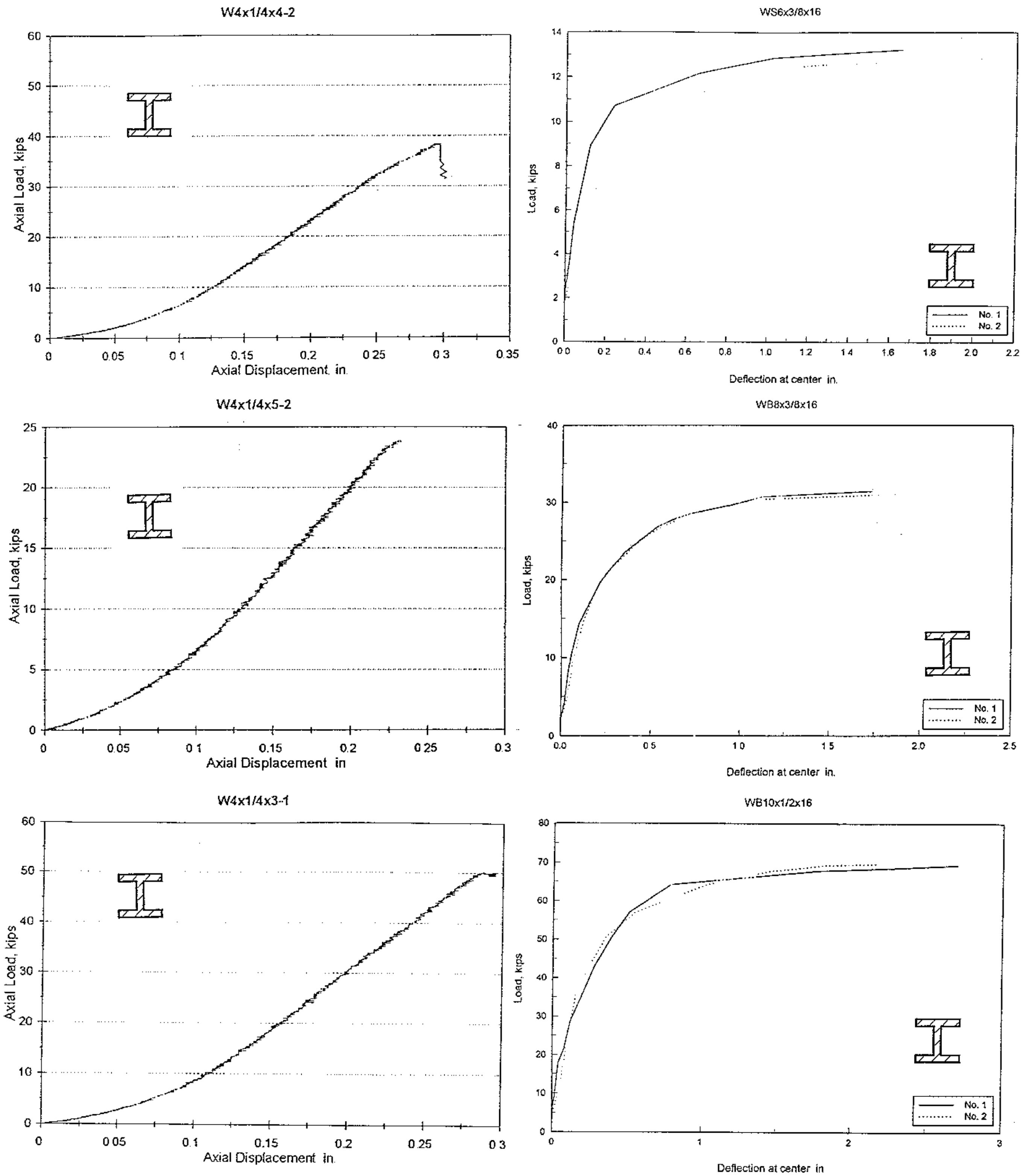
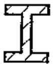
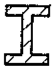
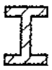


FIGURE 6 - TYPICAL AXIAL LOAD VERSUS AXIAL AND LATERAL CENTER DISPLACEMENT RELATIONS FOR W-SECTION COLUMNS WITH VARIOUS DIMENSIONS AND LENGTHS

3.2.2 I-Section

Section Dimension (in.)	Length (ft.)	Avg. Ult. Load (kips)
 (a) 4 x 2 x 1/4 (1525)	1	57.9
	2	19.7
	3	9.1
	5	2.9
	7	1.3
	10	0.7
 (b) 6 x 3 x 3/8 (1525)	2	94.0
	3	51.0
	4	29.8
	5	14.8
	7	8.1
	9	5.4
	12	2.4
 (c) 8 x 4 x 3/8 (1525)	2	113.0
	3	92.8
	4	51.8
	5	40.0
	7	18.8
	9	13.6
	12	7.6

The typical axial load versus axial displacement relations for I-section columns with various dimensions and lengths are shown in Figure 7.

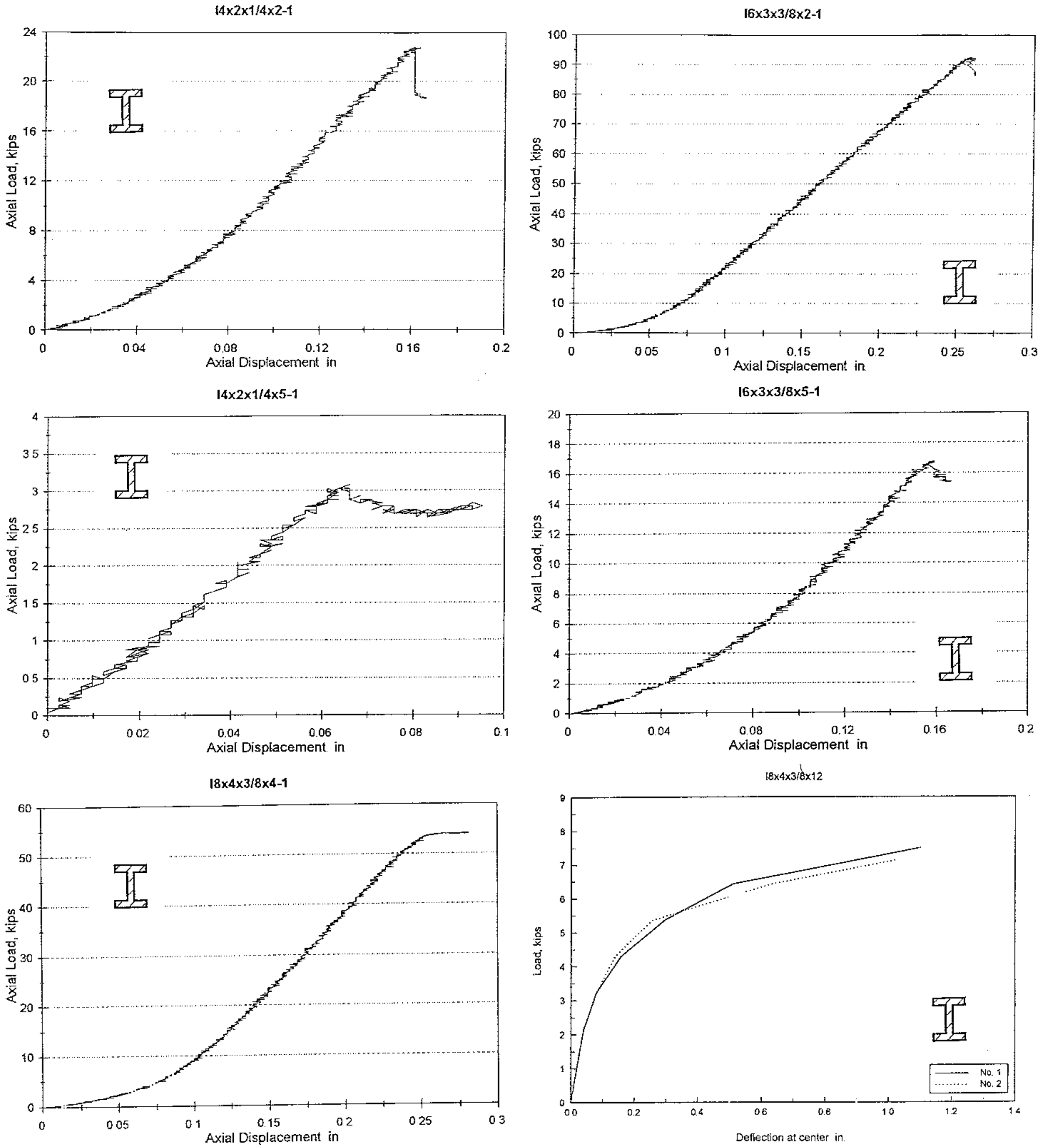
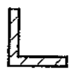


FIGURE 7 - TYPICAL AXIAL LOAD VERSUS AXIAL AND LATERAL CENTER DISPLACEMENT RELATIONS FOR I-SECTION COLUMNS WITH VARIOUS DIMENSIONS AND LENGTHS

3.2.3 Angle-Section

Section Dimension (in.)	Length (ft.)	Avg. Ult. Load (kips)
 (a) 3 x 3 x 3/8 (1525)	1	37.0
	3	22.4
	5	13.9
	7	4.6
	9	6.3
 (b) 4 x 4 x 1/4 (1525)	1	11.8
	2	10.9
	3	no specimen
	5	6.9
	7	3.6
	9	5.5
 (c) 6 x 6 x 1/2 (1525)	1	107.0
	2	55.5
	3	40.5
	5	32.0
	9	31.0
	12	27.4

The typical axial load versus axial displacement relations for angle section columns with various dimensions and lengths are shown in Figure 8.

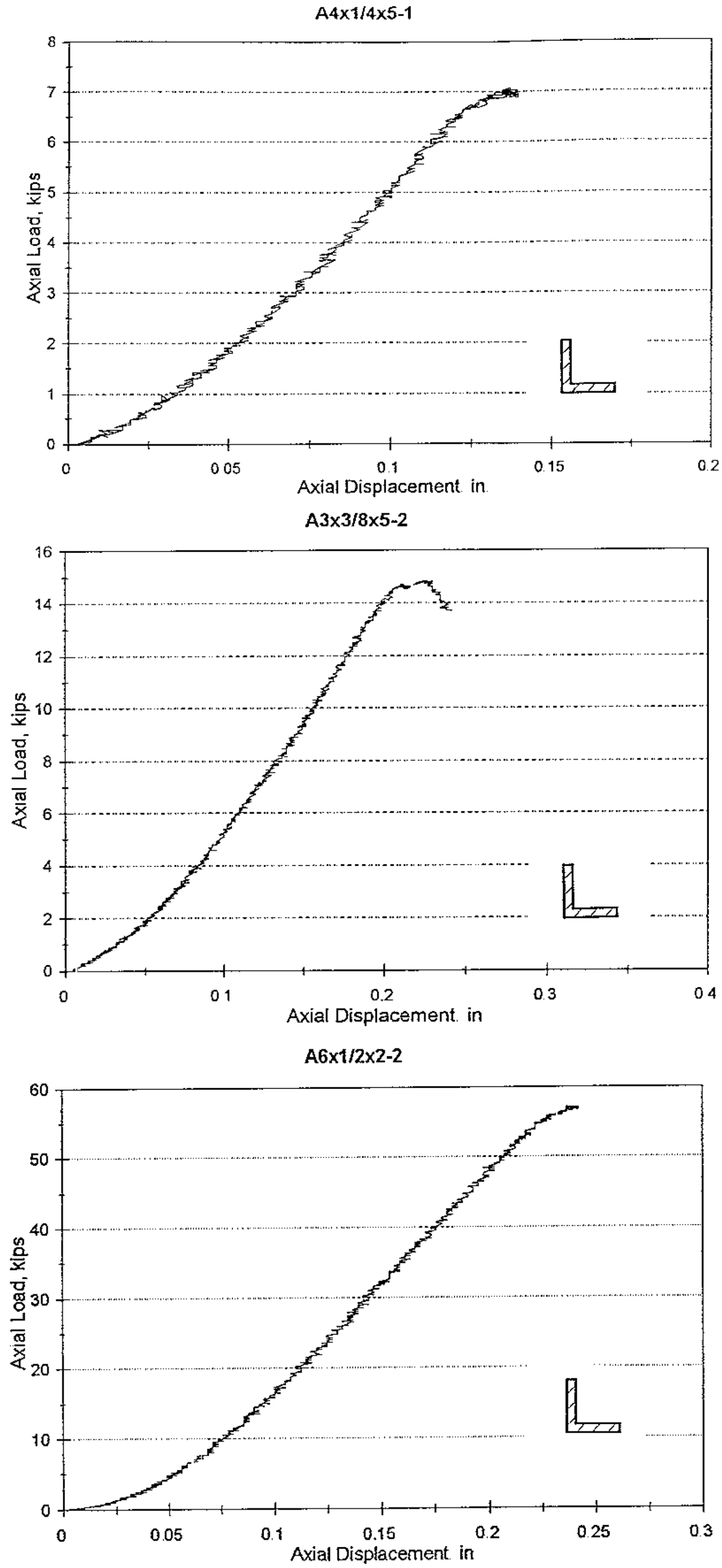


FIGURE 8 - TYPICAL AXIAL LOAD AND AXIAL DISPLACEMENT RELATIONS FOR ANGLE SECTION COLUMNS WITH VARIOUS DIMENSIONS AND LENGTHS

IV. ANALYSIS AND DISCUSSION

4.1 Columns with Box Section

For the short column with box section, the ultimate load capacity is a function of the bearing strength of the composite material and the column cross sectional area. In general, the bearing strength of structural composite is about 30 ksi (200 MPa), therefore, the ultimate strength of short column with box section depends upon the cross sectional area, for a given area, the column with box section appears to have the highest ultimate load strength among the columns with other section configurations. For a given wall thickness of box section, the ultimate load capacity appears to increase linearly with an increase in the section dimensions, e.g., for thickness t = 1/4 in. (6.4 mm), length L = 2 ft. (0.67 m), the ultimate load strength was 40 kips (178 kN) for 1 3/4 x 1 3/4 in. (45 x 45 mm) box section, 58 kips (258 kN) for 2 x 2 in. (50 x 50 mm) section, and 88 kips (392 kN) for 3 x 3 in. (76 x 76 mm) section.

For the long columns, the ultimate column strength is a function of the slenderness ratio kl/r The column strength decreases with an increase in the slenderness ratio as shown in Figure 9. For columns with box section, the dividing line at the slenderness ratio for short and long columns appears to be 35. For columns with kl/r less than 35, the bearing strength of the composite controls the ultimate load. For columns with kl/r longer than 35, global buckling strength controls the ultimate load.

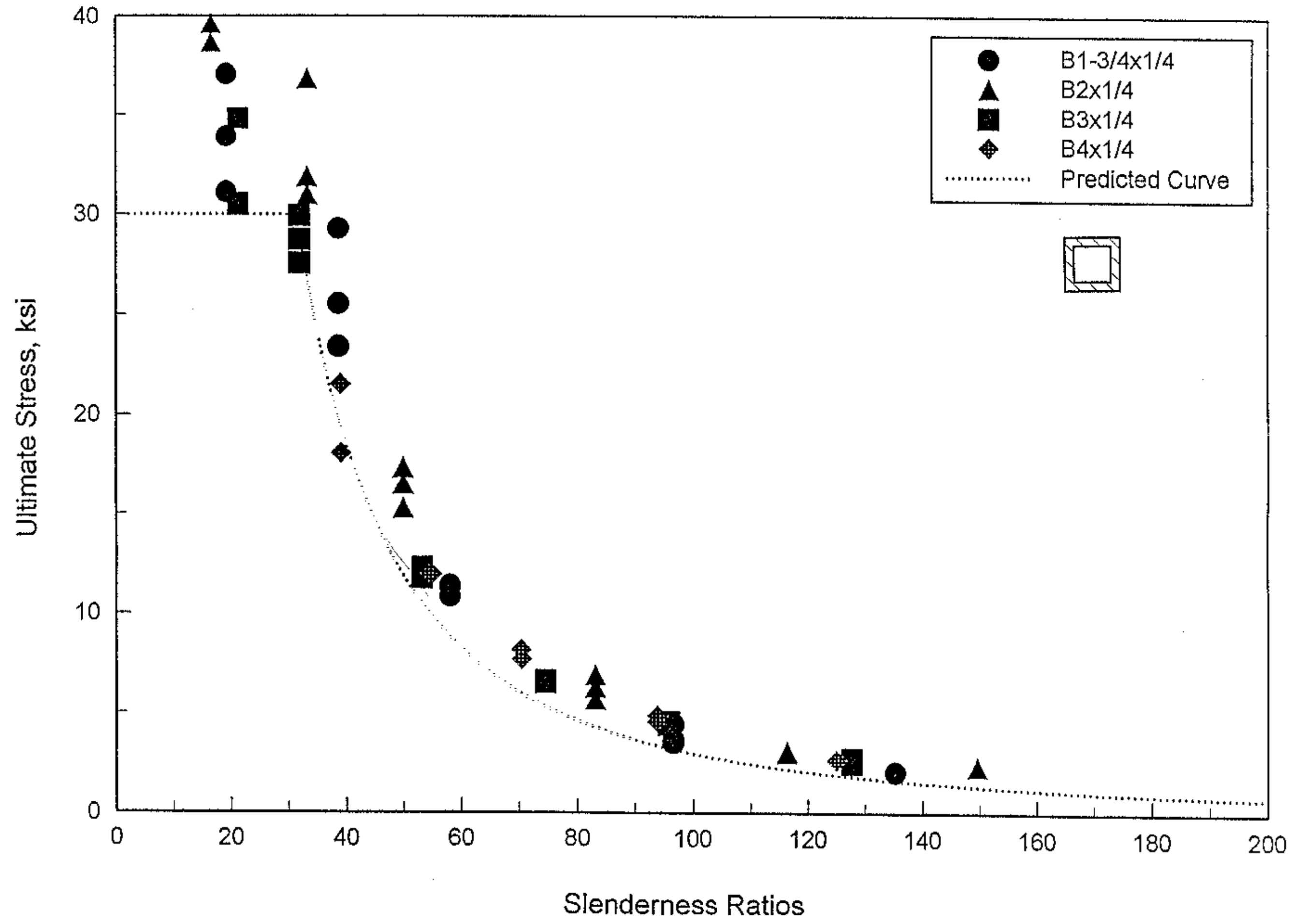


FIGURE 9 - ULTIMATE COLUMN STRENGTH AND SLENDERNESS RATIO RELATION FOR COLUMNS WITH BOX SECTION

4.2 Columns with Round Section

Like the columns with box section, the ultimate load capacity of the short round column is also a function of the bearing strength of the composites and column cross sectional area. For a given area and length, the ultimate column strength of a short round column is about 20 percent lower than that of a short box column.

For the long round columns, the ultimate column strength is a function of the slenderness ratio kl/r. The round column strength decreases with an increase in the slenderness ratio as shown in Figure 10. For round columns, the dividing line at the slenderness ratio appears to be between 30 to 40. For round columns with kl/r larger than 40, the columns have the characterization of an Euler behavior. For round columns with kl/r less than 30, bearing mode of failure dominates the ultimate column strength. At kl/r = 25, the ultimate stress of the round column from test results is less than the bearing strength of 30 ksi (200 MPa) of the composites. Therefore, the prediction curve in the short round column region becomes an inclined straight line as shown in Figure 10.

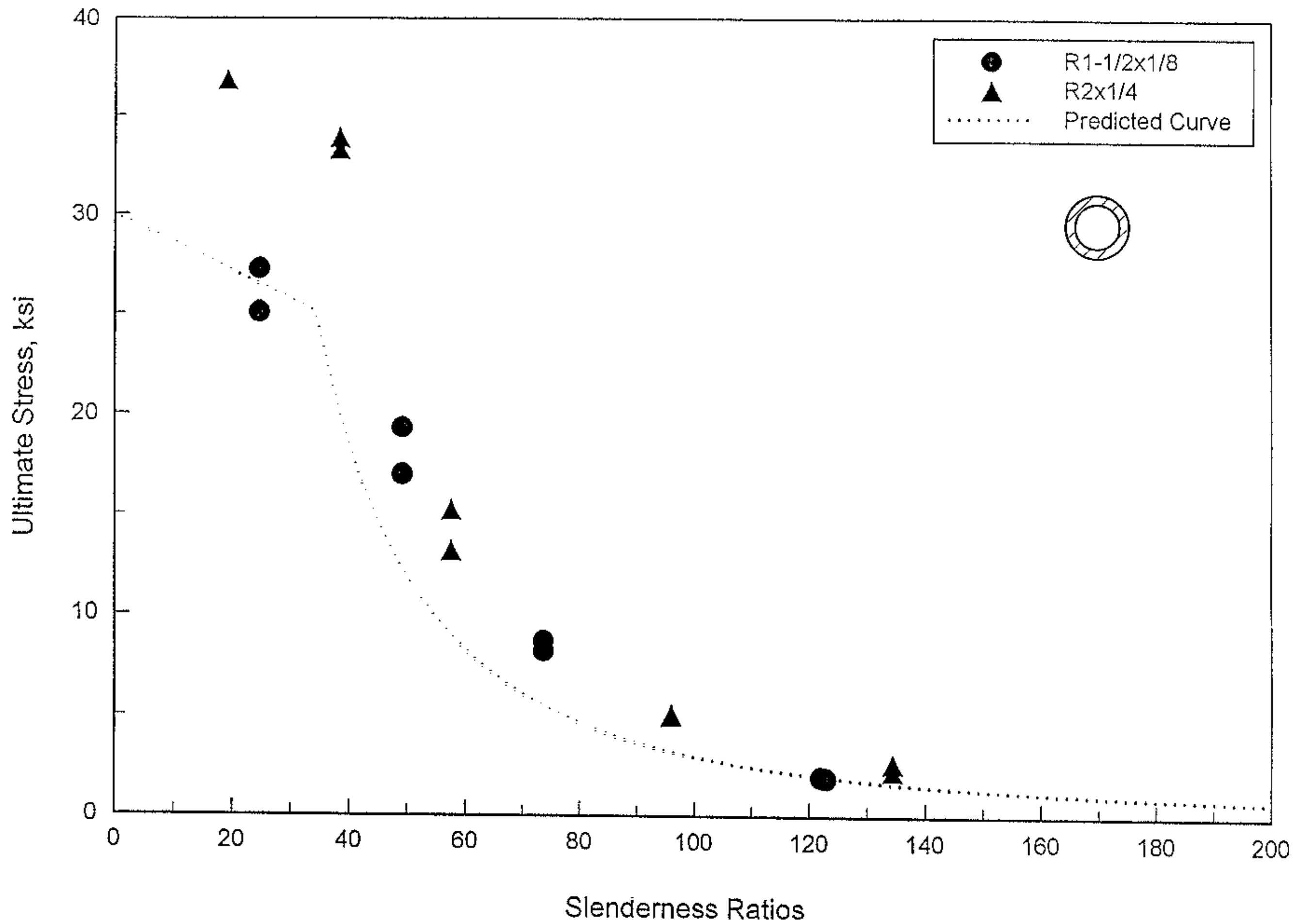


FIGURE 10 - ULTIMATE COLUMN STRENGTH AND SLENDERNESS RATIO RELATION FOR COLUMN WITH ROUND SECTION

4.3 Columns with W-Section

From experimental results, the ultimate strength of columns with W-section is about 30 percent of the ultimate strength of columns with box section for a given cross sectional dimension and member length. The indication is quite consistent and the comparisons are given in the following:

Sectional Dimension (in.)	Length (ft.)	Column with Box Section Ultimate Strength (kips)	Column with W-Section Ultimate Strength (kips)
4 x 4 x 1/4	5	74.3	22.5
	7	44.8	11.8
	9	29.8	8.1
	12	14.5	3.8
	16	9.7	2.2

For the long columns, the ultimate column strength is a function of the slenderness ratio kl/r. The column strength decreases with an increase in the slenderness ratio as shown in Figure 10. For column with W-section, the dividing line at the slenderness ratio for short and long columns appears to be in the range of 40 to 60. For columns with kl/r less than 60, the column ultimate load depends on the flange 1/2 width-to-thickness ratio 1/2 b_f/t_f. The higher the 1/2 b_f/t_f ratio, the lower the ultimate load capacity.

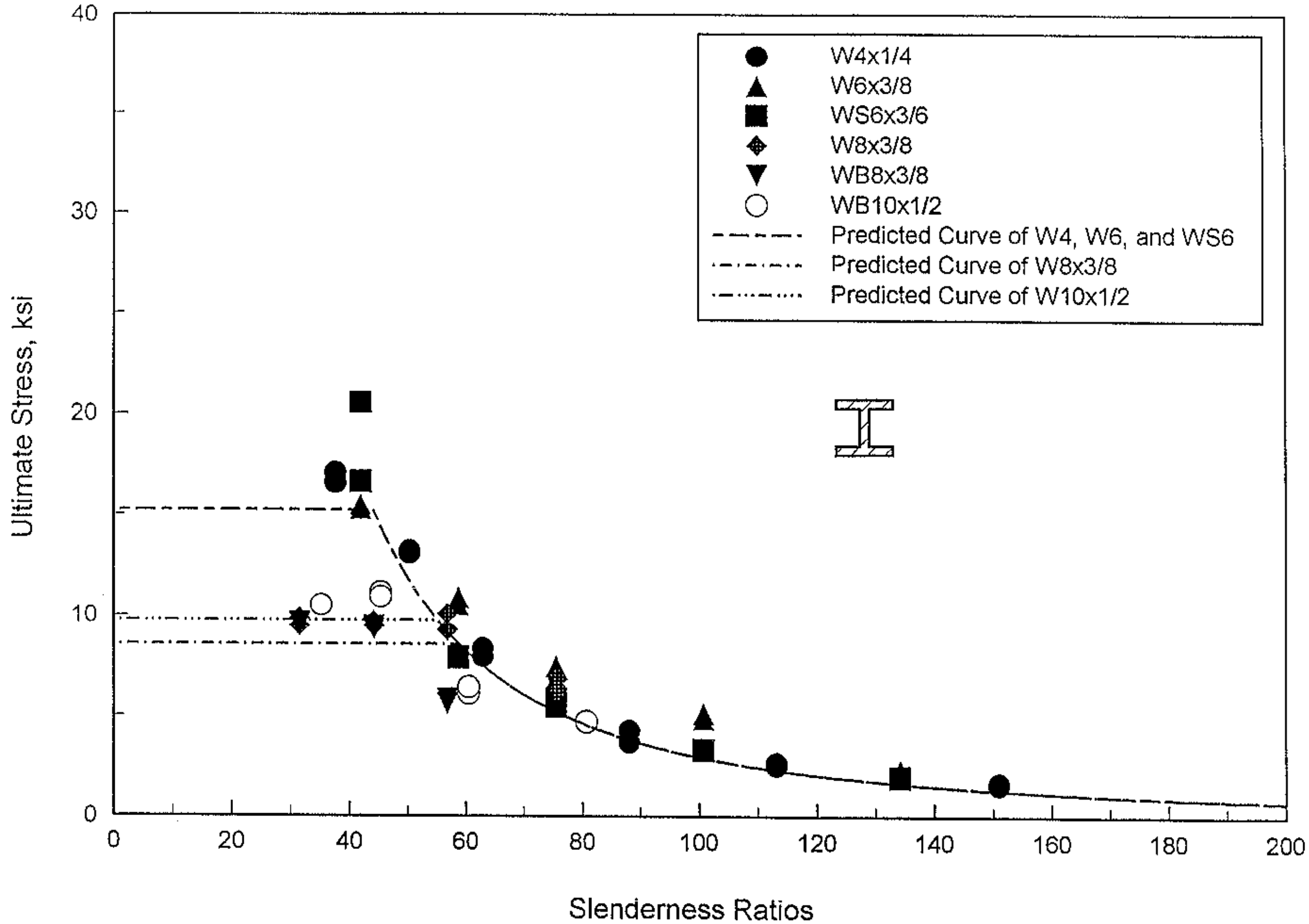


FIGURE 10 - ULTIMATE COLUMN STRENGTH AND SLENDERNESS RATIO RELATION FOR COLUMN WITH W-SECTION

4.4 Columns with I-Section

Like the columns with W-section, the ultimate load capacity of the columns with I-section is a function of the slenderness ratio kl/r. The column strength decreases with an increase in the slenderness ratio as shown in Figure 11. For columns with an I-section, the dividing line at the slenderness ratio for short and long columns appears to be in the range of 30 to 40. For columns with kl/r larger than 40, the Euler characteristics of the column with I-section is close to that of the column with W-section. However, for I-section columns with kl/r less than 30, the ultimate stress is significantly higher than the ultimate stress of the W-section column due to a smaller b_f/t_f ratio. The crippling of flange in the testing of I-section columns was not observed. There was no warning of failure during the test, column buckles in a catastrophic mode. At kl/r = 30, the ultimate stress of the I-section column from test result is less than the bearing strength of 30 ksi (200 MPa) of the composites. Therefore, the prediction curve in the short I-section column region becomes an inclined straight line as shown in Figure 11.

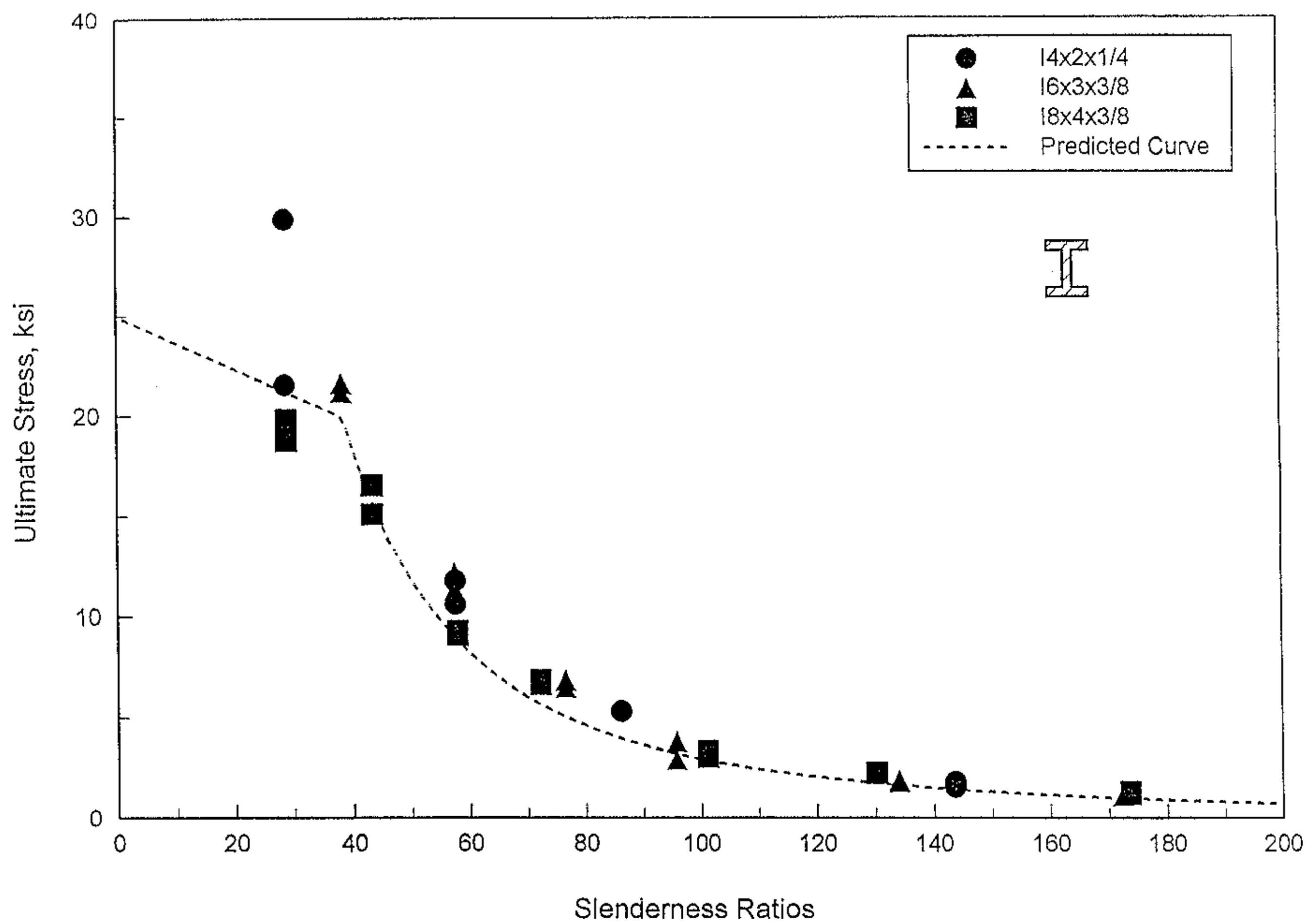


FIGURE 11 - ULTIMATE COLUMN STRENGTH AND SLENDERNESS RATIO RELATION FOR COLUMN WITH I-SECTION

4.5 Columns with Angle Section

Columns with angle sections were axially loaded at the centroid of the section. The ultimate load capacity is a function of the slenderness ratio kl/r. The column strength decreases with an increase in the slenderness ratio as shown in Figure 12. For columns with an angle section, the dividing line at the slenderness ratio for short and long columns appears to be in the range of 45 to 60. For columns with kl/r larger than 60, the Euler characteristics of the column with angle section is close to that of the column with W-section. However, the angle-section column with kl/r less than 45, the ultimate stress is significantly lower than that of the W-section column due to a larger b_f/t_f ratio and localized instability. The crippling of flange in the testing of angle-section column was observed for all specimens; the local buckling instigated a torsion and global buckling of the column. In the short angle-section column region, the ultimate column strength is sensitive to the b_f/t_f ratio. For a b_f/t_f larger than 8, the ultimate strength of the column with angle section decreases significantly as shown in Figure 12.

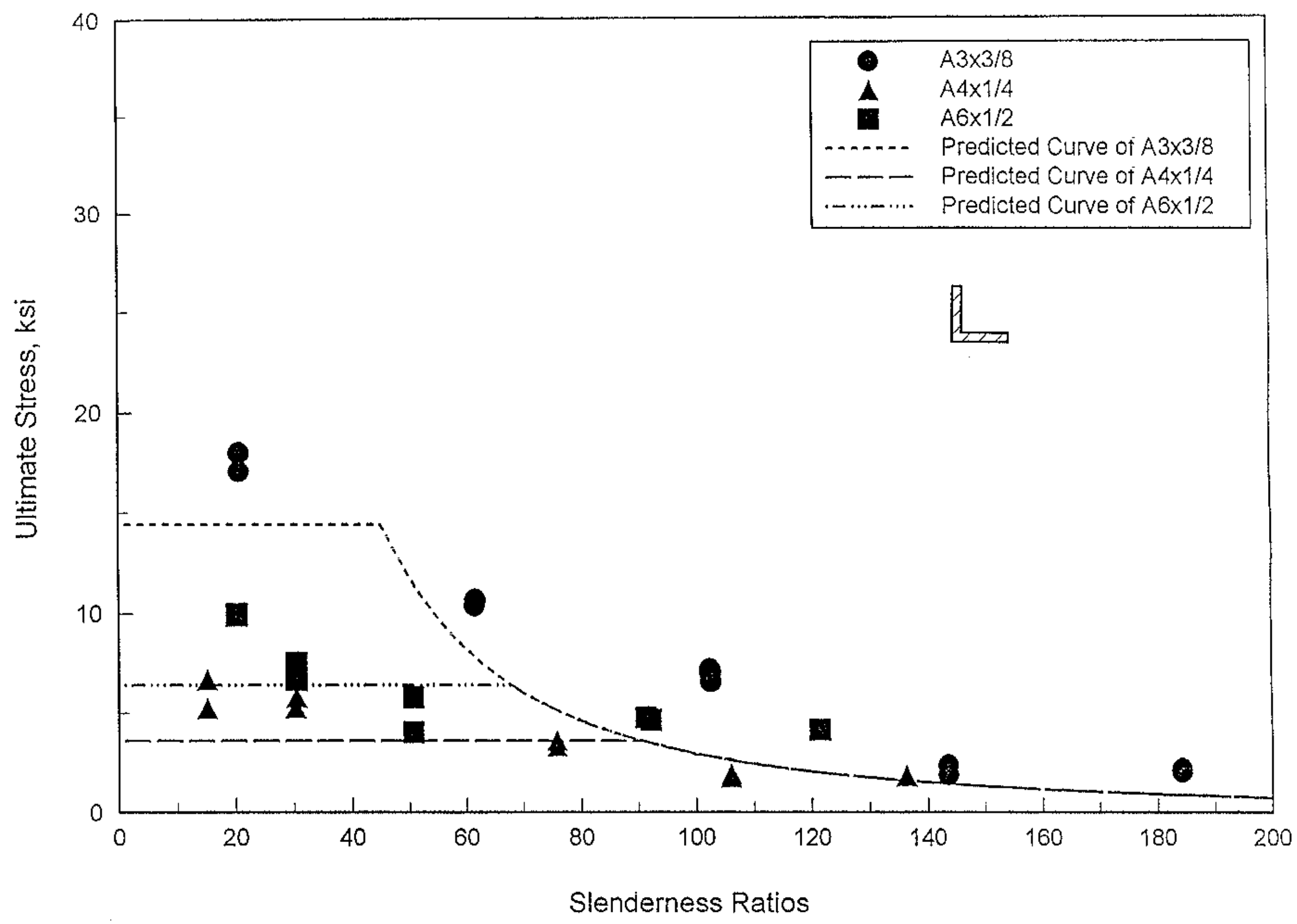


FIGURE 12 - ULTIMATE COLUMN STRENGTH AND SLENDERNESS RATIO RELATION FOR COLUMNS WITH ANGLE SECTION

V. PROPOSED DESIGN EQUATIONS

The design equations for FRP composite columns are developed in this report based on a large group of data points from test results. The observed column failure can be categorized into two modes: bearing failure and local/global instability. Figure 13 shows a general behavior for all FRP composite columns. The curve can be divided into two groups: short column and long column as plotted compressive stress versus slenderness ratio. The short FRP composite columns are generally failed in bearing deformation or local buckling; the long FRP composite columns are generally failed in the global buckling mode.

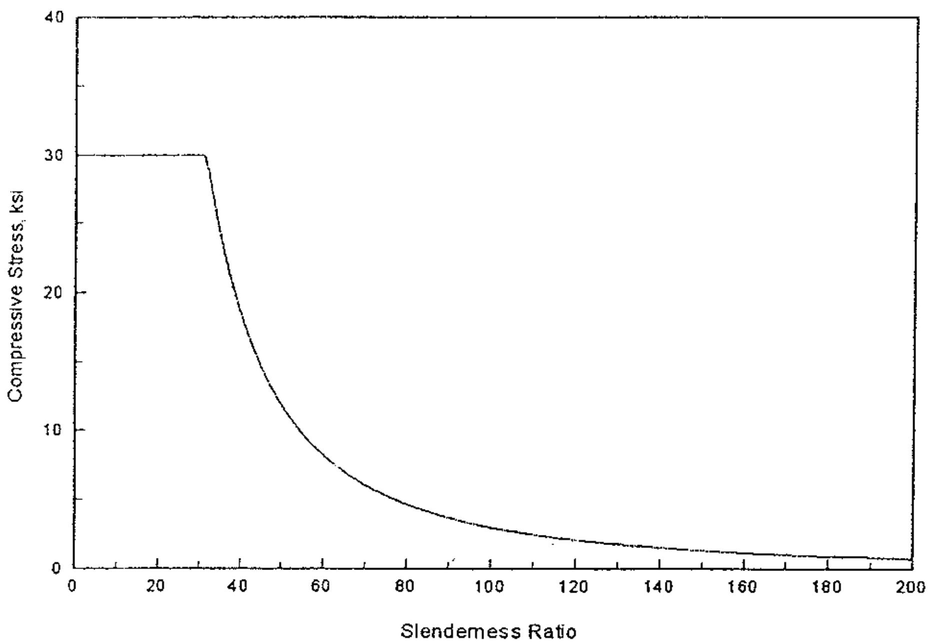


FIGURE 13 - TYPICAL COLUMN STRENGTH CURVE

5.1 Design Equations for Short Columns

5.1.1 Columns with Box Section

For short columns with box section, a bearing failure due to axial compressive load governs the design equation as follows:

$$\sigma_{ult} = \frac{P_{ult}}{A} = 30\ ksi \text{ for short FRP Box-section column} \quad (1)$$

where P_{ult} = ultimate axial load
A = cross-sectional area
σ_{ult} = bearing strength of the composite

5.1.2 Column with Round and I-Sections

For short columns with round and I-sections, the columns fail due to a combination of axial load and bending moment. The design equations consider the interaction of bearing and flexural buckling failure. A linear equation is developed from the test results for the transition behavior as follows:

$$\sigma_{ult} = 30 - \frac{1}{7}\frac{KL}{r}\ ksi \text{ for short FRP Round-section column} \quad (2)$$

$$\sigma_{ult} = 25 - \frac{5}{38}\frac{KL}{r}\ ksi \text{ for short FRP I-section column} \quad (3)$$

where σ_{ult} = ultimate compressive stress
K = effective length coefficient
L = column length
r = radius of gyration of the section

5.1.3 Columns with W-Section

For short columns with w-section, local buckling or crippling occurs on the flanges. According to the test results, the ultimate local buckling stress, $\sigma_{ult,l}$, of the FRP composite W-section column can be predicted by using a modified buckling equation of thin plate for isotropic material as follows:

$$\sigma_{ult,l} = \Phi\, k \,\frac{\pi^2 E}{12\,(1-\upsilon^2)} \left(\frac{t_f}{b_f}\right)^2 \quad \text{for short FRP W-section column} \qquad (4)$$

where E = modulus of elasticity in the loading direction
υ = Poisson's ratio
t_f = thickness of the local flange element
b_f = width of the local flange element
Φ = 0.8, a coefficient to account for the orthotropic material of the composite
k = 0.5 is recommended for unstiffened outstanding flanges of the W-section
k = 4.0 is recommended for stiffened outstanding webs of the W-section

It should be noted that the ultimate local buckling strength needs to be checked against bearing strength. The lower value will be used for the ultimate strength of the short composite column with the W-section. Then, the ultimate strength of the short column is compared with the flexural buckling strength to determine the dividing point for short and long columns.

5.1.4 Columns with Angle Section

For short columns with angle section, the local buckling of the flange occurs as in the column with W-section. Thus, the design Equation (4) can be also applied to predict the ultimate strength of a short column with angle section.

5.2 Design Equations for Long Columns

The flexural buckling, as known as the Euler buckling, is the general behavior of a long slender FRP column under an axial compression load. According to the test results, the ultimate buckling strength of the composite columns was in a good agreement with the Euler buckling equation:

$$\sigma_{ult,Euler} = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} \quad \text{for all long FRP column} \qquad (5)$$

This equation can be applied to the long FRP composite column with box, round, I, W, and angle sections. However, for columns with angle section, the flexural-torsional buckling governs the ultimate strength. In the test, the coupling of the flexural and torsional buckling was observed in a form of lateral deflection and global twisting for the angle section column. The ultimate flexural-torsional buckling stress can be approximated by the lower value from Equation (5) for flexural buckling strength about the weak axis, or from the torsional buckling equation as follows:

$$\sigma_{ult,ft} = \Phi \, \frac{E}{2\,(1+\upsilon)} \left(\frac{t_f}{b_f}\right)^2 \quad \text{for short FRP Angle column} \qquad (6)$$

According to the test results, the coefficient $\Phi = 0.8$ is recommended for Equation (6) in order to account for the orthotropic material of the composite.

The effective length coefficient, *K*-value, in the equation is to account for different end conditions. For FRP composite columns with various end supports, the *K*-value is recommended in Table 1.

TABLE 1 - EFFECTIVE LENGTH COEFFICIENT, *K*-VALUE

End Conditions	Recommended K-Value
Pined-Pined	1.00
Fixed-Fixed	0.65
Pined-Fixed	0.80
Fixed-Translation Fixed	1.20
Fixed-Translation Free	2.10
Pined-Translation Fixed	2.00

VI. SOFTWARE DEVELOPMENT

The calculation procedures used in the software development for FRP composite column design are described as follows. It should be noted that the following material properties are assumed to be a constant; modulus of elasticity, E_{comp} = 3,000,000 psi, and Possion's ratio, **Mu** = 0.3

1. Input column length (inch), **L**
2. Input supporting condition, **K**.
   If "*Pinned-Pinned*", **K**=1.00
   If "*Fixed-Fixed*", **K**=0.65
   If "*Pinned-Fixed*", **K**=0.80
   If "*Fixed-Free*", **K**=2.10
   If "*Fixed-Translated*", **K**=1.20
   If "*Pinned-Translated*", **K**=2.00
3. Input operating temperature, **Temp**.
4. Input factor of safety, **FS**. Set default value = 3.0
5. Calculate temperature reduction factor for ultimate strength, **TRFS**
   If Temp <= 75, TRFS =1.0
   If Temp > 75, TRFS = 1-0.3841*(Temp-75)
6. Input structural profile.
   If "*R1-1/2x8*", **A**=0.540, **r**=0.488, and go to 7.1
   If "*R2x1/4*", **A**=1.374, **r**=0.625, and go to 7.1
   If "*B1-3/4x1/4*", **A**=1.500, **r**=0.621, and go to 7.2
   If "*B2x1/4*", **A**=1.750, **r**=0.722, and go to 7.2
   If "*B3x1/4*", **A**=2.750, **r**=1.127, and go to 7.2
   If "*B3x1/4*", **A**=3.750, **r**=1.534, and go to 7.2
   If "*A3x3/8*", **A**=2.109, **r**=0.586, **tf**=0.375, and **bf**=3.0, and go to 7.3
   If "*A4x1/4*", **A**=1.938, **r**=0.792, **tf**=0.250, and **bf**=4.0, and go to 7.3
   If "*A6x1/2*", **A**=5.750, **r**=1.185, **tf**=0.500, and **bf**=6.0, and go to 7.3
   If "*I4x2x1/4*", **A**=1.938, **r**=0.418, and go to 7.4
   If "*I6x3x3/8*", **A**=4.359, **r**=0.627, and go to 7.4
   If "*I8x4x3/8*", **A**=5.859, **r**=0.830, and go to 7.4
   If "*W4x1/4*", **A**=2.938, **r**=0.954, **tf**=0.250, and **bf**=2.0, and go to 7.5
   If "*W6x3/8*", **A**=6.609, **r**=1.430, **tf**=0.375, and **bf**=3.0, and go to 7.5
   If "*WS6x3/8*", **A**=6.609, **r**=1.430, **tf**=0.375, and **bf**=3.0, and go to 7.5
   If "*W8x3/8*", **A**=8.859, **r**=1.902, **tf**=0.375, and **bf**=4.0, and go to 7.5
   If "*WB8x3/8*", **A**=8.859, **r**=1.902, **tf**=0.375, and **bf**=4.0, and go to 7.5
   If "*WB10x1/2*", **A**=14.75, **r**=2.378, **tf**=0.50, and **bf**=5.0, and go to 7.5
7. Calculation of allowable load

7.1 Effective length, **KLr** = **K*L/r**

Allowable load for short column,

$$ALS = FS^{-1} *TRFS*(30-KLr/7)*A*1000$$

Allowable load for long column,

$$ALL = FS^{-1} *TRFS*(\pi^2 *E/(KLr)^2)*A$$

go to 8.

7.2 Effective length, **KLr** = **K*L/r**

Allowable load for short column,

$$ALS = FS^{-1} *TRFS*30*A*1000$$

Allowable load for long column,

$$ALL = FS^{-1} *TRFS*(\pi^2 *E/(KLr)^2)*A$$

go to 8.

7.3 Effective length, **KLr** = **K*L/r**

Allowable load for short column,

$$ALS = FS^{-1} *TRFS*(0.8*E/(2*(1+Mu))*(tf/bf)^2)*A$$

Allowable load for long column,

$$ALL = FS^{-1} *TRFS*(\pi^2 *E/(KLr)^2)*A$$

go to 8.

7.4 Effective length, **KLr** = **K*L/r**

Allowable load for short column,

$$ALS = FS^{-1} *TRFS*(25-5*KLr/38)*A*1000$$

Allowable load for long column,

$$ALL = FS^{-1} *TRFS*(\pi^2 *E/(KLr)^2)*A$$

go to 8.

7.5 Effective length, **KLr** = **K*L/r**

Allowable load for short column,

$$ALS = FS^{-1} *TRFS*(0.8*0.45*\pi^2 *E/(12*(1-Mu^2))*(tf/bf)^2)*A$$

Allowable load for long column,

$$ALL = FS^{-1} *TRFS*(\pi^2 *E/(KLr)^2)*A$$

go to 8.

8. Comparison of the allowable load for long and short column

If **ALS<ALL**,

print "*This is a short column having the allowable load =*", **ALS**, "*lb*"

If not, print "*This is a long column having the allowable load =*", **ALL**, "*lb*"

End

VII. TABLES FOR ALLOWABLE COMPRESSIVE STRESSES AND LOADS

The following are the allowable stress (Fa) tables and the allowable load (Pa) tables for columns with box section, round section, W-section, I-section, and angle section when used as compressive members (columns). These tables are developed based on:

1. Experimental test results
2. Room temperature (73° F)
3. A Safety factory of S.F. = 3.0
4. A value of $K = 1.0$
5. A value of $E = 3 \times 10^6$ psi
6. No damages on the composite columns
7. These tables show kl/r values to 200 for reference. It is recommended that kl/r be limited to 120.

7.1 COLUMN WITH BOX SECTION

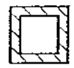
Allowable Load Tables

Allowable Stress Tables

Allowable Axial Stresses and Loads for Box-Section 1-3/4x1/4

A = 1.50 in^2

r = 0.62 in.

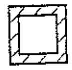


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	4.8	10000	15000	**SHORT COLUMN**
0.50	9.7	10000	15000	
0.75	14.5	10000	15000	
1.00	19.3	10000	15000	
1.25	24.2	10000	15000	
1.50	29.0	10000	15000	
1.75	33.8	8631	12946	
2.00	38.6	6608	9912	**LONG COLUMN**
2.25	43.5	5221	7832	
2.50	48.3	4229	6344	
2.75	53.1	3495	5243	
3.00	58.0	2937	4405	
3.25	62.8	2502	3754	
3.50	67.6	2158	3237	
3.75	72.5	1880	2819	
4.00	77.3	1652	2478	
4.25	82.1	1463	2195	
4.50	87.0	1305	1958	
4.75	91.8	1171	1757	
5.00	96.6	1057	1586	
5.25	101.4	959	1438	
5.50	106.3	874	1311	
5.75	111.1	799	1199	
6.00	115.9	734	1101	
6.25	120.8	677	1015	
6.50	125.6	626	938	
6.75	130.4	580	870	
7.00	135.3	539	809	
7.25	140.1	503	754	
7.50	144.9	470	705	
7.75	149.8	440	660	
8.00	154.6	413	619	
8.25	159.4	388	583	
8.50	164.3	366	549	
8.75	169.1	345	518	
9.00	173.9	326	489	
9.25	178.7	309	463	
9.50	183.6	293	439	
9.75	188.4	278	417	
10.00	193.2	264	396	
10.25	198.1	252	377	

Allowable Axial Stresses and Loads for Box-Section 2x1/4

A = 1.75 in^2

r = 0.72 in.

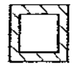


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	4.2	10000	17500	**SHORT COLUMN**
0.50	8.3	10000	17500	
0.75	12.5	10000	17500	
1.00	16.6	10000	17500	
1.25	20.8	10000	17500	
1.50	24.9	10000	17500	
1.75	29.1	10000	17500	
2.00	33.2	8932	15631	**LONG COLUMN**
2.25	37.4	7057	12351	
2.50	41.6	5717	10004	
2.75	45.7	4724	8268	
3.00	49.9	3970	6947	
3.25	54.0	3383	5919	
3.50	58.2	2917	5104	
3.75	62.3	2541	4446	
4.00	66.5	2233	3908	
4.25	70.6	1978	3462	
4.50	74.8	1764	3088	
4.75	78.9	1584	2771	
5.00	83.1	1429	2501	
5.25	87.3	1296	2268	
5.50	91.4	1181	2067	
5.75	95.6	1081	1891	
6.00	99.7	992	1737	
6.25	103.9	915	1601	
6.50	108.0	846	1480	
6.75	112.2	784	1372	
7.00	116.3	729	1276	
7.25	120.5	680	1190	
7.50	124.7	635	1112	
7.75	128.8	595	1041	
8.00	133.0	558	977	
8.25	137.1	525	919	
8.50	141.3	495	865	
8.75	145.4	467	817	
9.00	149.6	441	772	
9.25	153.7	418	731	
9.50	157.9	396	693	
9.75	162.0	376	658	
10.00	166.2	357	625	
10.25	170.4	340	595	
10.50	174.5	324	567	
10.75	178.7	309	541	
11.00	182.8	295	517	
11.25	187.0	282	494	
11.50	191.1	270	473	
11.75	195.3	259	453	
12 00	199.4	248	434	

Allowable Axial Stresses and Loads for Box-Section 3x1/4

A = 2.75 in^2

r = 1.13 in.

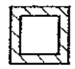


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	2.7	10000	27500	**SHORT COLUMN**
0.50	5.3	10000	27500	
0.75	8.0	10000	27500	
1.00	10.6	10000	27500	
1.25	13.3	10000	27500	
1.50	16.0	10000	27500	
1.75	18.6	10000	27500	
2.00	21.3	10000	27500	
2.25	24.0	10000	27500	
2.50	26.6	10000	27500	
2.75	29.3	10000	27500	
3.00	31.9	9673	26600	
3.25	34.6	8242	22665	**LONG COLUMN**
3.50	37.3	7106	19543	
3.75	39.9	6190	17024	
4.00	42.6	5441	14962	
4.25	45.3	4820	13254	
4.50	47.9	4299	11822	
4.75	50.6	3858	10610	
5.00	53.2	3482	9576	
5.25	55.9	3158	8686	
5.50	58.6	2878	7914	
5.75	61.2	2633	7241	
6.00	63.9	2418	6650	
6.25	66.5	2229	6129	
6.50	69.2	2060	5666	
6.75	71.9	1911	5254	
7.00	74.5	1777	4886	
7.25	77.2	1656	4555	
7.50	79.9	1548	4256	
7.75	82.5	1449	3986	
8.00	85.2	1360	3741	
8.25	87.8	1279	3517	
8.50	90.5	1205	3313	
8.75	93.2	1137	3127	
9.00	95.8	1075	2956	
9.25	98.5	1017	2798	
9.50	101.2	965	2653	
9.75	103.8	916	2518	
10.00	106.5	871	2394	
10.25	109.1	829	2279	
10.50	111.8	790	2171	
10.75	114.5	753	2072	
11.00	117.1	719	1978	
11.25	119.8	688	1892	
11.50	122.4	658	1810	
11.75	125.1	631	1734	
12.00	127.8	605	1662	

Allowable Axial Stresses and Loads for Box-Section 3x1/4

A = 2.75 in^2

r = 1.13 in.



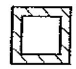
LONG COLUMN

Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)
12.25	130.4	580	1595
12.50	133.1	557	1532
12.75	135.8	536	1473
13.00	138.4	515	1417
13.25	141.1	496	1364
13.50	143.7	478	1314
13.75	146.4	460	1266
14.00	149.1	444	1221
14.25	151.7	429	1179
14.50	154.4	414	1139
14.75	157.1	400	1100
15.00	159.7	387	1064
15.25	162.4	374	1029
15.50	165.0	362	996
15.75	167.7	351	965
16.00	170.4	340	935
16.25	173.0	330	907
16.50	175.7	320	879
16.75	178.3	310	853
17.00	181.0	301	828
17.25	183.7	293	805
17.50	186.3	284	782
17.75	189.0	276	760
18.00	191.7	269	739
18.25	194.3	261	719
18.50	197.0	254	699

Allowable Axial Stresses and Loads for Box-Section 4x1/4

A = 2.75 in^2 ← 3.728

r = 1.13 in.
1.33

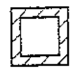


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	2.0	10000	37500	**SHORT COLUMN**
0.50	3.9	10000	37500	
0.75	5.9	10000	37500	
1.00	7.8	10000	37500	
1.25	9.8	10000	37500	
1.50	11.7	10000	37500	
1.75	13.7	10000	37500	
2.00	15.6	10000	37500	
2.25	17.6	10000	37500	
2.50	19.6	10000	37500	
2.75	21.5	10000	37500	
3.00	23.5	10000	37500	
3.25	25.4	10000	37500	
3.50	27.4	10000	37500	
3.75	29.3	10000	37500	
4.00	31.3	10000	37500	
4.25	33.2	8929	33484	
4.50	35.2	7965	29867	
4.75	37.2	7148	26806	**LONG COLUMN**
5.00	39.1	6451	24193	
5.25	41.1	5852	21943	
5.50	43.0	5332	19994	
5.75	45.0	4878	18293	
6.00	46.9	4480	16800	
6.25	48.9	4129	15483	
6.50	50.8	3817	14315	
6.75	52.8	3540	13274	
7.00	54.8	3292	12343	
7.25	56.7	3068	11507	
7.50	58.7	2867	10752	
7.75	60.6	2685	10070	
8.00	62.6	2520	9450	
8.25	64.5	2370	8886	
8.50	66.5	2232	8371	
8.75	68.4	2107	7900	
9.00	70.4	1991	7467	
9.25	72.4	1885	7069	
9.50	74.3	1787	6702	
9.75	76.3	1697	6362	
10.00	78.2	1613	6048	
10.25	80.2	1535	5757	
10.50	82.1	1463	5486	
10.75	84.1	1396	5234	
11.00	86.0	1333	4998	
11.25	88.0	1274	4779	
11.50	90.0	1220	4573	
11.75	91.9	1168	4381	
12.00	93.9	1120	4200	

Allowable Axial Stresses and Loads for Box-Section 4x1/4

A = 2.75 in^2

r = 1.13 in.



LONG COLUMN

Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)
12.25	95.8	1075	4030
12.50	97.8	1032	3871
12.75	99.7	992	3720
13.00	101.7	954	3579
13.25	103.7	919	3445
13.50	105.6	885	3319
13.75	107.6	853	3199
14.00	109.5	823	3086
14.25	111.5	794	2978
14.50	113.4	767	2877
14.75	115.4	741	2780
15.00	117.3	717	2688
15.25	119.3	694	2601
15.50	121.3	671	2517
15.75	123.2	650	2438
16.00	125.2	630	2363
16.25	127.1	611	2290
16.50	129.1	592	2222
16.75	131.0	575	2156
17.00	133.0	558	2093
17.25	134.9	542	2033
17.50	136.9	527	1975
17.75	138.9	512	1920
18.00	140.8	498	1867
18.25	142.8	484	1816
18.50	144.7	471	1767
18.75	146.7	459	1720
19.00	148.6	447	1675
19.25	150.6	435	1632
19.50	152.5	424	1591
19.75	154.5	413	1551
20.00	156.5	403	1512

7.2 COLUMN WITH ROUND SECTION

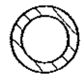
Allowable Load Tables

Allowable Stress Tables

Allowable Axial Stresses and Loads for Round Tube 1-1/2x1/8

A = 0.54 in^2

r = 0.49 in.

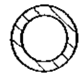


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	6.1	9707	5242	SHORT COLUMN
0.50	12.3	9415	5084	
0.75	18.4	9122	4926	
1.00	24.6	8829	4768	
1.25	30.7	8536	4610	
1.50	36.9	7254	3917	LONG COLUMN
1.75	43.0	5330	2878	
2.00	49.2	4081	2203	
2.25	55.3	3224	1741	
2.50	61.5	2612	1410	
2.75	67.6	2158	1165	
3.00	73.8	1814	979	
3.25	79.9	1545	834	
3.50	86.1	1332	720	
3.75	92.2	1161	627	
4.00	98.4	1020	551	
4.25	104.5	904	488	
4.50	110.7	806	435	
4.75	116.8	723	391	
5.00	123.0	653	353	
5.25	129.1	592	320	
5.50	135.2	540	291	
5.75	141.4	494	267	
6.00	147.5	453	245	
6.25	153.7	418	226	
6.50	159.8	386	209	
6.75	166.0	358	193	
7.00	172.1	333	180	
7.25	178.3	311	168	
7.50	184.4	290	157	
7.75	190.6	272	147	
8.00	196.7	255	138	

Allowable Axial Stresses and Loads for Round Tube 2x1/4

A = 1.37 in^2

r = 0.63 in.



Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	4.8	9771	13426	**SHORT COLUMN**
0.50	9.6	9543	13112	
0.75	14.4	9314	12798	
1.00	19.2	9086	12484	
1.25	24.0	8857	12170	
1.50	28.8	8629	11856	
1.75	33.6	8400	11542	
2.00	38.4	6693	9197	**LONG COLUMN**
2.25	43.2	5289	7266	
2.50	48.0	4284	5886	
2.75	52.8	3540	4864	
3.00	57.6	2975	4087	
3.25	62.4	2535	3483	
3.50	67.2	2186	3003	
3.75	72.0	1904	2616	
4.00	76.8	1673	2299	
4.25	81.6	1482	2037	
4.50	86.4	1322	1817	
4.75	91.2	1187	1630	
5.00	96.0	1071	1471	
5.25	100.8	971	1335	
5.50	105.6	885	1216	
5.75	110.4	810	1113	
6.00	115.2	744	1022	
6.25	120.0	685	942	
6.50	124.8	634	871	
6.75	129.6	588	807	
7.00	134.4	546	751	
7.25	139.2	509	700	
7.50	144.0	476	654	
7.75	148.8	446	612	
8.00	153.6	418	575	
8.25	158.4	393	540	
8.50	163.2	371	509	
8.75	168.0	350	480	
9.00	172.8	331	454	
9.25	177.6	313	430	
9.50	182.4	297	408	
9.75	187.2	282	387	
10.00	192.0	268	368	
10.25	196.8	255	350	

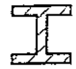
7.3 COLUMN WITH W-SECTION

Allowable Load Tables

Allowable Stress Tables

Allowable Axial Stresses and Loads for W-Section 4x1/4

A = 2.94 in^2
r = 0.95 in.

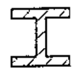


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	3.1	5083	14935	SHORT COLUMN
0.50	6.3	5083	14935	
0.75	9.4	5083	14935	
1.00	12.6	5083	14935	
1.25	15.7	5083	14935	
1.50	18.9	5083	14935	
1.75	22.0	5083	14935	
2.00	25.2	5083	14935	
2.25	28.3	5083	14935	
2.50	31.4	5083	14935	
2.75	34.6	5083	14935	
3.00	37.7	5083	14935	
3.25	40.9	5083	14935	
3.50	44.0	5083	14935	
3.75	47.2	4436	13032	
4.00	50.3	3899	11454	
4.25	53.5	3453	10146	
4.50	56.6	3080	9050	
4.75	59.7	2765	8123	
5.00	62.9	2495	7331	LONG COLUMN
5.25	66.0	2263	6649	
5.50	69.2	2062	6058	
5.75	72.3	1887	5543	
6.00	75.5	1733	5091	
6.25	78.6	1597	4692	
6.50	81.8	1476	4338	
6.75	84.9	1369	4022	
7.00	88.1	1273	3740	
7.25	91.2	1187	3487	
7.50	94.3	1109	3258	
7.75	97.5	1039	3051	
8.00	100.6	975	2864	
8.25	103.8	916	2693	
8.50	106.9	863	2537	
8.75	110.1	815	2394	
9.00	113.2	770	2263	
9.25	116.4	729	2142	
9.50	119.5	691	2031	
9.75	122.6	656	1928	
10.00	125.8	624	1833	
10.25	128.9	594	1744	
10.50	132.1	566	1662	
10.75	135.2	540	1586	
11.00	138.4	516	1515	
11.25	141.5	493	1448	
11.50	144.7	472	1386	
11.75	147.8	452	1327	
12.00	150.9	433	1273	

Allowable Axial Stresses and Loads for W-Section 4x1/4

A = 2.94 in^2

r = 0.95 in.



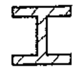
Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)
12.25	154.1	416	1221
12.50	157.2	399	1173
12.75	160.4	384	1127
13.00	163.5	369	1084
13.25	166.7	355	1044
13.50	169.8	342	1006
13.75	173.0	330	969
14.00	176.1	318	935
14.25	179.2	307	903
14.50	182.4	297	872
14.75	185.5	287	842
15.00	188.7	277	815
15.25	191.8	268	788
15.50	195.0	260	763
15.75	198.1	251	739

LONG COLUMN

Allowable Axial Stresses and Loads for W-Section 6x3/8

A = 6.61 in^2

r = 1.43 in.

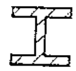


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	2.1	5083	33596	**SHORT COLUMN**
0.50	4.2	5083	33596	
0.75	6.3	5083	33596	
1.00	8.4	5083	33596	
1.25	10.5	5083	33596	
1.50	12.6	5083	33596	
1.75	14.7	5083	33596	
2.00	16.8	5083	33596	
2.25	18.9	5083	33596	
2.50	21.0	5083	33596	
2.75	23.1	5083	33596	
3.00	25.2	5083	33596	
3.25	27.3	5083	33596	
3.50	29.4	5083	33596	
3.75	31.5	5083	33596	
4.00	33.6	5083	33596	
4.25	35.7	5083	33596	
4.50	37.8	5083	33596	
4.75	39.9	5083	33596	
5.00	42.0	5083	33596	
5.25	44.1	5083	33596	
5.50	46.2	4633	30621	
5.75	48.3	4239	28016	
6.00	50.3	3893	25730	
6.25	52.4	3588	23713	
6.50	54.5	3317	21924	
6.75	56.6	3076	20330	
7.00	58.7	2860	18904	
7.25	60.8	2666	17623	
7.50	62.9	2492	16467	**LONG COLUMN**
7.75	65.0	2334	15422	
8.00	67.1	2190	14473	
8.25	69.2	2059	13609	
8.50	71.3	1940	12821	
8.75	73.4	1831	12098	
9.00	75.5	1730	11436	
9.25	77.6	1638	10826	
9.50	79.7	1553	10264	
9.75	81.8	1474	9744	
10.00	83.9	1402	9263	
10.25	86.0	1334	8817	
10.50	88.1	1271	8402	
10.75	90.2	1213	8015	
11.00	92.3	1158	7655	
11.25	94.4	1107	7319	
11.50	96.5	1060	7004	
11.75	98.6	1015	6709	
12.00	100.7	973	6433	

Allowable Axial Stresses and Loads for W-Section 6x3/8

A = 6.61 in^2

r = 1.43 in.



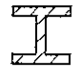
Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)
12.25	102.8	934	6173
12.50	104.9	897	5928
12.75	107.0	862	5698
13.00	109.1	829	5481
13.25	111.2	798	5276
13.50	113.3	769	5083
13.75	115.4	741	4899
14.00	117.5	715	4726
14.25	119.6	690	4562
14.50	121.7	667	4406
14.75	123.8	644	4258
15.00	125.9	623	4117
15.25	128.0	603	3983
15.50	130.1	583	3856
15.75	132.2	565	3734
16.00	134.3	547	3618
16.25	136.4	531	3508
16.50	138.5	515	3402
16.75	140.6	500	3302
17.00	142.7	485	3205
17.25	144.8	471	3113
17.50	146.9	458	3025
17.75	149.0	445	2940
18.00	151.0	433	2859
18.25	153.1	421	2781
18.50	155.2	410	2706
18.75	157.3	399	2635
19.00	159.4	388	2566
19.25	161.5	378	2500
19.50	163.6	369	2436
19.75	165.7	359	2375
20.00	167.8	350	2316

LONG COLUMN

Allowable Axial Stresses and Loads for W-Section 8x3/8 (1625)

A = 8.86 in^2

r = 1.90 in.

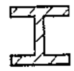


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	1.6	2853	25278	SHORT COLUMN
0.50	3.2	2853	25278	
0.75	4.7	2853	25278	
1.00	6.3	2853	25278	
1.25	7.9	2853	25278	
1.50	9.5	2853	25278	
1.75	11.0	2853	25278	
2.00	12.6	2853	25278	
2.25	14.2	2853	25278	
2.50	15.8	2853	25278	
2.75	17.4	2853	25278	
3.00	18.9	2853	25278	
3.25	20.5	2853	25278	
3.50	22.1	2853	25278	
3.75	23.7	2853	25278	
4.00	25.2	2853	25278	
4.25	26.8	2853	25278	
4.50	28.4	2853	25278	
4.75	30.0	2853	25278	
5.00	31.5	2853	25278	
5.25	33.1	2853	25278	
5.50	34.7	2853	25278	
5.75	36.3	2853	25278	
6.00	37.9	2853	25278	
6.25	39.4	2853	25278	
6.50	41.0	2853	25278	
6.75	42.6	2853	25278	
7.00	44.2	2853	25278	
7.25	45.7	2853	25278	
7.50	47.3	2853	25278	
7.75	48.9	2853	25278	
8.00	50.5	2853	25278	
8.25	52.1	2853	25278	
8.50	53.6	2853	25278	
8.75	55.2	2853	25278	
9.00	56.8	2853	25278	
9.25	58.4	2853	25278	
9.50	59.9	2747	24339	
9.75	61.5	2608	23107	LONG COLUMN
10.00	63.1	2479	21966	
10.25	64.7	2360	20907	
10.50	66.2	2249	19924	
10.75	67.8	2146	19008	
11.00	69.4	2049	18153	
11.25	71.0	1959	17356	
11.50	72.6	1875	16609	
11.75	74.1	1796	15910	
12.00	75.7	1722	15254	

Allowable Axial Stresses and Loads for W-Section 8x3/8 (1625)

A = 8.86 in^2

r = 1.90 in.

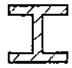


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)
12.25	77.3	1652	14638
12.50	78.9	1587	14058
12.75	80.4	1525	13512
13.00	82.0	1467	12997
13.25	83.6	1412	12512
13.50	85.2	1360	12053
13.75	86.8	1311	11618
14.00	88.3	1265	11207
14.25	89.9	1221	10817
14.50	91.5	1179	10447
14.75	93.1	1140	10096
15.00	94.6	1102	9763
15.25	96.2	1066	9445
15.50	97.8	1032	9143
15.75	99.4	1000	8855
16.00	100.9	969	8580
16.25	102.5	939	8318
16.50	104.1	911	8068
16.75	105.7	884	7829
17.00	107.3	858	7601
17.25	108.8	833	7382
17.50	110.4	810	7172
17.75	112.0	787	6972
18.00	113.6	765	6780
18.25	115.1	744	6595
18.50	116.7	724	6418
18.75	118.3	705	6248
19.00	119.9	687	6085
19.25	121.5	669	5928
19.50	123.0	652	5777
19.75	124.6	636	5631
20.00	126.2	620	5491

LONG COLUMN

Allowable Axial Stresses and Loads for W-Section 10x1/2 (1625)

A = 14.75 in^2
r = 2.38 in.



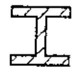
SHORT COLUMN

Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)
0.25	1.3	3253	47987
0.50	2.5	3253	47987
0.75	3.8	3253	47987
1.00	5.0	3253	47987
1.25	6.3	3253	47987
1.50	7.6	3253	47987
1.75	8.8	3253	47987
2.00	10.1	3253	47987
2.25	11.4	3253	47987
2.50	12.6	3253	47987
2.75	13.9	3253	47987
3.00	15.1	3253	47987
3.25	16.4	3253	47987
3.50	17.7	3253	47987
3.75	18.9	3253	47987
4.00	20.2	3253	47987
4.25	21.4	3253	47987
4.50	22.7	3253	47987
4.75	24.0	3253	47987
5.00	25.2	3253	47987
5.25	26.5	3253	47987
5.50	27.8	3253	47987
5.75	29.0	3253	47987
6.00	30.3	3253	47987
6.25	31.5	3253	47987
6.50	32.8	3253	47987
6.75	34.1	3253	47987
7.00	35.3	3253	47987
7.25	36.6	3253	47987
7.50	37.8	3253	47987
7.75	39.1	3253	47987
8.00	40.4	3253	47987
8.25	41.6	3253	47987
8.50	42.9	3253	47987
8.75	44.2	3253	47987
9.00	45.4	3253	47987
9.25	46.7	3253	47987
9.50	47.9	3253	47987
9.75	49.2	3253	47987
10.00	50.5	3253	47987
10.25	51.7	3253	47987
10.50	53.0	3253	47987
10.75	54.2	3253	47987
11.00	55.5	3203	47246
11.25	56.8	3062	45170
11.50	58.0	2931	43227
11.75	59.3	2807	41408
12.00	60.6	2692	39700

Allowable Axial Stresses and Loads for W-Section 10x1/2 (1625)

A = 14.75 in^2

r = 2.38 in.



Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)
12.25	61.8	2583	38096
12.50	63.1	2481	36588
12.75	64.3	2384	35167
13.00	65.6	2293	33827
13.25	66.9	2208	32563
13.50	68.1	2127	31368
13.75	69.4	2050	30238
14.00	70.6	1977	29167
14.25	71.9	1909	28153
14.50	73.2	1843	27191
14.75	74.4	1781	26277
15.00	75.7	1723	25408
15.25	77.0	1667	24582
15.50	78.2	1613	23795
15.75	79.5	1562	23046
16.00	80.7	1514	22331
16.25	82.0	1468	21650
16.50	83.3	1424	20998
16.75	84.5	1381	20376
17.00	85.8	1341	19781
17.25	87.0	1303	19212
17.50	88.3	1266	18667
17.75	89.6	1230	18145
18.00	90.8	1196	17645
18.25	92.1	1164	17164
18.50	93.4	1132	16704
18.75	94.6	1102	16261
19.00	95.9	1074	15836
19.25	97.1	1046	15427
19.50	98.4	1019	15034
19.75	99.7	994	14656
20.00	100.9	969	14292

LONG COLUMN

7.4 COLUMN WITH I-SECTION

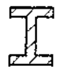
Allowable Load Tables

Allowable Stress Tables

Allowable Axial Stresses and Loads for I-Section 4x2x1/4

A = 1.94 in^2

r = 0.42 in.



Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	7.2	8019	15540	**SHORT COLUMN**
0.50	14.4	7704	14930	
0.75	21.5	7389	14320	
1.00	28.7	7074	13710	
1.25	35.9	6759	13100	
1.50	43.1	5322	10315	**LONG COLUMN**
1.75	50.2	3910	7578	
2.00	57.4	2994	5802	
2.25	64.6	2366	4584	
2.50	71.8	1916	3713	
2.75	78.9	1584	3069	
3.00	86.1	1331	2579	
3.25	93.3	1134	2197	
3.50	100.5	978	1895	
3.75	107.7	852	1650	
4.00	114.8	748	1451	
4.25	122.0	663	1285	
4.50	129.2	591	1146	
4.75	136.4	531	1029	
5.00	143.5	479	928	
5.25	150.7	434	842	
5.50	157.9	396	767	
5.75	165.1	362	702	
6.00	172.2	333	645	
6.25	179.4	307	594	
6.50	186.6	283	549	
6.75	193.8	263	509	

Allowable Axial Stresses and Loads for I-Section 6x3x3/8

A = 4.36 in^2

r = 0.63 in.

Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	4.8	8123	35410	**SHORT COLUMN**
0.50	9.6	7914	34495	
0.75	14.4	7704	33581	
1.00	19.1	7494	32666	
1.25	23.9	7284	31751	
1.50	28.7	7074	30836	
1.75	33.5	6864	29922	
2.00	38.3	6736	29363	
2.25	43.1	5322	23200	**LONG COLUMN**
2.50	47.8	4311	18792	
2.75	52.6	3563	15531	
3.00	57.4	2994	13050	
3.25	62.2	2551	11120	
3.50	67.0	2200	9588	
3.75	71.8	1916	8352	
4.00	76.6	1684	7341	
4.25	81.3	1492	6503	
4.50	86.1	1331	5800	
4.75	90.9	1194	5206	
5.00	95.7	1078	4698	
5.25	100.5	978	4261	
5.50	105.3	891	3883	
5.75	110.0	815	3552	
6.00	114.8	748	3263	
6.25	119.6	690	3007	
6.50	124.4	638	2780	
6.75	129.2	591	2578	
7.00	134.0	550	2397	
7.25	138.8	513	2235	
7.50	143.5	479	2088	
7.75	148.3	449	1956	
8.00	153.1	421	1835	
8.25	157.9	396	1726	
8.50	162.7	373	1626	
8.75	167.5	352	1534	
9.00	172.2	333	1450	
9.25	177.0	315	1373	
9.50	181.8	299	1301	
9.75	186.6	283	1236	
10.00	191.4	269	1175	
10.25	196.2	256	1118	

Allowable Axial Stresses and Loads for I-Section 8x4x3/8

A = 5.86 in^2

r = 0.83 in.

Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	3.6	8175	47896	**SHORT COLUMN**
0.50	7.2	8016	46967	
0.75	10.8	7858	46039	
1.00	14.5	7699	45110	
1.25	18.1	7541	44181	
1.50	21.7	7382	43252	
1.75	25.3	7224	42323	
2.00	28.9	7065	41394	
2.25	32.5	6907	40466	
2.50	36.1	6748	39537	
2.75	39.8	6244	36581	
3.00	43.4	5246	30738	**LONG COLUMN**
3.25	47.0	4470	26191	
3.50	50.6	3854	22583	
3.75	54.2	3358	19672	
4.00	57.8	2951	17290	
4.25	61.4	2614	15316	
4.50	65.1	2332	13661	
4.75	68.7	2093	12261	
5.00	72.3	1889	11066	
5.25	75.9	1713	10037	
5.50	79.5	1561	9145	
5.75	83.1	1428	8367	
6.00	86.7	1312	7685	
6.25	90.4	1209	7082	
6.50	94.0	1118	6548	
6.75	97.6	1036	6072	
7.00	101.2	964	5646	
7.25	104.8	898	5263	
7.50	108.4	839	4918	
7.75	112.0	786	4606	
8.00	115.7	738	4323	
8.25	119.3	694	4065	
8.50	122.9	654	3829	
8.75	126.5	617	3613	
9.00	130.1	583	3415	
9.25	133.7	552	3233	
9.50	137.3	523	3065	
9.75	141.0	497	2910	
10.00	144.6	472	2766	
10.25	148.2	449	2633	
10.50	151.8	428	2509	
10.75	155.4	409	2394	
11.00	159.0	390	2286	
11.25	162.7	373	2186	
11.50	166.3	357	2092	
11.75	169.9	342	2004	
12.00	173.5	328	1921	
12.25	177.1	315	1844	
12.50	180.7	302	1771	
12.75	184.3	290	1702	
13.00	188.0	279	1637	
13.25	191.6	269	1576	
13.50	195.2	259	1518	
13.75	198.8	250	1463	

7.5 COLUMN WITH EQUAL LEG ANGLE SECTION

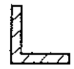
Allowable Load Tables

Allowable Stress Tables

Allowable Axial Stresses and Loads for Equal Leg Angle 3x3/8

A = 2.11 in^2

ry = 0.59 in.

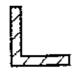


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	5.1	4807	10137	**SHORT COLUMN**
0.50	10.2	4807	10137	
0.75	15.4	4807	10137	
1.00	20.5	4807	10137	
1.25	25.6	4807	10137	
1.50	30.7	4807	10137	
1.75	35.8	4807	10137	
2.00	41.0	4807	10137	
2.25	46.1	4649	9805	
2.50	51.2	3766	7942	
2.75	56.3	3112	6564	
3.00	61.4	2615	5515	**LONG COLUMN**
3.25	66.6	2228	4699	
3.50	71.7	1921	4052	
3.75	76.8	1674	3530	
4.00	81.9	1471	3102	
4.25	87.0	1303	2748	
4.50	92.2	1162	2451	
4.75	97.3	1043	2200	
5.00	102.4	941	1986	
5.25	107.5	854	1801	
5.50	112.6	778	1641	
5.75	117.7	712	1501	
6.00	122.9	654	1379	
6.25	128.0	603	1271	
6.50	133.1	557	1175	
6.75	138.2	517	1089	
7.00	143.3	480	1013	
7.25	148.5	448	944	
7.50	153.6	418	882	
7.75	158.7	392	826	
8.00	163.8	368	776	
8.25	168.9	346	729	
8.50	174.1	326	687	
8.75	179.2	307	648	
9.00	184.3	291	613	
9.25	189.4	275	580	
9.50	194.5	261	550	
9.75	199.7	248	522	

Allowable Axial Stresses and Loads for Equal Leg Angle 4x1/4

A = 1.94 in^2

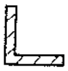
ry = 0.79 in.



Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	3.8	1203	2332	**SHORT COLUMN**
0.50	7.6	1203	2332	
0.75	11.4	1203	2332	
1.00	15.2	1203	2332	
1.25	18.9	1203	2332	
1.50	22.7	1203	2332	
1.75	26.5	1203	2332	
2.00	30.3	1203	2332	
2.25	34.1	1203	2332	
2.50	37.9	1203	2332	
2.75	41.7	1203	2332	
3.00	45.5	1203	2332	
3.25	49.2	1203	2332	
3.50	53.0	1203	2332	
3.75	56.8	1203	2332	
4.00	60.6	1203	2332	
4.25	64.4	1203	2332	**LONG COLUMN**
4.50	68.2	1203	2332	
4.75	72.0	1203	2332	
5.00	75.8	1203	2332	
5.25	79.5	1203	2332	
5.50	83.3	1203	2332	
5.75	87.1	1203	2332	
6.00	90.9	1194	2314	
6.25	94.7	1101	2133	
6.50	98.5	1018	1972	
6.75	102.3	944	1829	
7.00	106.1	877	1700	
7.25	109.8	818	1585	
7.50	113.6	764	1481	
7.75	117.4	716	1387	
8.00	121.2	672	1302	
8.25	125.0	632	1224	
8.50	128.8	595	1153	
8.75	132.6	562	1088	
9.00	136.4	531	1029	
9.25	140.2	502	974	
9.50	143.9	476	923	
9.75	147.7	452	876	
10.00	151.5	430	833	
10.25	155.3	409	793	
10.50	159.1	390	756	
10.75	162.9	372	721	
11.00	166.7	355	689	
11.25	170.5	340	658	
11.50	174.2	325	630	
11.75	178.0	311	603	
12.00	181.8	299	579	
12.25	185.6	286	555	
12.50	189.4	275	533	
12.75	193.2	264	513	
13.00	197.0	254	493	

Allowable Axial Stresses and Loads for Equal Leg Angle 6x1/2

A = 5.75 in^2
ry = 1.19 in.

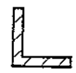


Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)	
0.25	2.5	2137	12286	SHORT COLUMN
0.50	5.1	2137	12286	
0.75	7.6	2137	12286	
1.00	10.1	2137	12286	
1.25	12.7	2137	12286	
1.50	15.2	2137	12286	
1.75	17.7	2137	12286	
2.00	20.3	2137	12286	
2.25	22.8	2137	12286	
2.50	25.3	2137	12286	
2.75	27.8	2137	12286	
3.00	30.4	2137	12286	
3.25	32.9	2137	12286	
3.50	35.4	2137	12286	
3.75	38.0	2137	12286	
4.00	40.5	2137	12286	
4.25	43.0	2137	12286	
4.50	45.6	2137	12286	
4.75	48.1	2137	12286	
5.00	50.6	2137	12286	
5.25	53.2	2137	12286	
5.50	55.7	2137	12286	
5.75	58.2	2137	12286	
6.00	60.8	2137	12286	
6.25	63.3	2137	12286	LONG COLUMN
6.50	65.8	2137	12286	
6.75	68.4	2112	12146	
7.00	70.9	1964	11294	
7.25	73.4	1831	10529	
7.50	75.9	1711	9838	
7.75	78.5	1602	9214	
8.00	81.0	1504	8647	
8.25	83.5	1414	8131	
8.50	86.1	1332	7660	
8.75	88.6	1257	7228	
9.00	91.1	1188	6832	
9.25	93.7	1125	6468	
9.50	96.2	1066	6132	
9.75	98.7	1012	5821	
10.00	101.3	962	5534	
10.25	103.8	916	5267	
10.50	106.3	873	5020	
10.75	108.9	833	4789	
11.00	111.4	795	4574	
11.25	113.9	760	4373	
11.50	116.5	728	4185	
11.75	119.0	697	4008	
12.00	121.5	668	3843	

Allowable Axial Stresses and Loads for Equal Leg Angle 6x1/2

A = 5.75 in^2

ry = 1.19 in.



LONG COLUMN

Effective Column Length (KL) (ft.)	KL/r	Fa (psi)	Pa (lbs)
13.25	134.2	548	3152
13.50	136.7	528	3037
13.75	139.2	509	2927
14.00	141.8	491	2823
14.25	144.3	474	2725
14.50	146.8	458	2632
14.75	149.4	442	2544
15.00	151.9	428	2460
15.25	154.4	414	2380
15.50	157.0	401	2303
15.75	159.5	388	2231
16.00	162.0	376	2162
16.25	164.6	364	2096
16.50	167.1	354	2033
16.75	169.6	343	1972
17.00	172.2	333	1915
17.25	174.7	323	1860
17.50	177.2	314	1807
17.75	179.7	305	1756
18.00	182.3	297	1708
18.25	184.8	289	1662
18.50	187.3	281	1617
18.75	189.9	274	1574
19.00	192.4	267	1533
19.25	194.9	260	1493
19.50	197.5	253	1455
19.75	200.0	247	1419

VII. SUMMARY AND CONCLUSION

More than 300 column members were tested under axial compressive load in a vertical position. The columns tested had five sectional configurations with various lengths to include short, intermediate, and long members. Based on the test results, the following conclusions can be made:

1. The ultimate load capacity and the mode of failure for FRP composite columns depend on the length and the cross-sectional configuration of the member. For a given column length and section shape, the significant parameters in the design and analysis are the column slenderness ratio and the flange width-to-thickness ratio.
2. The Euler's curve for FRP composite columns can be divided into short and long columns by the slenderness ratio; the dividing slenderness ratios are in the range of 30 to 40 for box, round, and I-sections, 40 to 60 for W-section, and 45 to 60 for angle section.
3. Columns with closed sections, such as square tube and round tube, have shown bearing failure for short column and buckling failure for long column as shown in Figure 14.
4. Columns with open sections, such as W, I, and angle sections, have indicated bearing and/or local buckling failure mode for short column and local/global buckling mode of failure for long column as shown in Figure 14.
5. Columns with I-section and a $kl/r > 30$ have shown no flange buckling or a decrease in load before failure. A sudden failure by buckling occurs at no warning in any fashion. The application of I-section column under a

compression load needs to be cautious.

6. There are no significant differences in ultimate strength for W-section column with a dimension of 8 x 8 x 3/8 in. made of polyester-based resin (1525) and of vinylester-based resin (1625).

7. For special construction of W-section columns with a dimension of 6 x 6 x 3/8 in., the ultimate strength of the short column is higher than that of the same dimension W-section column made of polyester-based resin (1525), and the ultimate strength of the long column with special construction is lower than that of the 1525 series column. The strengthening of flange/web joint obviously helps in reducing crippling of the flanges but has no significant effect on the global buckling.

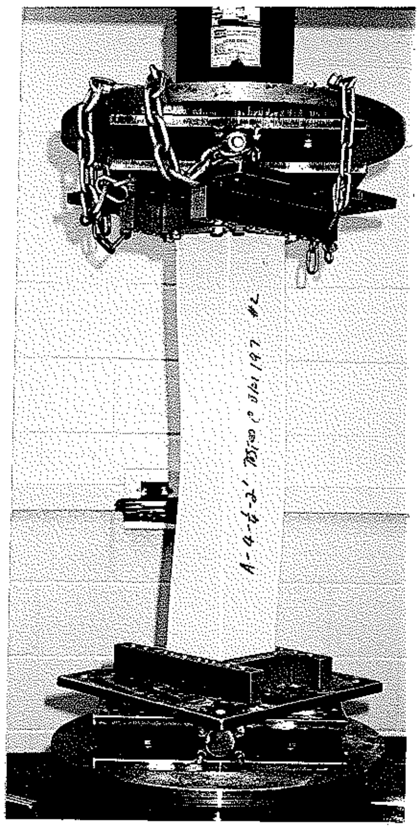


FIGURE 14 - MODE OF FAILURE FOR SHORT AND LONG COLUMNS

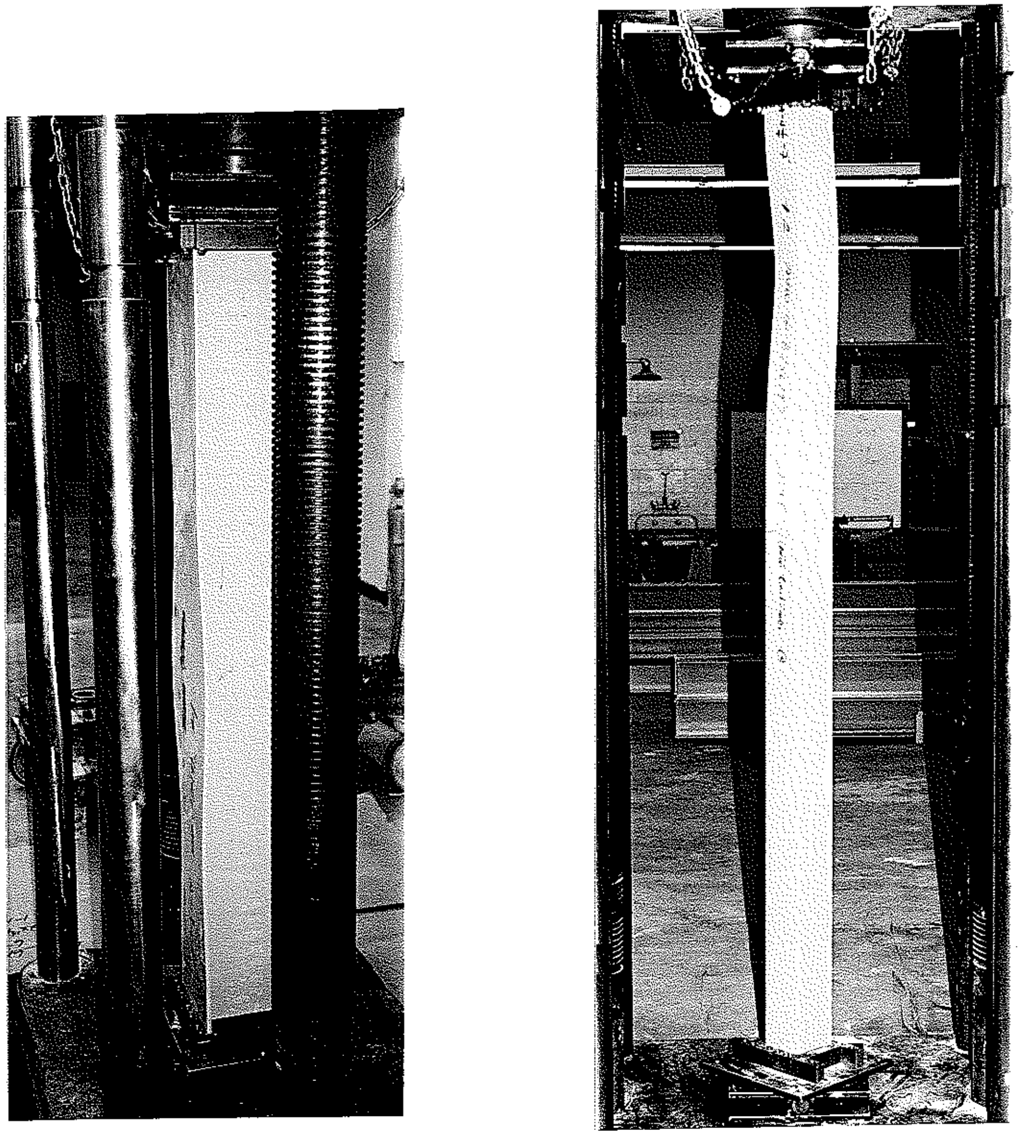


FIGURE 14 - MODE OF FAILURE FOR SHORT AND LONG COLUMNS

IX. SOFTWARE MANUAL

AND

DOCUMENTATION

This program contains the function ***main()***, the function ***print_header()***, the function ***input_supporting_condition()***, the function ***get_k()***, the function ***input_temperature()***, the function ***input_structural_profile()***, and the function ***allow_load()***.

The function ***main()*** is a driver. It handles the steps under the following:

step 1: It calls the function ***clrscr()*** to clear the screen.

step 2: It asks for input the value for **length.**

step 3: It calls the function ***input_supporting_condition()*** to asks for select the choice and return the value of integer choice to the function ***main().***

step 4: It calls the function ***get_K()***. The function ***get_K()*** get value of **choice1** from function ***main()*** and return the value of **k** to the function ***main()***.

Note: Function **get_K()** does a little bit of error handling. It will give you last chance to input again if you input the number not between 1 to 6. This time you have to be careful to give the right input otherwise it will calculates the wrong results.

step 5: It calls the function ***input_temperature()*** to ask for input the value of temperature and return this value to the function ***main()***.

step 6: It calls the function ***input_factor_safety()*** to ask for input the value of **FS** (factor safety) and return this value to the function **main()**.

step 7: It calls the function ***input_structural_profile()***. This function asks for select the choice and return this value to function ***main()***.

step 8: It calls the function ***allow_load()***. This function is the main part of the program. It does the calculations as receives the values of **FS** (factor safety), **choice2**, **Length**, **k**, **ALS** (allow load for short column), **ALL** (allow load for long column) and the **temperature** from the function **main()**. Each case in the function ***allow_load()*** the value of **A** and **R** will be assigned base on the choice that you will select from the function ***input_structural_profile()***. Also, in each case of the function ***allow_load()*** it calls the function ***temperature_deduction()*** then does the calculations and print out the result on the screen.

This program is easy to run. You need to run this program on **Borland C++** or run it on **windows**.

If you run this program on **Borland C++** do the following:
- Open the file name **yuan.cpp**
- Select the **menu compile** then click **compile** or press **Alt+F9**
- After the program finish compile, select the **menu run** then lick on **run** or **Ctrl+F9** to run the program.

If you want to run this program on **windows** do the following:
- Create any name for the **icon**
- Move the file name **yuan.exe** into this **icon**
- Run the program just click on this **icon**.

```
#include <iostream.h>
#include <stdiostream.h>
#include <string.h>
#include <stdlib.h>
#include <iomanip.h>
#include <conio.h>

#define  Mu  0.3
#define  E   3000000
#define  PI  3.141592654

void print_header();
int input_supporting_condition();
float get_K(int);
int input_temperature();
float input_factor_safety();
float temperature_reduction(int);
int input_structural_profile();
void allow_load(float, int, float, float, float, float, int);


main()
{
  char resp;
  float Length; float k;
  float FS, ALS, ALL;
  int choice1, choice2, temperature;

  do
  {
     clrscr();
     print_header();
     cout << "\n\tEnter column length, inches: ";
     cin >> Length;
     choice1 = input_supporting_condition();
     k = get_K(choice1);
     temperature = input_temperature();
     FS = input_factor_safety(),
     choice2 = input_structural_profile();
     allow_load(FS,choice2,Length,k,ALS,ALL,temperature);
     cout << "\n\n\tDo you want another input (y/n) ? ";
     cin >> resp;
  } while (resp != 'n');
 return 0;
}


void print_header()
```

```
{
  cout << endl;
  cout.width(60);
  cout << "CALCULATION PROCEDURES FOR FRP COLUMN DESIGN \n\n";
  cout <<setw(63)<<"*****************************************************\n";
  cout <<setw(63)<<"|  E = 3,000,000 PSI, and Poisson's ratio, Nu = 0.3. |\n";
  cout <<setw(63)<<"*****************************************************\n";
}


int input_supporting_condition()
{
  int ch;

     cout << endl;
     cout << "\tInput supporting condition, K.\n";
     cout << "\t1-> If \"Pinned-Pinned\", K=1.00\n";
     cout << "\t2-> If \"Fixed-Fixed\", K=0.65\n";
     cout << "\t3-> If \"Pinned-Fixed\", K=0.80\n";
     cout << "\t4-> If \"Fixed-Free\", K=2.10\n";
     cout << "\t5-> If \"Fixed-Translated\", K=1.20\n";
     cout << "\t6-> If \"Pinned-Translated\", K=2.00\n\n";
     cout << "\tEnter choice between (1-6): ";
     cin >> ch;

  return ch;
}


float get_K(int ch)
{
  float K;

  switch(ch)
    {
      case 1: { K=1.00; break; }
      case 2: { K=0.65; break; }
      case 3: { K=0.80; break; }
      case 4: { K=2.10; break; }
      case 5: { K=1.20; break; }
      case 6: { K=2.00; break; }
      default:
        cout << "\n\tYou must enter a number between 1 and 6.\n";
        cout << "\tLast chance please enter your choice again between (1-6): ";
        cin >> ch;
     switch(ch)
      {
         case 1: { K=1.00; break; }
         case 2: { K=0.65; break; }
```

```
        cas [illegible] { K=0.80; break; }
        case 4: { K=2.10; break; }
        case 5: { K=1.20; break; }
        case 6: { K=2.00; break; }
      }
    }
  return K,
}


int input_temperature()
{
  int temperature;

     cout << endl;
     cout << "\tEnter operating temperature: ";
     cin >> temperature;

  return temperature;
}


float input_factor_safety()
{
  float FS;

    cout << "\n\tInput factor of safety, FS. Set default value = 3.0: ";
    cin >> FS;

  return FS;
}


float temperature_reduction(int temperature)
{
  float TRFS;

     if (temperature <= 75)
        TRFS = 1.0;
     else if (temperature > 75)
        TRFS = 1 - 0.3841 * (temperature - 75);

  return TRFS;
}


int input_structural_profile()
{
  int ch;
```

```
  cout << endl;
  cout << "\n\tInput structural profile.\n";
  cout << "\t1--> If \"R1-1/2x8\", A=0.540, r=0.488.\n";
  cout << "\t2--> If \"R2x1/4\", A=1.374, r=0.625.\n";
  cout << "\t3--> If \"B1-3/4x1/4\", A=1.500, r=0.621.\n";
  cout << "\t4--> If \"B2x1/4\", A=1.750, r=0.722.\n";
  cout << "\t5--> If \"B3x1/4\", A=2.750, r=1.127 \n";
  cout << "\t6--> If \"B3x1/4\", A=3.750, r=1.534.\n";
  cout << "\t7--> If \"A3x3/8\", A=2.109, r=0.586, tf=0.375, bf=3.0.\n";
  cout << "\t8--> If \"A4x1/4\", A=1.938, r=0.792, tf=0.250, bf=4.0.\n";
  cout << "\t9--> If \"A6x1/2\", A=5.750, r=0.586, tf=1.185, bf=6.0.\n";
  cout << "\t10-> If \"I4x2x1/4\", A=1.938, r=0.418.\n";
  cout << "\t11-> If \"I6x3x3/8\", A=4.359, r=0.627.\n";
  cout << "\t12-> If \"I8x4x3/8\", A=5.859, r=0.830.\n";
  cout << "\t13-> If \"W4x1/4\", A=2.938, r=0.954, tf=0.250, bf=2.0.\n";
  cout << "\t14-> If \"W6x3/8\", A=6.609, r=1.430, tf=0.375, bf=3.0.\n";
  cout << "\t15-> If \"WS6x3/8\", A=6.609, r=1.430, tf=0.375, bf=3.0.\n";
  cout << "\t16-> If \"W8x3/8\", A=8.859, r=1.902, tf=0.375, bf=4.0.\n";
  cout << "\t17-> If \"WB8x3/8\", A=8.859, r=1.902, tf=0.375, bf=4.0.\n";
  cout << "\t18-> If \"WB10x1/2\", A=14.75, r=2.378, tf=0.50, bf=5.0.\n";
  cout << "\n\tEnter choice between (1-18): ";
  cin >> ch;

 return ch;
}


void allow_load(float FS, int ch, float L, float K, float ALS,
                        float ALL, int temp)
{
 float KLr=0, TRFS;
 float A=0, r=0, tf=0, bf=0;

 switch(ch)
   {
    case 1.
     {
        A = 0.540; r = 0.488;
        KLr = (K*L)/r;
        TRFS = temperature_reduction(temp);
        ALS = (1/FS)*TRFS*(30-(KLr/7))*A*1000;
        ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
        if (ALS < ALL)
   {
    cout << "\n\tThis is a short column having the allowable load = ";
    printf("%.2f lb", ALS);
   }
        else
```

```
{
 cout << "\n\tThis is a long column having the allowable load = ";
 printf("%.2f lb", ALL);

}
     break;
  }
 case 2:
  {
    A = 1.374; r = 0.625;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*(30-(KLr/7))*A*1000;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
     {
cout << "\n\tThis is a short column having the allowable load = ";
printf("%.2f lb", ALS);
     }
    else
     {
cout << "\n\tThis is a long column having the allowable load = ";
printf("%.2f lb", ALL);
     }
    break;
  }
 case 3:
  {
    A = 1.500; r = 0.621;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp),
    ALS = (1/FS)*TRFS*30*A*1000;
    ALL = ( (1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
     {
cout << "\n\tThis is a short column having the allowable load = ";
printf("%.2f lb", ALS);
     }
    else
     {
cout << "\n\tThis is a long column having the allowable load = ";
printf("%.2f lb", ALL);
     }
    break;
  }
 case 4:
  {
    A = 1.750; r = 0.722;
    KLr = (K*L)/r;
```

```
    TRFS _ temperature_reduction(temp);
    ALS = (1/FS)*TRFS*30*A*1000;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
     {
cout << "\n\tThis is a short column having the allowable load = ";
printf("%.2f lb", ALS);
     }
    else if (ALS >= ALL)
     {
cout << "\n\tThis is a long column having the allowable load = ";
printf("%.2f lb", ALL),
     }
    break;
  }
 case 5:
  {
    A = 2.750; r = 1.127;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*30*A*1000;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
     {
cout << "\n\tThis is a short column having the allowable load = ";
printf("%.2f lb", ALS);
     }
    else
     {
cout << "\n\tThis is a long column having the allowable load = ";
printf("%.2f lb", ALL);
     }
    break;
  }
 case 6:
  {
    A = 3.750; r = 1.534;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp),
    ALS = (1/FS)*TRFS*30*A*1000;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A),
    if (ALS < ALL)
     {
cout << "\n\tThis is a short column having the allowable load = ";
printf("%.2f lb", ALS);
     }
    else
     {
cout << "\n\tThis is a long column having the allowable load = ";
```

```
printf(" ..f lb", ALL);
      }
    break;
  }
 case 7:
  {
    A = 2.109; r = 0.586; tf = 0.375; bf = 3.0;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*(0.8*E/(2*(1+Mu))*((tf/bf)*(tf/bf)))*A;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A),
    if (ALS < ALL)
      {
cout << "\n\tThis is a short column having the allowable load = ";
printf("%.2f lb", ALS);
      }
    else if (ALS >= ALL)
      {
cout << "\n\tThis is a long column having the allowable load = ";
printf("%.2f lb", ALL);
      }
    break;
  }
 case 8:
  {
    A = 1.938; r = 0.792; tf = 0.250; bf = 4.0;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*(0.8*E/(2*(1+Mu))*((tf/bf)*(tf/bf)))*A;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
      {
cout << "\n\tThis is a short column having the allowable load = ";
printf("%.2f lb", ALS);
      }
    else
      {
cout << "\n\tThis is a long column having the allowable load = ";
printf("%.2f lb", ALL);
      }
    break;
  }
 case 9:
  {
    A = 5.750; r = 1.19; tf = 0.5; bf = 6.0;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*(0.8*E/(2*(1+Mu))*((tf/bf)*(tf/bf)))*A;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A),
```

```
    if (ALS < ALL)
      {
        cout << "\n\tThis is a short column having the allowable load = ";
        printf("%.2f lb", ALS);
      }
    else
      {
        cout << "\n\tThis is a long column having the allowable load = ";
        printf("%.2f lb", ALL);
      }
    break;
  }
case 10:
  {
    A = 1.938; r = 0.418;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*(25-5*KLr/38)*A*1000;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
      {
        cout << "\n\tThis is a short column having the allowable load = ";
        printf("%.2f lb", ALS);
      }
    else
      {
        cout << "\n\tThis is a long column having the allowable load = ";
        printf("%.2f lb", ALL);
      }
    break;
  }
case 11:
  {
    A = 4.359; r = 0.627;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp),
    ALS = (1/FS)*TRFS*(25-5*KLr/38)*A*1000;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
      {
        cout << "\n\tThis is a short column having the allowable load = ";
        printf("%.2f lb", ALS);
      }
    else
      {
        cout << "\n\tThis is a long column having the allowable load = ";
        printf("%.2f lb", ALL);
      }
    break;
```

```
  }
case 12:
  {
    A = 5.859; r = 0.830;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*(25-5*KLr/38)*A*1000;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
      {
        cout << "\n\tThis is a short column having the allowable load = ";
        printf("%.2f lb", ALS);
      }
    else
      {
        cout << "\n\tThis is a long column having the allowable load = ";
        printf("%.2f lb", ALL);
      }
    break;
  }
case 13:
  {
    A = 2.938; r = 0.954; tf = 0.250; bf = 2.0;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*(0.8*0.45*(PI*PI)*(E/(12*(1-(Mu*Mu))))*
                                              ((tf/bf)*(tf/bf)))*A;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
      {
        cout << "\n\tThis is a short column having the allowable load = ";
        printf("%.2f lb", ALS);
      }
    else
      {
        cout << "\n\tThis is a long column having the allowable load = ";
        printf("%.2f lb", ALL);
      }
    break;
  }
case 14:
  {
    A = 6.609; r = 1.430; tf = 0.375; bf = 3.0;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*(0.8*0.45*(PI*PI)*(E/(12*(1-(Mu*Mu))))*
                                              ((tf/bf)*(tf/bf)))*A;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A),
    if (ALS < ALL)
```

```
      {
        cout << "\n\tThis is a short column having the allowable load = ";
        printf("%.2f lb", ALS);
      }
    else
      {
        cout << "\n\tThis is a long column having the allowable load = ";
        printf("%.2f lb", ALL);
      }
    break;
  }
case 15:
  {
    A = 6.609; r = 1.430; tf = 0.375; bf = 3.0;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp),
    ALS = (1/FS)*TRFS*(0.8*0.45*(PI*PI)*(E/(12*(1-(Mu*Mu))))*
                                              ((tf/bf)*(tf/bf)))*A;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
      {
        cout << "\n\tThis is a short column having the allowable load = ";
        printf("%.2f lb", ALS),
      }
    else
      {
        cout << "\n\tThis is a long column having the allowable load = ";
        printf("%.2f lb", ALL),
      }
    break;
  }
case 16:
  {
    A = 8.859; r = 1.902; tf = 0.375; bf = 4.0;59;
    KLr = (K*L)/r;
    TRFS = temperature_reduction(temp);
    ALS = (1/FS)*TRFS*(0.8*0.45*(PI*PI)*(E/(12*(1-(Mu*Mu))))*
                                              ((tf/bf)*(tf/bf)))*A;
    ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
    if (ALS < ALL)
      {
        cout << "\n\tThis is a short column having the allowable load = ";
        printf("%.2f lb", ALS),
      }
    else
      {
        cout << "\n\tThis is a long column having the allowable load = ";
        printf("%.2f lb", ALL);
      }
```

```
        br
      }
    case 17:
      {
        A = 8.859; r = 1.902; tf = 0.375; bf = 4.0;
        KLr = (K*L)/r;
        TRFS = temperature_reduction(temp);
        ALS = (1/FS)*TRFS*(0.8*0.45*(PI*PI)*(E/(12*(1-(Mu*Mu))))*
                                                ((tf/bf)*(tf/bf)))*A;
        ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
        if (ALS < ALL)
          {
            cout << "\n\tThis is a short column having the allowable load = ";
            printf("%.2f lb", ALS);
          }
        else
          {
            cout << "\n\tThis is a long column having the allowable load = ";
            printf("%.2f lb", ALL);
          }
        break;
      }
    case 18:
      {
        A = 14.75; r = 2.378; tf = 0.50; bf = 5.0;
        KLr = (K*L)/r;
        TRFS = temperature_reduction(temp);
        ALS = (1/FS)*TRFS*(0.8*0.45*(PI*PI)*(E/(12*(1-(Mu*Mu))))*
                                                 ((tf/bf)*(tf/bf)))*A;
        ALL = ((1/FS)*TRFS* ( (PI*PI)*(E/(KLr*KLr)) )*A);
        if (ALS < ALL)
          {
            cout << "\n\tThis is a short column having the allowable load = ";
            printf("%.2f lb", ALS);
          }
        else
          {
            cout << "\n\tThis is a long column having the allowable load = ";
            printf("%.2f lb", ALL);
          }
    break;
      }
    }
}
```