STUB–COLUMN TEST METHOD[1] FOR EFFECTIVE AREA OF COLD–FORMED STEEL COLUMNS

1. Scope

1.1 This test method covers the determination of the effective cross–sectional area of cold–formed steel columns. It primarily considers the effects of local buckling and residual stresses and applies to solid or perforated columns that have holes (or hole patterns) in the flat and/or curved elements of the cross section (1).[2]

1.2 The effective area is used to determine the allowable axial loads of cold–formed column sections in accordance with the *AISI Specification for the Design of Cold–Formed Steel Structural Members,* hereafter called AISI *Specification.*

1.3 The effective area is a variable section property of columns. It reflects the effects of local buckling in relatively thin area elements caused by axial stresses, or loads. When the axial load is zero, the effective area is equal to the gross cross–sectional area; however, when an axial load is applied, the effective area may be less than the gross area. In such a case, the effective area will reduce with increasing load.

1.4 Local buckling reduces the axial load–carrying capacity that would otherwise be limited only by general yielding or overall column buckling. The amount of the reduction depends on the width–to–thickness ratio of the flat elements of the column cross section, the yield strength of the steel sheet from which the column is formed, and the size and frequency of holes or hole patterns, if present.

2. Applicable Documents

2.1 ASTM Standards:
A370 – Tensile Test Method for Steel Sheets
E4 – Verification of Testing Machines

2.2 *AISI Specification for the Design of Cold–Formed Steel Structural Members, 1996 Edition.*

3. Terminology

3.1 ASTM Definitions Standards:
E6 – Definitions of Terms Relating to Methods of Mechanical Testing.
E380 – Standard for Metric Practice.

3.2 Description of terms specific to this standard:

[1]This test and evaluation method will be proposed to the appropriate ASTM Committee for review and adoption.
[2]Numbers in parentheses refer to references at the end of this test method.

Elements = Straight or curved portions of the cross section of a column or stub column.
Local Buckling = The local buckling mode of a flat element of a column cross section, which influences the overall column-buckling behavior.
Overall Buckling = Buckling of a column as a function of its overall length.
Stub-Column = An axial compression member of the same cross section and material as the column for which the strength needs to be determined, but of sufficiently short length to preclude overall column buckling, if possible.

3.3 Symbols

A = the gross cross-sectional area of a column without holes or perforation, or the minimum gross cross-sectional area of a column with holes or perforation.

A_a = the average of all gross cross-sectional areas of the stub columns in a test unit, or the average of gross cross-sectional areas of a stub column.

A_e = the effective cross-sectional area of a stub column at a load less than the ultimate test load, or the effective area of a full-length column.

A_{ei} = the effective cross-sectional area of a stub column at load P_i.

A_{eu} = the nominal effective cross-sectional area at ultimate load adjusted to the nominal thickness and the minimum specified yield strength.

A_{eua} = the average effective cross-sectional area of a test unit of stub columns at the ultimate axial load.

A_{eu1} = the effective cross-sectional area of a stub column with parameters of Test Unit 1 at ultimate load.

A_{eu2} = the effective cross-sectional area of a stub column with parameters of Test Unit 2 at ultimate load.

A_1 = the minimum gross cross-sectional area of a stub column with parameters of Test Unit 1 at ultimate load.

A_2 = the minimum gross cross-sectional area of a stub column with parameters of Test Unit 2 at ultimate load

D = the axial shortening of a stub column at load P.

D_i = the axial shortening of a stub column at load P_i.

D_u = the axial shortening of a stub column at load P_u.

f = the average axial stress assumed to be uniformly distributed over the effective cross-sectional area A_e.

f_i = the average axial stress assumed to be uniformly distributed over the effective cross–sectional area, A_{ei} at load P_i.

f_o = the average axial stress assumed to be uniformly distributed over the effective cross–sectional area, A_e, above which the section is not fully effective.

F_n = the nominal ultimate stress, assumed to be uniformly distributed over the effective cross section of a column as calculated from Section C4 of the AISI *Specification*, at which flexural, torsional, torsional–flexural, or local buckling, and/or yielding, may occur.

F_u = the ultimate stress, assumed to be uniformly distributed, at which local failure occurs in a tested stub column.

F_y = the minimum specified elastic limit or yield stress of column or stub–column material.

F_{ya} = the average elastic limit or yield stress of the sheet steel for a given test unit.

F_{yi} = the individual elastic limit or yield stress of the sheet–steel specimens in a test unit.

i = load–displacement–reading number for a particular stub–column test (load displacement D_i at load P_i).

j = total number of load–displacement readings taken for a particular stub–column test.

L = the length of the stub–column test specimen.

L_p = the pitch of a repeating pattern of perforations along the longitudinal column axis.

n = the ratio of the effective cross–sectional area at the ultimate load to the full cross–sectional area, A_{eu}/A.

P = the applied axial compression force (column load).

P_i = the applied load at load–increment i.

P_n = the nominal failure load of a column.

P_u = the ultimate stub–column load at which local failure occurs.

P_{ua} = the average of all ultimate stub–column loads within a test unit.

r = the minimum radius of gyration of the cross–sectional area, A.

t = the nominal base–steel thickness exclusive of coating.

t_a = the average of all base–steel thicknesses within a test unit, exclusive of coating.

W = the greatest overall width of the cross section including corner(s).

4. Significance

4.1 This test method provides requirements for testing, and equations to determine, the effective area of a cold–formed column section at ultimate load, A_{eu}, and the load–

or stress–dependent effective area, A_e. These properties are used in the AISI *Specification* to determine the ultimate and less–than–ultimate column strengths. The ultimate column strength, P_u, is the product of the minimum specified yield stress, F_y, or the buckling stress F_n, and the corresponding effective cross–sectional area at that stress, A_{eu}. At an applied column strength of P less than P_u, the corresponding effective cross–sectional area shall be A_e.

4.2 The test method also provides a means to observe, measure, and account for local buckling deformations when the appearance of a column section under stress must be determined.

4.3 An inherent assumption of the test method is that true stub–column behavior (which considers local buckling effects only) is achieved when overall column–buckling effects are eliminated. For this condition the ultimate test load on a stub column, P_u, equals the product of the effective cross–sectional area at ultimate load, A_{eu}, times the stress that causes local buckling, or times the yield stress of the virgin steel sheet. In case overall buckling cannot be avoided because of geometrical constraints, the critical column–buckling stress must be used.

4.4 The determination of A_e may be conducted by either one of the two following methods:

(1) The basic, more simple and conservative method:
This method is embodied in the main part of this document and is based on the measured test loads of stub columns and their measured and tested physical and mechanical properties.

(2) An alternate and less conservative method:
This method is based on the shortening of stub columns which occurs during testing. Also, this evaluation method requires more calculations. The results of this method lead to more accurate results for A_e, and to higher allowable axial loads at lower–than–ultimate stress levels. The evaluation procedure for this method is described in Appendix A.

5. Apparatus

5.1 The tests shall be conducted on a testing machine that complies with the requirements of ASTM E4.

5.2 Linear displacement devices for measuring lateral displacements shall have a 0.001 in. (0.0254 mm) least–reading capability.

5.3 Measuring devices for determination of the actual geometry of a test specimen shall have a 0.001 in. (0.0254 mm) least–reading capability.

5.4 If axial shortening is recorded, the measuring device shall have a 0.0001 in. (0.00254 mm) least–reading capability.

6. Test Unit

6.1 A test unit shall include a minimum of three identical stub–column specimens and a minimum of two corresponding sheet–type tensile specimens.

6.2 The specimens within a unit shall represent one type of cold–formed steel section with the same specified geometrical, physical, and chemical properties. The specimens may be taken from the same column or from different production runs provided the source of the specimens is properly identified and recorded.

6.3 If stub–column specimens are taken from different production runs, at least two corresponding sheet–type specimens must be taken and tested from each production run.

6.4 The stub–column test specimens shall be used to determine:

(1) The actual geometry of each specimen.

(2) The ultimate stub–column test load.

(3) Axial shortening at each load level if the alternate test–evaluation method described in Appendix A is used.

(4) Lateral displacements of the specimen at locations of interest (if desired).

6.5 The tensile test specimens shall be used to define the yield stress of each stub–column specimen according to the requirements described in ASTM A370.

6.6 For each test specimen and test unit, the measured geometrical and tested physical properties of the individual specimens shall meet the requirements stated by the fabricator and material producer, respectively.

6.7 If the average area, thickness, or yield strength of a test unit varies by more than 20 percent from the respective nominal or specified–minimum value, the test unit is considered to be non–representative of the column section, and further evaluations of the effective area are considered to be invalid.

7. Stub–Column Specimens

The stub–column specimens shall meet length and end–flatness requirements as follows, depending on whether or not unconnected or welded endplates are used.

7.1 Stub–Column Length – The length requirements of the stub–column test specimen, L, as shown in Figures 1 and 2, are that it be (1) sufficiently short to eliminate overall column buckling effects, and (2) sufficiently long to minimize the end effects during loading, which means that its center portion be representative of the repetitive hole pattern in the full column.

7.1.1 To eliminate overall column–buckling effects, the stub–column length shall not exceed twenty times the minimum radius of gyration, r, of the cross section, A, except where necessary to meet the requirements of Sections 7.1.2 through 7.1.5.

7.1.2 For unperforated columns (Figure 1a) the stub–column length shall not be less than three times the greatest overall width of the cross section, W.

7.1.3 For perforated columns in which the pitch (gage length) of the perforation pattern, L_p, for a single hole or a group of holes, is smaller than, or equal to, the great-

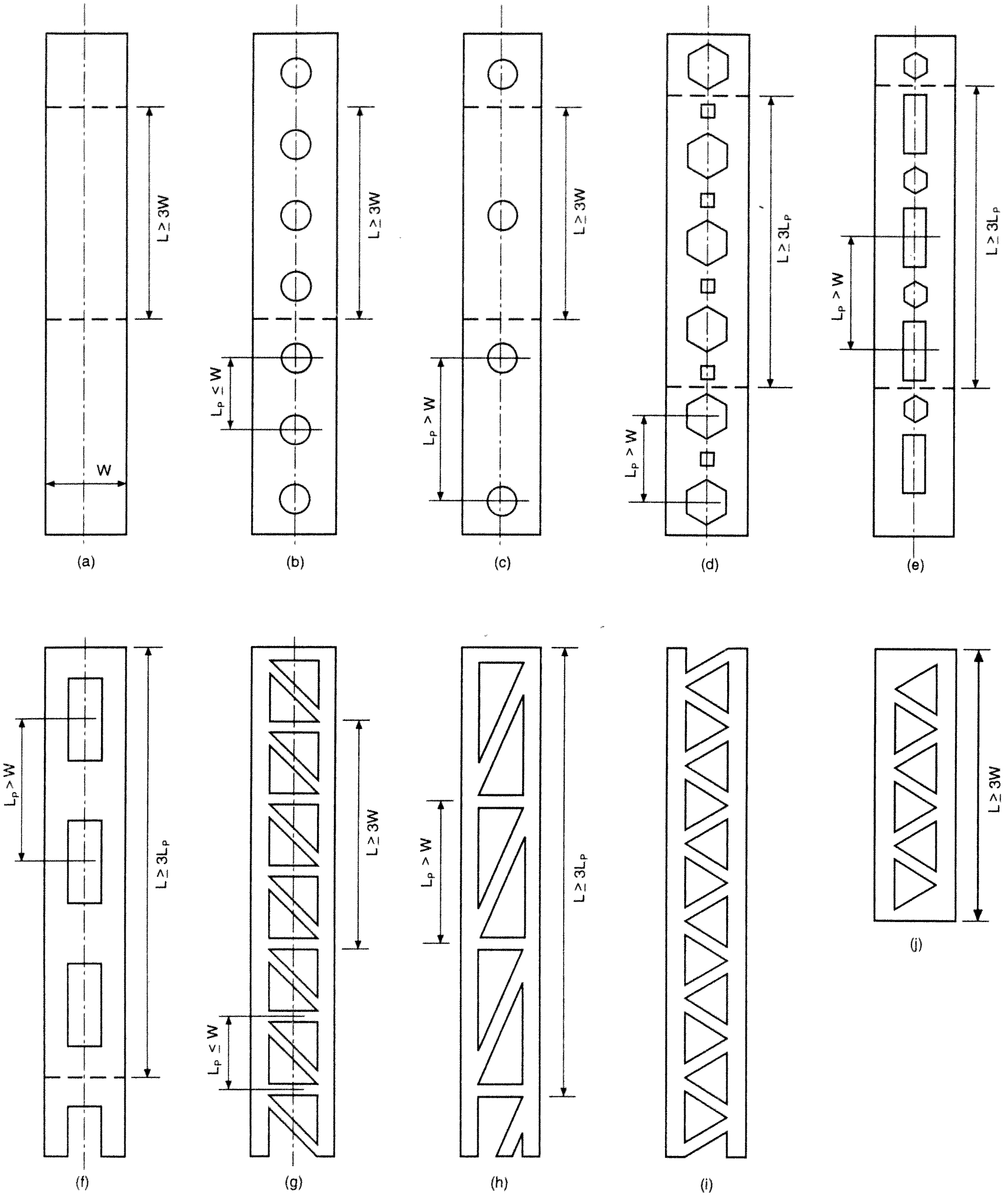

Figure 1 – Hypothetical Perforation Patterns and Suggested Stub Column Lengths

NOTES:
(1) Perforations shown are in a flat portion of a member with width W
(2) L = Length of Stub Column
(3) Lp = Pitch Length of Perforation Pattern

est overall width, W, of the cross section (Figures 1b and 1g), or for a single hole pattern with a gage length larger than the greatest overall width (Figure 1c), the specimen length shall not be less than three times the greatest overall width of the cross section, W. For widely spaced hole patterns (Figure 1c) the significant hole or hole pattern shall be located at or near the midlength of the stub column.

7.1.4 For perforated columns in which the pitch of the perforation pattern, L_p, is greater than the widest side, W, of the cross section (Figures 1d, 1e, 1f, and 1h), the specimen length shall not be less than three times the pitch of the perforation pattern.

7.1.5 For perforated sections in which the specimen end planes must pass through the normal perforation pattern (Figure 1i), a special section (Figure 1j) may be fabricated to obtain full cross–sectional surfaces at the specimen ends.

7.2 Stub–Column End Surface Preparation – The end planes of the stub–column test specimens shall be carefully cut to a flatness tolerance of plus or minus 0.002 in. (0.0508 mm). When the required flatness can be achieved, welding of the stub–column ends to the endplates is not required. However, when this flatness cannot be achieved, steel endplates shall be continuously welded to both ends of the specimen so that there shall be no gap between the ends of the stub column and the endplates.

7.3 Stub–Column Specimen Source – Stub–column test specimens may be cut from the commercially fabricated column product. Alternatively, stub columns may be specially fabricated provided care is taken not to exceed the cold work of forming expected in the commercial product; however, subsequent proof tests using specimens from commercially produced columns are recommended.

7.4 Tensile Specimen Source – Longitudinal tensile specimens shall be cut from the center of the widest flat of a formed section from which the stub–column specimens have been taken. If perforations are large and frequent in all flats of the formed section, the tensile specimens may be taken from the sheet or coil material used for the fabrication of the stub–column specimens. The tensile specimens shall not be taken from parts of a previously tested stub column.

7.5 Endplate Requirements – Steel endplates shall be at least 0.5 in. (12.7 mm) thick and have a flatness tolerance of plus or minus 0.0002 in. (0.00508 mm).

8.0 Stub–Column Test Procedure

8.1 Vertical alignment of the stub column is essential to ensure that the applied load is uniformly distributed over the specimen end surfaces. Care should also be taken to center the specimen on the axis of the test machine.

8.1.1 Steel endplates shall be used to transfer the test loads uniformly into the stub columns (Figure 2).

8.1.2 A $^1/_2$ in. (12.7 mm) thick layer of grout, similar to gypsum–based concrete capping compound used for fast setting, shall be placed between the stub–column endplates and the machine heads to facilitate aligning the test specimen (Figure 2).

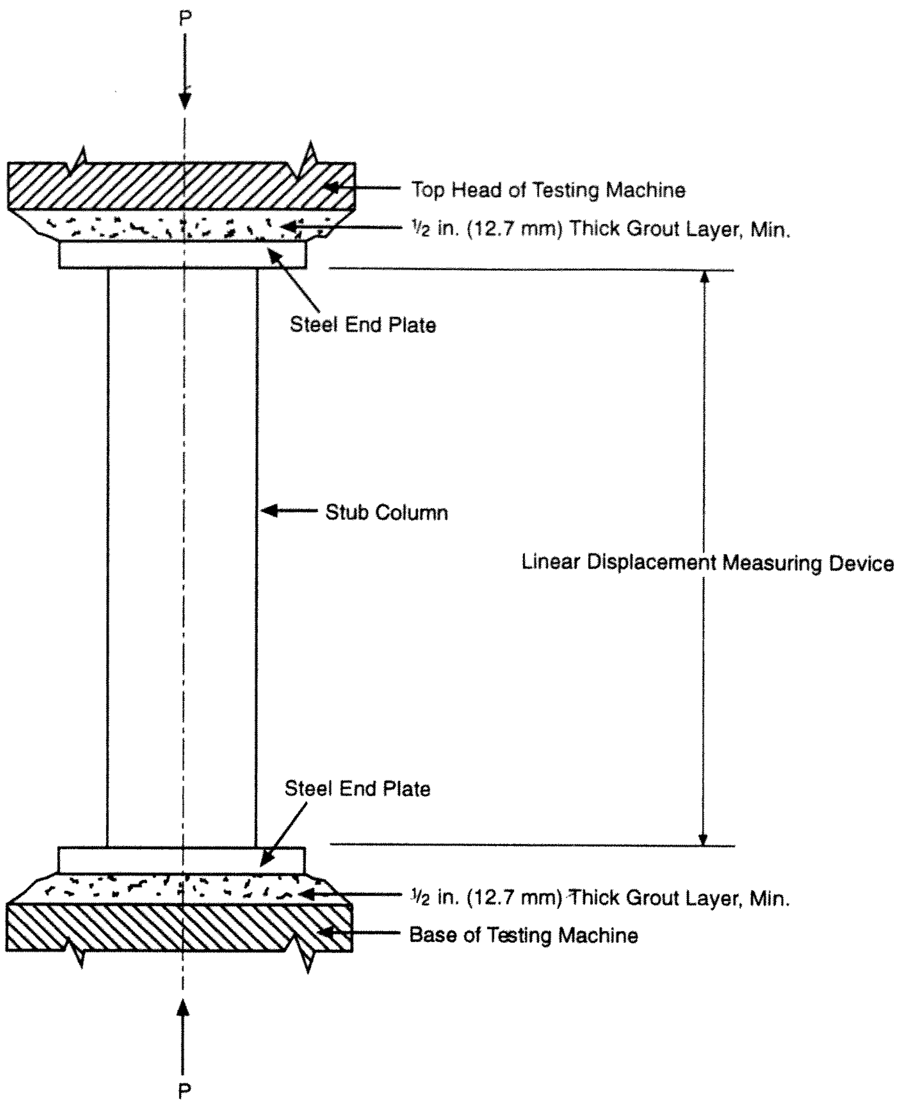

Figure 2 – Test Setup

8.2 When an axial compression load is applied to the test specimen as a result of grout expansion during curing, or if a small preload is purposely applied to ensure proper contact between the stub–column endplates and the machine heads, the load shall be treated as part of the applied test load.

8.3 The load increments applied during the test shall not exceed 10 percent of the estimated ultimate test load.

8.4 The maximum loading rate between load increments shall not exceed a corresponding applied stress rate of 3 ksi (21 MPa) of cross–sectional area per minute.

8.5 When axial shortening values are recorded, the following procedures shall be required:

(1) The change in the vertical distance between the inside surfaces of the endplates (Figure 2) shall be measured to the nearest 0.0001 in. (0.00254 mm) at each load increment for each specimen.

(2) The load increments applied during the test shall be the same for each specimen within a test unit, with a variation not to exceed one percent.

Calculations

9.1 For a given test unit, all individual ultimate loads, P_u, derived from the stub–column tests shall be used to calculate the average ultimate load, P_{ua}. Similarly, all individual yield strengths, F_{yi}, derived from the tensile tests of the same unit shall be used to calculate the average yield stress of the same test unit, F_{ya}.

9.2 The effective areas A_{eua}, A_{eu}, and A_e shall be calculated as specified in Sections 9.3 through 9.6; however, the final value of these effective areas shall not exceed that of the minimum gross cross–sectional area, A.

9.3 For tests in which the length of the stub column does not exceed twenty times the minimum radius of gyration of the cross section, r, the average effective area at the ultimate load, A_{eua}, for a given test unit shall be calculated as

$$A_{eua} = P_{ua}/F_{ya}$$

9.4 For tests in which the length of the stub column exceeds twenty times the minimum radius of gyration of the cross section, the average effective area at the ultimate load shall be determined by iteration of the following equations:

$$A_{eua} = A_a - (A_a - P_{ua}/F_n)/(F_n/F_{ya})^n$$

where A_a is the average minimum gross area of the stub columns in the test unit, and F_n is the flexural or torsional–flexural buckling stress derived from Section C4 of the AISI Specification with $K = 0.5$ (using the average cross–sectional properties of the test unit). The exponent n is determined as follows:

$$n = A_{eua}/A_a$$

Assuming an initial value for n equal to less than 1.0, A_{eua} can be calculated from the first equation. Using this A_{eua} in the second equation will provide a new value for n. Repeating this process will lead to convergence of the above equations and an acceptable value of A_{eau} for one specific test unit.

9.5 The value of A_{eau} for a specific test unit shall be adjusted to A_{eu}, which is the effective cross–sectional area of a column at ultimate load with a nominal cross section of A and a specified minimum yield strength of F_y. The adjustment shall be performed in one or two steps as follows.

9.5.1 If the average area of the stub columns in the test unit, A_a, or the average base steel thickness, t_a, are different from the nominal area or thickness, respectively, the effective cross–sectional area at ultimate load shall be calculated as follows:

$$A_{eu} = A_{eua}(A/A_a)$$

or

$$A_{eu} = A_{eua}(t/t_a)$$

9.5.2 If the average yield strength of all stub columns in a test unit, F_{ya}, is different from the nominal yield strength, F_y, the effective cross–sectional area at ultimate load shall be the lower of the two values calculated as follows:

$$A_{eu} = A[1-A_{eua}/A)(F_y/F_{ya})]$$

or

$$A_{eu} = A_{eua}(F_{ya}/F_y)^{0.4}$$

9.5.3 If the average area and the minimum specified yield strength are different from the nominal values of a test unit, A_{eu} derived from the equation in Section 9.5.1 shall be used as A_{eua} in the equations of Section 9.5.2, which will lead to an acceptable value of A_{eu}.

9.6 The effective area at any working stress level, A_e, may be determined by

$$A_e = A-(A-A_{eu})(f/F_y)^n$$

9.7 For a series of sections, such as in a parameter study during which only one parameter (thickness, depth, width, yield strength, etc.) is changed, interpolations between test units, or extrapolations beyond test units, shall be acceptable as described in Appendix B.

9.8 Extrapolations beyond 20 percent of the extreme parameters tested shall not be permitted.

10. Report

10.1 Documentation – The report shall include a complete record of the sources and locations of all stub–column and tensile–test specimens and shall describe whether the specimens were taken from one or several columns, one or several production runs, coil stock, or other sources.

10.2 The documentation shall include all measurements taken for each stub–column test specimen, including (1) cross–section dimensions, (2) uncoated sheet thickness, (3) longitudinal yield strength, (4) end preparation procedure, (5) applicable material specification, and (6) test and evaluation procedure used.

10.3 The determination of the selected stub–column length shall be fully documented with appropriate calculations.

10.4 A description of the test setup – including the endplates, the grout layer used for alignment, and the instrumentation used to measure lateral displacements and axial shortening – shall be included.

10.5 The report shall include the load increments, rate of loading, and intermediate and ultimate loads for each stub column tested.

10.6 The report shall include complete calculations and results of the effective area, A_{eu}, for each test unit and calculations of A_e, if requested.

11. Precision

11.1 The following criteria shall be used to judge the acceptability of the test results.

11.1.1 Repeatability – Individual stub–column test results shall be considered suspect if they differ by more than 10 percent from the mean value for a test unit with at least three specimens.

11.1.2 Reproducibility – The results of tests on stub–columns conducted at two or more laboratories should agree within ten (10) percent when adjusted for differences in cross sectional dimensions and yield strength.

REFERENCES

(1) T. Pekoz, "Development of a Unified Approach to the Design of Cold–Formed Steel Members", Committee of Sheet Steel Producers, American Iron and Steel Institute, 1101 17th Street, NW, Washington, DC 20036–4700, 1986.

APPENDIX A

Use of Axial Shortening Measurements In Design

A–1 Axial shortening measurements as part of thin–walled cold–formed steel stub–column tests may be used as an alternative method of determining the effective area of a column, A_e, at a certain design load or stress. This method provides a more accurate and less conservative alternative to design engineers to determine the effective area of a column section, A_e.

A–2 The calculations by this method shall be made separately for each stub–column specimen within a test unit. This shall result in a total of j calculations as a result of a total of j load–displacement tests for each test unit.

A–3 For a given specimen the effective area at ultimate load, A_{eu}, shall be calculated from Section 9.3 or 9.4 letting $A_{eua} = A_{eu}$, $A_a = A$, $F_{ya} = F_y$, and $P_{ua} = P_u$.

A–3.1 Calculations at each load–displacement reading, i, shall be conducted according to the following procedure; however, at zero load, the effective area, A_e, shall be equal to the minimum gross cross–sectional area, A. This provides results for the effective area at each load point:

(1) Starting with the lowest load–displacement reading, the effective area, A_i, and the assumed uniformly distributed stress f_i, shall be calculated for each reading, i, from:

$$A_{ei} = \frac{P_i D_u}{F_y D_i}$$

and

$$f_i = F_y D_i / D_u$$

where D_i and D_u are the axial shortening at loads P_i and P_u, respectively.

(2) If A_{ei} calculated is greater than A, A_{ei} shall be set equal to A.

(3) If A_{ei} calculated is less than A, A_{ei} shall be as calculated, and f_o, the stress above which the section is not fully effective, shall be set equal to f_{i-1}, as calculated for the previous load–displacement reading.

A.3.2 For specimens within a test unit, the lowest A_{ei} values shall be used for further evaluations.

A–4 For any load that causes a stress f higher than f_o, an exponential equation may be developed as follows:

$$A_c = A[1-(1-A_{eu}/A)\,(f-f_o)/F_y-f_o)]^b$$

where $$b = \frac{\sum_{i=1}^{j}(X_i)(Y_i) - (a)\sum_{i=1}^{j}(X_i)}{\sum_{i=1}^{j}(X_i)^2}$$

and

$$X = \ln[(f_i - f_o)/(F_y - f_o)]$$
$$Y_i = \ln(1 - A'_{ei}/A)$$
$$a = \ln(1 - A_{eu}/A)$$

and ln designates the natural logarithm.

A–5 If the effective areas for a section with specified dimensions and minimum yield strength are desired, which are different from the tested specimens, the A_{eu} and A_{ei} values calculated under Section A–3 shall be normalized to the specified parameters according to Section 9.5 before the curve–fitting procedure of Section A–4 is employed.

A–6 All calculations pertaining to this procedure shall be included in the report, as discussed in Section 10.

APPENDIX B

Parametric Studies

B–1 For parametric studies intended to develop the effective area for a series of sections with the same basic cross section (either C, U, H, or any other shape) and the same hole pattern, but with one or more changing parameters, the required number of test units may be less than the sum of all sections with different geometries and yield strengths.

B–1.1 For a series of sections with three different values for one parameter only (dimension or nominal yield strength), at least two test units shall be chosen to include the minimum and the maximum value of the changing parameter. For the third value, A_{eu} may be interpolated according to Section B–2.

B–1.2 If more than three different values for one parameter are included in a series of sections, additional units with intermediate values shall be tested such that the ratio of the changing values in adjacent units is not greater than 1.5 or be less than 0.67. For intermediate values of the changing parameter, A_{eu} may be interpolated according to Section B–2.

B–1.3 For a series of sections with the same basic cross section that includes different values for several parameters (dimensions and/or yield strength), an appropriate factorial of test units shall be established by the responsible professional engineer in accordance with the guidelines for changes in an individual parameter, and in compliance with responsible code authorities. Interpolations and extrapolations may be made as mutually agreeable, following the general guidelines set forth in Section B–2 for changes of one parameter only.

B–1.4 For a section that falls outside a series of tested members with the same basic cross section, A_{eu} may be extrapolated provided the changing parameter does not exceed a value of 20 percent below or above the respective minimum or maximum values tested in the series.

B–2 Interpolations and extrapolations are allowed as part of a parametric study, and as defined under B–1.

B–2.1 For a section with a thickness different from the thicknesses tested, but with identical overall nominal cross–sectional dimensions and minimum specified yield strength, A_{eu} for a thickness t and an area A may be calculated provided t does not exceed the limits described under Section B–1.2 and B–1.4. Under these conditions, A_{eu} may be determined by interpolation or extrapolation from the results of the nearest two test units with thicknesses t_1 and t_2, respectively.

$$A_{eu} = A[A_{eu1}/A_1 + (A_{eu2}/A_2 - A_{eu1}/A_1)(t_1 - t)/(t_1 - t_2)]$$

where A_1 and A_2 are the minimum gross cross–sectional areas, and A_{ue1} and A_{eu2} are the nominal effective cross–sectional areas for Test Units 1 and 2, respectively.

B–2.2 For a section with a yield strength different from the yield strengths tested, but with identical cross–sectional dimensions, A_{eu} for a yield strength F_y may be calculated provided F_y does not exceed the limits described under Section B–1.2 and B–1.4. Under these conditions, A_{eu} may be determined by interpolation or extrapolation from the results of the nearest two test units with yield strengths F_{y1} and F_{y2}, and with effective areas A_{eu1} and A_{eu2}, respectively.

$$A_{eu} = A[A_{eu1}/A_1 + (A_{eu2}/A_2 - A_{eu1}/A_1)(F_{y1} - F_y)/(F_{y1} - F_{y2})]$$