The University of Sydney

School of Civil Engineering

CIVL3206 Steel Structures 1

Lab Session – Stub Column Tests

General Information

Acknowledgement – The School of Civil Engineering is grateful to Smorgon Steel Tube Mills for providing the specimens for this experiment. Please visit their web site at http://www.smorgonsteel.com.au.

SMORGONSTEEL

Aim - This laboratory session provides examples of local buckling of stub columns of cold-formed rectangular hollow sections. Students are to compare the behaviour of "stocky" and "slender" sections in compression, and calculate the section capacity N_s in compression comparing it to theoretical calculations.

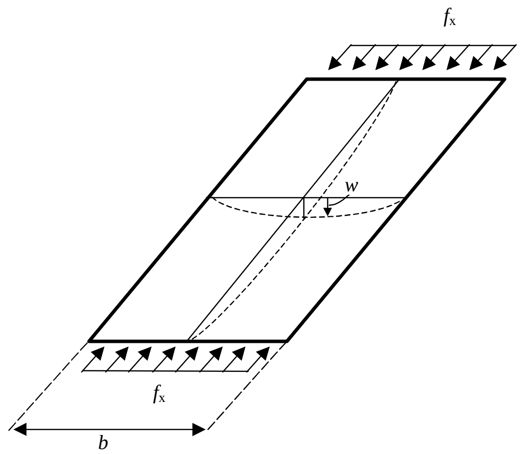
Other References - These notes should be read in conjunction with Sections 4.3 and 4.4 of the Steel Structures 1 lecture notes, and Section 6.2 of AS 4100, and the relevant product literature/section properties in the OneSteel/BHP/Smorgon Steel brochures.

Requirements - Students will be required to examine the specimens, measure the relevant dimensions, perform preliminary calculations, observe the stub column tests, and write a report.

Theory

Introduction to elastic local buckling of thin rectangular plates

Consider a long plate of width b and thickness t, with in plane stress f_x acting on the plate, as shown in Figure 1. The plate in Figure 1 is simply supported on all four edges, but any type of edge restraint could be considered. The plate can buckle out-of-plane, with out-of-plane deflections denoted w.



It can be shown that the solution to the differential equation for elastic local buckling of the plate is :

$$f_{ol} = \frac{k\pi^2 E}{12(1-\nu^2)(b/t)^2} = \frac{H^2}{(b/t)^2} \quad \text{(Eq. 1)}$$

The equation is simplified by using the term H^2 is Equation 2.2:

$$H^2 = \frac{k\pi^2 E}{12(1-\nu^2)} \quad \text{(Eq. 2)}$$

where v is Poisson=s ratio, and E is Young=s modulus of elasticity, and f_{ol} is the elastic local buckling stress. k is the plate buckling coefficient, and depends on the nature of the stress distribution across the plate and the support conditions of the plate. ***The most important point to note is that the elastic buckling stress is inversely proportional to (b/t)^2.***

To prevent a plate from buckling before it reaches it yields (ie to avoid elastic local buckling), then the yield stress must be less than the local buckling stress (f_y # f_{ol}), or from Equation 2.1: $f_y \leq \frac{H^2}{(b/t)^2}$ (Eq. 3)

This can be written in terms of a ***b/t* limit** for some value *H* to prevent elastic local buckling: $\frac{b}{t} \leq \frac{H}{\sqrt{f_y}}$ (Eq. 4)

Steel plates are not "perfect", and contain residual stresses and initial imperfections. By adjusting *H* to *H*N, (a lower value than the elastic value of *H* in Equation 2.2), the effects of residual stresses and initial imperfections are taken into account.

Equation 2.4 can be further rearranged to the format of AS 4100: $\lambda_e = \frac{b}{t}\sqrt{\frac{f_y}{250}} \leq \frac{H'}{\sqrt{250}}$. (Eq. 5)

Local Buckling of a Rectangular Hollow Section Column

Most structural sections can be idealised as consisting of individual flat plate elements. An RHS can be considered as four plates joined to form the hollow section.

Both the flanges and the webs of an RHS can be thought of as individual simply supported plates. The "width" of the flange or web is taken in AS 4100 as the "clear width" of the section, so the values *b* - 2*t*, and *d* - 2*t* are used. Equation 2.3 is rearranged to become: $\lambda_e = \frac{b - 2t}{t}\sqrt{\frac{f_y}{250}} \leq \lambda_{ey}$ (Eq. 6)

λ_e refers to the slenderness of an element, and in particular λ_{ew} is the web slenderness and λ_{ef} is the flange slenderness. λ_{ey} is the yield slenderness limit which is given by *H*N//250 in Equation 2.5. Table 6.2.4 of AS 4100 lists values of λ_{ey} for different support conditions. The values of λ_{ey} were based on testing of actual plates with residual stress and imperfections. The flanges and webs of an RHS are supported on *both* edges and are considered *cold-formed*.

If the web slenderness or flange slenderness (λ_{ew} or λ_{ef}) is less than the appropriate yield slenderness limit (λ_{ey}) specified in Table 6.2.4 then that element is *fully effective* in compression. If the web or flange slenderness is greater than the limit, it is not fully effective, and only the proportion of the web or flange which is less than the limit can be considered effective.

The effective width (b_e) of the section is defined as $b_e = b\left(\frac{\lambda_{ey}}{\lambda_e}\right) \leq b$ (Eq. 7). The *effective area* of the section is then calculated by adding up the effective areas of the elements (flange and web) in the sections, but it is sometimes easier to subtract the ineffective area from the gross area.

The *form factor*, k_f, is then defined as $k_f = A_e / A_g$ (Eq. 8), and the nominal section capacity, N_s, is given by $N_s = k_f A_n f_y$ (Eq. 9).

The *design* section capacity is φN_s where $\varphi = 0.9$ is the capacity reduction factor (phi).

Experiment

1. There are two stub columns to be tested. Students should divide themselves into four groups and each specimen will be shared between two groups.
2. Measure the relevant dimensions of the specimen: flange width, b, web depth, d, thickness, t, external corner radius, r_e, and length, L. Pass the specimen onto the other group responsible for this specimen.
3. A tensile coupon test has been performed previously on the sample. The measured yield stress, f_y, will be given. What is the *nominal* value of yield stress, f_{yn}, for your specimen?
4. Calculate N_s and φN_s for your sample twice. The first should be based on the nominal yield stress and the nominal dimensions. The second values should be based on the actual yield stress and the actual dimensions. The gross area, A_g, and the form factor, k_f will need to be calculated first.
5. The demonstrator will perform the stub column tests in the structures laboratory. Watch the test closely and note any interesting occurrences, as well as the ultimate load.
6. The demonstrator will make available the results of the tests (ie a text file of load versus stroke) by the next working day.

Report

A report is required to be submitted. There is no need to replicate the information given in these notes. Please give *brief* answers to the following questions in report format. While working together is encouraged, students are expected to make *individual* submissions.

Students should read the accompanying information on the requirements of a written report.

Introduction: Include a brief introduction, outlining the aim of the experiment.

Method: Very briefly summarise the test procedure and any observations made during each test. A brief sketch of the testing machine and the deformed shape of the specimen would be useful.

Results: Describe any important observations made during the test.

Tabulate the results. The table should show the d, b, t, r, f_y, A_g, k_f, N_s, φN_s, N_{max}, N_{max}/N_s, and $N_{max}/\varphi N_s$ for both specimens based on both the nominal properties and the actual (measured) properties. Units should be included. Include any other data considered important.

Include a separate graph for each test, plotting load (y axis) against deflection (x axis). Each graph should clearly show values of N_s and φN_s for both the measured and nominal yield stresses/dimensions. **Some manipulation of the data may be required to ensure that the curve begins at the origin (0, 0) and that the load and deflection are shown as positive.**

Discussion: Include a brief discussion of the following points, and other points considered important. A paragraph of approximately 100 words for each point might be suitable.

X Is there a difference between the nominal and measured properties? How might this affect the calculations of an engineer in a design office using the data available from tables such as the BHP section handbook? How is this considered in design?

X Briefly describe the difference in behaviour of a section with $k_f = 1.0$, and a section with $k_f < 1.0$, with reference to the graphs plotted.

X Which prediction of strength, $N_{s,measured}$, $\varphi N_{s,\ measured}$, $N_{s,nominal}$, or $\varphi N_{s,\ nominal}$, provides the best estimate of the experimental result? Include the ratio of the experiment load to each of the four aforementioned values. Suggest reasons why (or why not), the maximum load equals/is less than/is greater than each of the four predictions of strength.

X Based on this experiment, why is a capacity reduction factor, φ, applied to the capacities calculated using AS 4100? Is the value of $\varphi = 0.9$ for a stub column appropriate? Use the test results to justify the answer.

Appendix: Any calculations can be included in an appendix.

Workload: It is anticipated that the preparation of the report should take approximately 3-4 hours.

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SECTION 6 MEMBERS SUBJECT TO AXIAL COMPRESSION

6.1 DESIGN FOR AXIAL COMPRESSION A concentrically loaded member subject to a design axial compression force (N^*) shall satisfy both—

$N^* \leq \phi N_s$, and

$N^* \leq \phi N_c$

where

ϕ = the capacity factor (see Table 3.4)

N_s = the nominal section capacity determined in accordance with Clause 6.2

N_c = the nominal member capacity determined in accordance with Clause 6.3.

6.2 NOMINAL SECTION CAPACITY

6.2.1 General The nominal section capacity (N_s) of a concentrically loaded compression member shall be calculated as follows:

$$N_s = k_f A_n f_y$$

where

k_f = the form factor given in Clause 6.2.2.

A_n = the net area of the cross-section, except that for sections with penetrations or unfilled holes that reduce the section area by less than $100\{1 - [f_y/(0.85f_u)]\}$%, the gross area may be used. Deductions for fastener holes shall be made in accordance with Clause 9.1.10.

6.2.2 Form factor The form factor (k_f) shall be calculated as follows:

$$k_f = \frac{A_e}{A_g}$$

where

A_e = the effective area

A_g = the gross area of the section.

The effective area (A_e) shall be calculated from the gross area by summing the effective areas of the individual elements, whose effective widths are specified in Clause 6.2.4.

6.2.3 Plate element slenderness The slenderness (λ_e) of a flat plate element shall be calculated as follows:

$$\lambda_e = \frac{b}{t}\sqrt{\left(\frac{f_y}{250}\right)}$$

where

b = the clear width of the element outstand from the face of the supporting plate element, *or* the clear width of the element between the faces of the supporting plate elements.

t = the thickness of the plate.

For circular hollow sections, the element slenderness (λ_e) shall be calculated as follows:

$$\lambda_e = \left(\frac{d_o}{t}\right)\left(\frac{f_y}{250}\right)$$

where

d_o = the outside diameter of the section

t = the wall thickness of the section.

6.2.4 Effective width The effective width (b_e) of a flat plate element of clear width (b), or the effective outside diameter (d_e) of a circular hollow section of outside diameter (d_o), shall be calculated from the value of the element slenderness (λ_e) given in Clause 6.2.3 and the element yield slenderness limit (λ_{ey}) given in Table 6.2.4.

The effective width (b_e) for a flat plate element shall be calculated as follows:

$$b_e = b\left(\frac{\lambda_{ey}}{\lambda_e}\right) \leq b$$

The effective outside diameter (d_e) for a circular hollow section shall be the lesser of—

$$d_e = d_o\sqrt{\left(\frac{\lambda_{ey}}{\lambda_e}\right)} \leq d_o, \text{ and}$$

$$d_e = d_o\left(\frac{3\lambda_{ey}}{\lambda_e}\right)^2$$

Alternatively, the effective width (b_e) for a flat plate element may be obtained from the following:

$$b_e = b\left(\frac{\lambda_{ey}}{\lambda_e}\right)\sqrt{\left(\frac{k_b}{k_{bo}}\right)} \leq b$$

where k_b is the elastic buckling coefficient for the element.

For a flat plate element supported along both longitudinal edges—

k_{bo} = 4.0

and for a flat plate element supported along one longitudinal edge (outstand)—

k_{bo} = 0.425

The elastic buckling coefficient (k_b) for the flat plate element shall be determined from a rational elastic buckling analysis of the whole member as a flat plate assemblage.

TABLE 6.2.4

VALUES OF PLATE ELEMENT YIELD SLENDERNESS LIMIT

Plate element type	Longitudinal edges supported	Residual stresses (see Notes)	Yield slenderness limit, λ_{ey}
Flat	One (Outstand)	SR	16
		HR	16
		LW, CF	15
		HW	14
	Both	SR	45
		HR	45
		LW, CF	40
		HW	35
Circular hollow sections		SR	82
		HR, CF	82
		LW	82
		HW	82

NOTES:

1 SR—stress relieved
HR—hot-rolled or hot-finished
CF—cold-formed
LW—lightly welded longitudinally
HW—heavily welded longitudinally

2 Welded members whose compressive residual stresses are less than 40 MPa may be considered to be lightly welded.