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Buckling behavior of cold-formed stub channels under compression

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Abstract. Channel section is one of the most common cold-formed steel sections uses today. Cold formed steel members are widely used in roof trusses. Yielding and crushing are the modes of failure for short compression members or stub column. Design equations can be used to determine local buckling load capacity of stub column. In building construction, the stub column is found in the roof trusses. The purpose of this study is to understand buckling behaviour of the cold formed stub channels under compression. Seven (7) specimens were tested in this study. The results of local buckling, maximum load capacity and axial displacement of seven (7) cold-formed stub channels specimens were obtained by conducting the stub column test (compression test) and tensile test. Five (5) specimens are conservative to mean ratio and two (2) specimens are unconservative. Load-displacement graphs were plotted and two (2) specimens had achieved the expected curve. The failure patterns of the stub channels showed that the buckling occurred at the top edge and bottom edge of stub channels.

1. Introduction

Cold formed steel is manufactured from steel sheet, strips, plates or flat bars in roll-forming machines or by press brake or bending brake operations. Cold-formed steel (CFS) members are being used extensively in building construction [1]. Cold formed steel products usually use in structure member, sheeting and sandwich panel. The AISI Standard provides integrity formulas for cold formed steel members. Given that the web and the flange of cold formed steel members are light and thin, the behaviour of member components become more complex. There is variety of failure modes such as the following: Flexural buckling, torsion buckling, flexural-torsion buckling and local buckling [2].

Cold formed steel structural members delivered many benefits in building construction including high strength-to-weight ratio, non-shrinking and non-creeping behaviour at ambient temperature and ease of prefabrication and mass production. Another major advantage of cold-formed steel construction is the sections allowing for compact packaging and shipping and easily for transportation. Cold formed channels are normally used to construct walls and partitions called stud and trusses. Trusses made of cold formed members may be found in industrial, storage buildings and roof truss. The main chords are usually channel sections joined back to back. The web members are normally single channels. Stub column is a short vertical structural member that are bolted between two other



members such as a rafter and ceiling beam. Currently, cold-formed steel (CFS) is regularly employed in low-to-mid-rise building construction both for non-structural and structural walls [3].

In building construction, the stub column is found in the roof truss. Cold formed channel is commonly used for interior wall such as studs and trusses. In trusses the compression force is acting to the cold formed channels members. Under axial loads the compression members can fail by yielding, local buckling and overall buckling. Yielding and local buckling are controlled by the slenderness of their section only, whereas overall buckling is dependent on the slenderness of the section as well as the slenderness of the column length. For short compression members or stub column, only the first two failure modes occur, that are yielding and buckling. Local buckling capacity of stub column can be determined using design equations. However, the channel could exhibit post buckling behaviour which gives higher load capacity. Therefore, there is a need to study the bulking behaviour of cold-formed stub channels under compression.

2. Method

Laboratory test was conducted for the analysis of the buckling behaviour of stub channel. Seven (7) stub channel column specimens were tested for compression test and yield strength. The laboratory tests to be carried out were stud column test and tensile test.

2.1. Stud column test

Stub column tests were conducted to know the relationship between load and axial displacement that occur during the compression by continuous load applied to the Specimen. Local buckling pattern can also be determined. From the stub column test, stress-strain curves were obtained. The stress and strain are obtained by dividing the applied load against the initial section area and the shortening divided by the initial length, respectively [4].

2.1.1. Stud column specimen

Seven specimens of stub channel were prepared as below:

- The stub column specimens were cold-sawed from the stock at a distance at least equal to the shape depth away from a flame-cut end.
- The length of each stub column was less than three times the largest dimension of the cross section and not more 20 times the least radius-of-gyration.
- The end of the column was milled plane and perpendicular to the longitudinal axis of the column.
- The thickness of the flange and webs and the length and cross sectional area of the stub column were measured and recorded.
- Descriptions of specimens are shown in Table 1.

Table 1. Geometry of stub channel.

| Specimen No. | Specimen (LC x B x b x t) | Thickness, t (mm) | Web Width, B (mm) | Flange Width, b (mm) | Length, L (mm) |
|--------------|------------------------------|----------------------|----------------------|-------------------------|-------------------|
| 1 | 75Cx25x20x1 | 1.0 | 25 | 20 | 75 |
| 2 | 150Cx50x25x1 | | 50 | 25 | 150 |
| 3 | 225Cx75x25x1 | | 75 | 25 | 225 |
| 4 | 300Cx100x25x1 | | 100 | 25 | 300 |
| 5 | 375Cx125x25x1 | | 125 | 25 | 375 |
| 6 | 450Cx150x30x1 | | 150 | 30 | 450 |
| 7 | 600Cx200x40x1 | | 200 | 40 | 600 |

Linear Variable Differential Transducers (LVDT) were used to determine the axial displacement or vertical displacement during test. Transducer provides linear output for small displacements where the core remains within the primary coils. The position of LVDT are placed at top bearing plate to measure the necessary displacements as shown Figure 1.

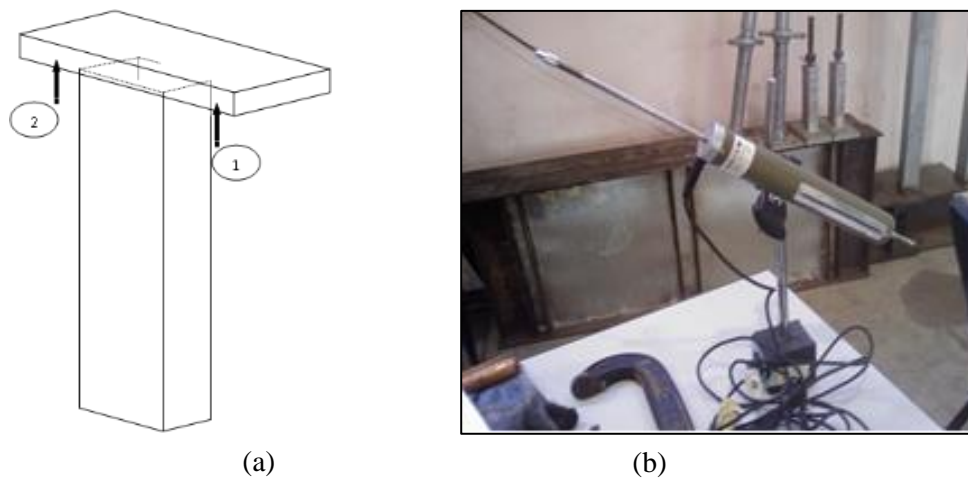


Figure 1. (a) The position of transducer (b) LVDT.

2.1.2. Test set-up

The stub column must be uniformly strained in compression over the entire section during test. To do so, a spherical base is adjusted before loading such that end faces, which are finishing flat, of the specimen keep full contact with the bearing plates, after which the rotation of the spherical base restrained by steel wedges. Linear Variable Differential Transducers (LVDT) was attached at top of bearing plate to determine the axial displacement when the load is applied to compress. Test setup of a stub column is shown in Figure 2.



Figure 2. Test setup of stub column.

The load increments in the elastic region should be less than 10% of the expected yield load [5]. In this experiment, the chosen load rate was 20N/sec.

2.2. Tensile test

Tensile tests were carried to determine the yield strength of the specimen. Yield strength of the material is defined as the stress applied to the material at which deformation start to occur while the material loaded. The determination of the yield strength is necessary because this value is to determine the effective width of stub column then applied into capacities calculation.

2.2.1. Test specimen

In this study, the specimen of test is in accordance with the BS EN 10002-1: 2001. Types of test piece to be used for thin products: sheets, strips and flat between 0, 1mm and 3mm thick. The thickness of specimen used in this study 1mm. The dimension specimen is shown in the Figure 3.

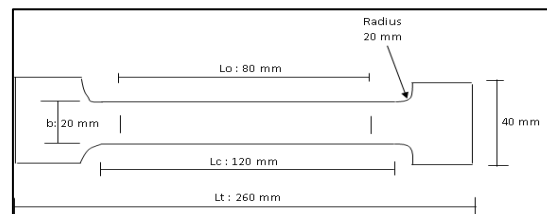


Figure 3. Dimension of test specimen.

2.2.2. Tensile test procedure

A test specimen was grasped at each end by a tensile testing machine and subjected to a tensile axial load. A standard specimen was used for tensile testing for calibration purposes. The specimen is generally a cylindrical rod with a precise diameter, although other specimen geometries can be used to evaluate certain situations. Gauge marks were scribed onto the surface of the specimen at specified distance. The specimen was loaded to a universal testing machine and load was applied to the specimen at a specific rate. As the specimen is axially loaded in tension, the distance between the gauge marks was monitored. This measurement can be made mechanically with an extensometer or optically with digital video.

The stress can be calculated based on the applied load. The change in the distance between the gauge marks can be converted into strain. These two factors can be used in order to plot a graph against each other to form a stress-strain diagram. A stress-strain curve illustrates the relationships between the applied load, the geometry of the part, the material properties of the part, and the reaction of the part to the applied load.

3. Result and discussion

3.1. Tensile stress

Table 2 shows the experimental results of tensile tests, for this study the yield stress used was 345 N/mm².

Table 2. Yield stress of cold-formed plate.

| | Specimen 1 | Specimen 2 | Specimen 3 | Average |
|-----------------------------------|------------|------------|------------|---------|
| Area (mm ²) | 20 | 20 | 20 | 20 |
| Yield load (kN) | 7.15 | 6.78 | 6.78 | 6.9 |
| Yield Stress (N/mm ²) | 357.5 | 339 | 339 | 345 |

3.2. Load vs displacement relationship stub channels under compression

In investigating the performance of the stub channels section, the test results were analyzed in the context of load-displacement profiles, shortening and mode of buckling. At the end of the experiment, it was found that the results of each stub channels section that can sustain are shown in the Table 3.

Table 3. Experimental results of the cold-formed stub channel.

| Specimen No. | Specimen | Maximum load (kN) | Axial Displacement (mm) at Maximum load |
|--------------|---------------|------------------------|--|
| 1 | 75Cx25x20x1 | 20.96 | 0.57 |
| 2 | 150Cx50x25x1 | 20.31 | 0.99 |
| 3 | 225Cx75x25x1 | 20.59 | 0.46 |
| 4 | 300Cx100x25x1 | 20.79 | 1.16 |
| 5 | 375Cx125x25x1 | 25.41 | 0.78 |
| 6 | 450Cx150x30x1 | 27.46 | 1.11 |
| 7 | 600Cx200x40x1 | 21.51 | 0.91 |

Figure 4 shows the load-axial displacement response of Specimen 1. At the 0.57 mm axial displacement, the stub channel could sustain the maximum load of 20.96 kN. After the specimen reached the maximum strength, the load decreased and axial displacement increase. The maximum axial displacement of the specimen was 2.10 mm shorter from the original length.

Figure 5 shows at the 0.99 mm axial displacement of the stub channel the maximum load can sustain was 20.31 kN. After the specimen reached the maximum strength, the load decreased and axial displacement increase. The maximum axial displacement of the specimen is 2.37 mm from the original length.

Figure 6 shows at the 0.46 mm axial displacement of the stub channel the maximum load can sustain was 20.59 kN. After the specimen reached the maximum strength, the load decreased and axial displacement increase. The maximum axial displacement of the specimen is 1.73 mm from the original length. Figure 7 shows at the 1.16 mm axial displacement of the stub channel the maximum load can sustain was 20.79 kN. After the specimen reached the maximum strength, the load decreased and axial displacement increase. The maximum axial displacement of the specimen is 2.17 mm from the original length.

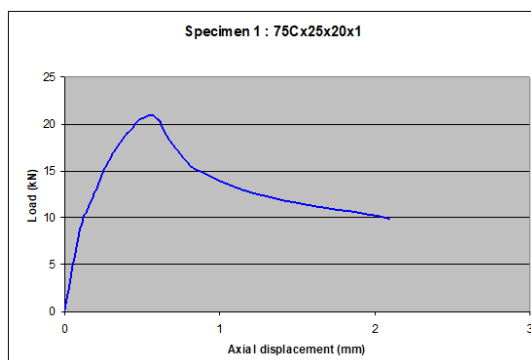


Figure 4. Graph of load versus axial displacement for specimen 1:75Cx25x20x1.

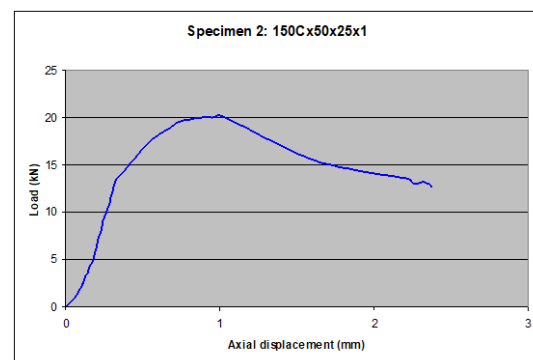


Figure 5. Graph of load versus axial displacement for specimen 2: 150Cx50x25x1.

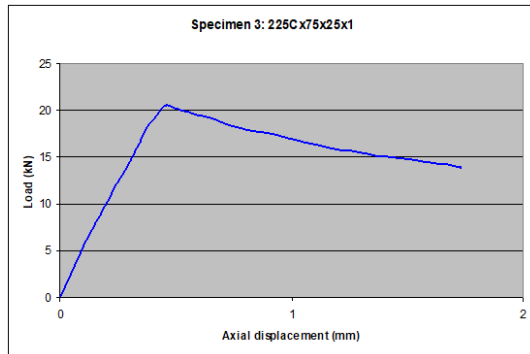


Figure 6. Graph of load versus axial displacement for specimen 3: 225Cx75x25x1.

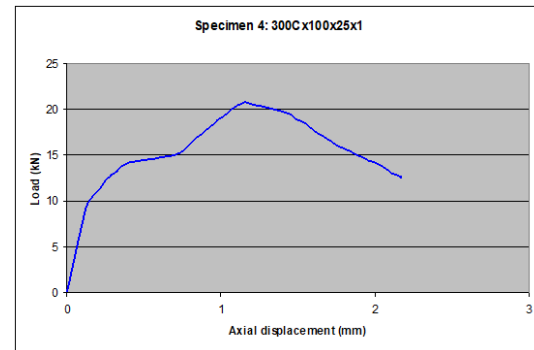


Figure 7. Graph of load versus axial displacement for specimen 4: 300Cx100x25x1.

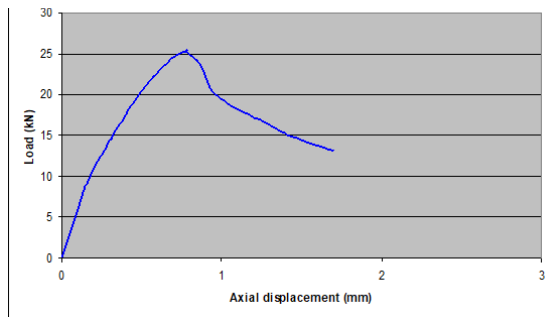


Figure 8. Graph of load versus axial displacement for specimen 5: 375Cx125x25x1.

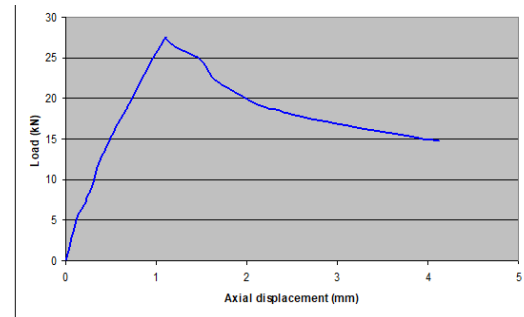


Figure 9. Graph of load versus axial displacement for specimen 6: 450Cx150x30x1.

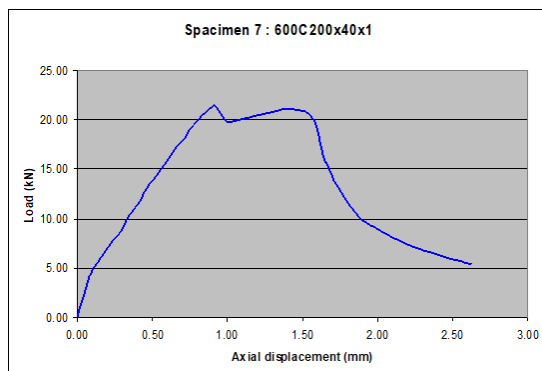


Figure 10. Graph of load versus axial displacement for specimen 7: 600Cx200x40x1.

From Figure 8, it is shown at the 0.78 mm axial displacement of the stub channel the maximum load can sustain was 25.41 kN. After the specimen reached the maximum strength, the load decreased and axial displacement increase. The maximum axial displacement of the specimen is 1.70 mm from the original length. Figure 9 shown at the 1.11 mm axial displacement of the stub channel the maximum load can sustain was 27.46 kN. After the specimen reached the maximum strength, the load decreased and axial displacement increase. The maximum axial displacement of the specimen is 4.12 mm from the original length. From Figure 10 shown at the 0.91 mm axial displacement of the stub channel the maximum load can sustain was 21.51 kN. After the specimen reached the maximum strength, the load decreased and axial displacement increase. The maximum axial displacement of the specimen is 2.62 mm from the original length.

The relationship of load and axial displacement is presented to know the behavior of mode buckling when the load is applied to specimens and to determine the maximum load (ultimate load) that the specimens can sustain before local buckling occurred. The expected load-displacement curve should comprise the post-buckling stage, in which after reaching the critical load, there were still further increased of applied loads until to the maximum load where local buckling take place and the specimens could no longer sustain the load.

From the experimental result, two specimens (150Cx50x25x1 and 300Cx125x25x1) were considered conservative as they achieved the expected curve. For other specimens, the curves showed immediate increased of load until they achieved the maximum load. All the specimens could carry the maximum load up to 20 kN and the range of axial displacement when reaching the maximum load was between 0.5 mm to 1.5 mm. The specimen 375Cx125x25x1 had the maximum load carrying capacity compared to other specimens. When the load increases, the non-linear behavior of load-axial displacement can be seen, most probably due to the on set of local buckling that occurred on the specimens. After the maximum load, the specimens start to unloading condition.

3.3. Load capacity

BS 5950: Part 5: 1987 provide the prediction of load capacity of the specimens. The calculation is based on the effective width approach where the yield stress is assumed to act on the reduced effective area. Then, the classification of element is used to determine the stiffened element and unstiffened element. From there, the load capacity is determined by using the stress formula.

Table 4. Comparison of compression load capacity.

| Specimen No. | Specimen | Load capacity (Experiment) kN | Load capacity (Theoretical) kN | The Ratio (Experimental/ Theoretical Load Capacity) |
|--------------|---------------|----------------------------------|--------------------------------------|--|
| 1 | 75Cx25x20x1 | 20.96 | 20.25 | 1.03 |
| 2 | 150Cx50x25x1 | 20.31 | 23.63 | 0.85 |
| 3 | 225Cx75x25x1 | 20.59 | 21.74 | 0.95 |
| 4 | 300Cx100x25x1 | 20.79 | 22.39 | 0.93 |
| 5 | 375Cx125x25x1 | 25.41 | 22.77 | 1.12 |
| 6 | 450Cx150x30x1 | 27.46 | 23.39 | 1.17 |
| 7 | 600Cx200x40x1 | 21.51 | 24.74 | 0.87 |
| | | | Mean | 0.99 |

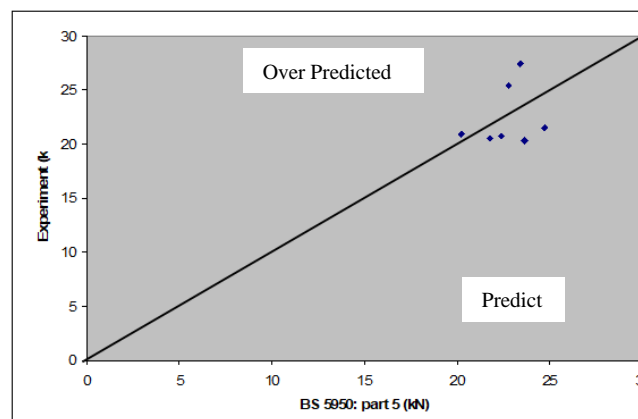


Figure 11. Experiment vs BS 5950:Part 5.

Table 4 and Figure 11 show the comparison between the experimental result and the predicted theoretical using the BS 5950: Part 5: 1987. The mean for the ratio of experimental result to the predicted theoretical were also calculated base on the geometry of the stub channels. Mean value for all specimens is 0.99, where the ratios of the predicted to theoretical result are close to one. The BS 5950: Part 5: 1987 predictions are more conservative. From Figure 11, it can be concluded that four specimens (150Cx50x25x1, 225Cx75x25x1, 300Cx100x25x1 and 600Cx200x25x1) is conservative and close to 1.0. However the prediction for specimen 75Cx25x20x1 is more accurate, close to 1.0 and the experimental result, and associated errors are less than 5% for most specimens. Specimen 375Cx150x25x1 and 450Cx150x25x1 are not conservative, the experimental loads are respectively 12% and 17% higher than predicted result.

3.4. Failure pattern of stub channels column under compression

The load was applied on the specimens incrementally until it failed. Buckling was observed on the specimen as they occurred at every increment. The load corresponding to the appearance of first buckling and the failure load were recorded. Buckling was observed at various positions on the specimens. Mostly the specimens found to be failed by buckling at the top edge and bottom edge of specimens. Figure 12 shows how the specimens buckled for all specimens. Almost in many cases, the buckling occurred at the web which at the stiffened element. Three (3) specimens buckled at the bottom edge and remaining four (4) specimens occurred at top edge. The buckling location can be concluded to occur near the support of the stub channel. The patterns of the buckling show that the unstiffened element of stub channel transferred the load to the stiffened element to cater the load and the occur early, at edge of stub channels.



Figure 12. Failure patterns of stub channels.

4. Conclusion

Buckling behaviour of cold-formed stub channels under compression was studied. The axial load and deformation characteristics of the specimens were measured experimentally. Load capacity predictions using BS 5950: Part5: 1987 are comparable with the experimental values. Five (5) specimens were conservative whereas two (2) specimens unconservative to the mean ratio.

Specimens 150Cx50x25x1 and 300Cx100x2x1 achieved the objective of study. This specimen complied with the expected load-displacement curve and predicted theoretical calculation with experimental result. The pattern of buckling is similar where buckling occurred at the bottom edge of stub channels respectively.

From the engineering principles, the cold-formed stub channel could be considered as an ideal stub column. Meaning that, the specimen is perfectly straight before loading and the load is to be applied through the centroid of the cross section. It is shown that cross section affects the ability of the specimen to sustain applied load.

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