

APPLICATIONS OF BUILT-UP SECTIONS IN LIGHTWEIGHT STEEL TRUSSES

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KEYWORDS

Cold-formed, lightweight, thin-walled, roof trusses, long span, built-up section.

ABSTRACT

Lightweight steel structures have been widely used in the construction industry. It is flexible and thus can be designed to cater for different usages. To enhance the application of cold-formed steel structures, innovative configurations are developed. These include increasing the load bearing capacity of the structure and stretching it over a larger span. Built-up section of lipped channels, either back-to-back or boxed-up for the critical elements of a truss is often adopted when it may have practical limitations in increasing the truss depth. This paper presents some of such applications in the construction industry. The built-up section possesses apparent improvement in lateral stiffness. Although these sections act together, they are currently designed individually. Current design codes do not have comprehensive provision for the design of built-up sections reflecting the improvement in design strength. The modified slenderness ratio for built-up sections in the American Iron and Steel Institute (AISI) North American Specification for the Design of Cold-Formed Steel Structural Members is adopted from researches and recommendations for hot-rolled sections. From literature search, field observation and preliminary test conducted, it reveals that the modification rule can be further developed to better reflect the improvement in the slenderness ratio of the built-up sections.

INTRODUCTION

With the improvement in the research and development works done, application of cold-formed steel structures in the construction industry has increased significantly in the recent years. This is because

cold-formed steel structure has many advantages over other construction methodology. It is lightweight, flexible, higher strength to weight ratio and is easily formed to the required profile shapes. The most common section profiles are Z- (zee) and C- (channel) sections. These sections are commonly used on roof and wall systems, floor decking, framing of residential, industrial, commercial and agricultural buildings.

Cold-formed steel sections behave differently from hot-rolled steel sections. These thin-walled sections are characterized by local instabilities; hot-rolled sections rarely exhibit local buckling. Thus, the slenderness of a section plays an important role in the design of cold-formed steel structures. Local buckling is expected in most cold-formed sections and often ensures greater economy than a heavier section that does not buckle locally. However, the presence of local buckling of an element does not necessarily mean that its load capacity has been reached as it is strengthened by post-buckling strength (edge and intermediate stiffeners).

Current practice to increase the load bearing capacity of a cold-formed steel structure stretching over a vast span is to use built-up section of lipped channels. This section could be either back-to-back or boxed-up. This section is widely used in local projects namely the Trinity Methodist Church, Kuching (Figure 1), the Curtin University of Technology, Miri (Figure 2), the Sarawak International Medical Centre, SIMC, Kota Samarahan (Figure 3) and a food court in Miri (Figure 4) (Mei et al, [1, 2]).



Figure 1: Trinity Methodist Church, Kuching



Figure 2: Curtin University of Technology, Miri



Figure 3: SIMC, Kota Samarahan



Figure 4: Food Court, Miri

In these projects, the primary trusses are required to span up to a maximum clear span of 32m. Under this condition, the major considerations that need to be account for besides load carrying capacity include deflection, lateral stability of the structure and constructability.

Instead of increasing the depth of the truss or using bigger sections, built-up section was adopted. This may be due to space limitation in the design and practicality in construction. This approach utilizes two lipped channels placed back-to-back at the top and bottom chords of a truss as shown in Figure 5. These channels are spaced apart to receive the web members which act as lacing on the structure forming a gap. This configuration is adopted in the design as it will improve lateral stiffness making handling especially lifting for installation becomes easier as seen in Figure 6. Besides that, it also simplifies the connection detailing of the web members to the chord members. The use of gusset plates is eliminated. Figure 7 shows the connections of the web members to the top chord.



Figure 5: Top and bottom chords built-up sections



Figure 6: Lifting of truss



Figure 7: Connections

DESIGN AND CODE PROVISION OF BUILT-UP SECTIONS

While it is apparent that the built-up sections with gap have improved lateral stiffness, the design codes do not present comprehensive guidelines for estimating the modification of slenderness ratio. In the absence of provision in design codes for built-up section using this configuration, practitioners will adopt a conservative design by simply assuming the built-up sections to act as two individual members without modifying the chord slenderness, basing on AS/NZS 4600. Table 1 summarizes requirements of various Codes.

TABLE 1
PROVISIONS FOR BUILT-UP SECTIONS

Code	Material	Remarks
AS/NZS 4600:1996 [3]	Cold-formed	<ul style="list-style-type: none"> • Provision for built-up section without gap only • specify max spacing of welds or screws connections • slenderness of the connected element shall not be less than 0.5 of the slenderness of the built-up I section • do not propose guidelines for modifying slenderness
2007 AISI Specification Section D1.2 [4, 5]	Cold-formed	<ul style="list-style-type: none"> • Provision for built-up section without gap • specify max spacing of welds or screws connections • slenderness of the connected element shall not be less than 0.5 of the slenderness of the built-up I section • propose guidelines for modifying slenderness adopted from researches on hot rolled section
AS/NZS 4100:1998 [6]	Hot rolled	<ul style="list-style-type: none"> • Provisions for laced and battened columns • provisions for built-up member with and without gap • detail provisions for design of batten members • guidelines on minimum slenderness of batten members • minimum dimensional requirements especially that of minimum thickness exceed material thickness of cold-formed steel

RECENT RESEARCHES OF BUILT-UP SECTIONS

Literature search further reveal that there are researches conducted to further understand the modification of slenderness ratio of built-up sections in hot-rolled and cold-formed steel. Liu et al [7] investigated the slenderness ratio of built-up compression members and tested various configurations of built-up hot rolled channel sections. They concluded that the load bearing capacities calculated using modified slenderness is conservative provided the required connector spacing is met.

Whittle and Ramseyer [8] identify that the estimated load bearing capacities of axially loaded, cold-formed, built-up section from AISI Specification is based on research adopted from hot rolled steel. Stone and LaBoube [9], Brueggen and Ramseyer [10], Sukumar et al [11] and Whittle and Ramseyer [2] all concluded that the axial load capacities estimated using modified slenderness ratio in the AISI Specification is conservative.

Young and Chen [12] show that the design strength of built-up closed sections with intermediate stiffeners is consistently higher than that of a single member. The experimental results also show an

average improvement of 19% load bearing capacities compared to that of a single member. The research findings are summarized in Table 2.

TABLE 2
RESEARCH IN BUILT-UP COMPRESSION MEMBERS

Researcher	Topic	Conclusions
Sukumar et al.	Buckling behavior of I-shaped built-up members formed with angles	AISI design strengths found slightly conservative or equal to the actual strength. Developed design curve for built-up columns undergoing distortional or local-distortional buckling
Stone and LaBoube	Behavior of cold-formed steel built-up I-sections (studs) formed with c-channels and screw attachments	AISI Section D1.2 (slenderness modification) is conservative on average for thin members and exceedingly for thick members
Brueggen and Ramseyer	Buckling of closed and open- built-up sections with channels and intermediately welded attachments	AISI Section D1.2 on average conservative for compact sections but potentially unconservative for members with slender elements
Whittle and Ramseyer	Behavior of cold-formed steel built-up closed sections formed with intermediately welded c-channels	Use of the modified slenderness ratio was exceedingly conservative. Capacities based on the unmodified slenderness ratio and C4.5 fastener and spacing provisions were consistently conservative
Young and Chen	Behavior of cold-formed steel built-up closed sections with intermediate stiffeners using self-tapping screws	Use of direct strength method to obtain the buckling stresses is conservative using single section. Experimental results of the built-up section show an average improvement of 19% compared to the design of the member individually

PRELIMINARY EXPERIMENT ON BUILT-UP SECTIONS

As it has been concluded by many researches that the estimation of load bearing capacities of built-up section is conservative, a simple preliminary test was carried out at the Curtin University of Technology, Sarawak Campus to assess the effect on load bearing capacities by varying the spacing of connectors. Two C10016 lipped channel connected back-to-back by self-drilling screws were used to build the built-up section. The nominal dimensions for C10016 lipped channel are web width of 100mm, lip of 20mm and flange width of 50mm with 1.6mm thickness. In the preliminary test, the spacing of the connectors used was greater than that specified in the AS4600 standard. Observation of the experiment shows that buckling occurs in between the connectors. This was because the spacing of the connector was too big and there was no rigidity in the connectors (two screws per stitching). The connected elements behaved as individual column and as expected, there was no strength improvement in the built-up section. Figure 8 shows the mode of buckling of the specimen.



Figure 8: Buckling mode of column

DISCUSSION

The theory adopted in the AISI specification on the modified slenderness ratio was based on research done on hot-rolled steel. Researches show that the performance of a structure is improved using built-up sections (Salem et al [13], Young and Chen [12] and Whittle and Ramseyer [8]). The modified slenderness ratio recommended in AISI was proven to be conservative for cold-formed built-up members. Current researches identified the shortcoming and hence further researches is necessary to propose a design rule change to better estimate the load bearing capacities of built-up cold-formed steel sections.

Furthermore, the Codes do not have comprehensive provisions to cater for various configurations of built-up sections such as back-to-back with gap, battened and laced members as shown in Figure 9. It hence does not give practitioners flexibility to vary the spacing of the lace and battens to suit design requirements and limitations. These provisions are needed as the application of cold-formed steel is becoming innovative and demanding.

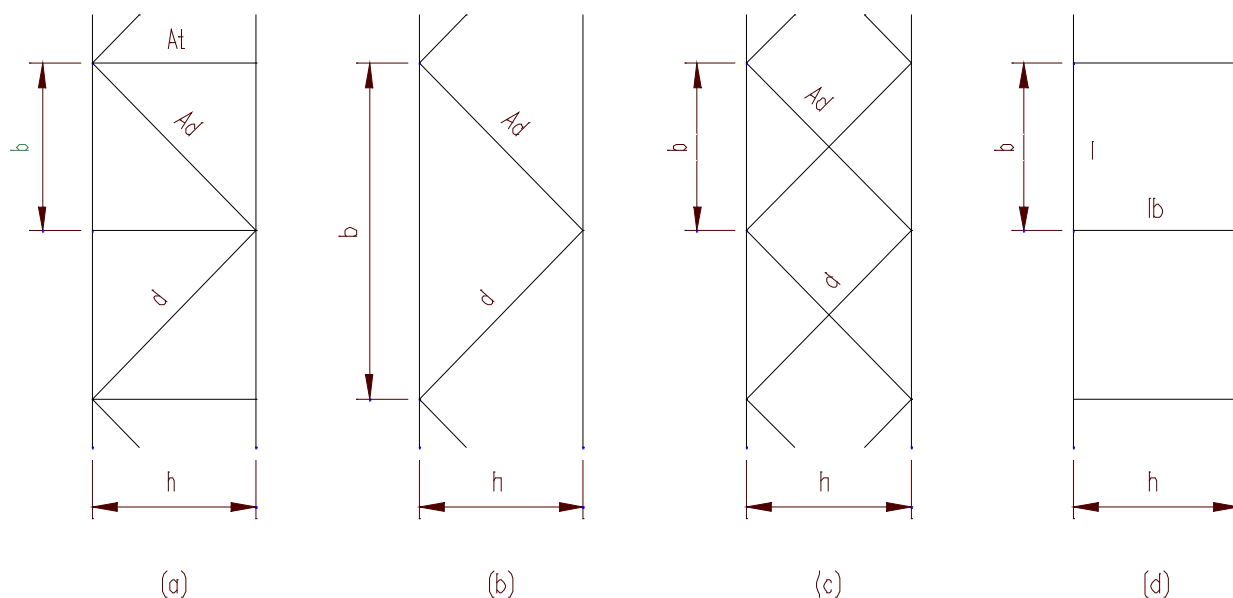


Figure 9: Different types of lacing (Shu and Fan [14])

Salem et al [13] demonstrate that load bearing capacities of the column depends on the following factors:

- gap in between the chords – the greater the gap, the lower the slenderness of the column.
- connectors spacing – load bearing capacities is inversely proportional to the spacing of connecting member
- batten plate thickness and width - the stiffer the battens, the higher it is the strength of the column.

Salem's research finding confirmed the field observation mentioned earlier. The configuration of the built-up sections will ultimately affect the load bearing capacities estimate of the section. It is evident from Salem et al that the buckling capacity of a built-up section shall be a function of the gap in between the chord, spacing and stiffness of connectors.

CONCLUSION

The demand of the construction industry call for innovation in the design of cold-formed steel structures and built-up sections is one such innovation. There are insufficient guidelines in the current codes and design standards to better estimate the load bearing capacities of built-up sections. Research show that the modified slenderness ratio used is conservative and inappropriate. More design rules is needed to provide guidelines for the design of built-up sections such as back-to-back without gap, back-to-back with gap, battened, and laced columns. The load bearing capacities of built-up sections is governed by the gap in between the chords, spacing and stiffness of connectors. Rules for modification of the design of cold-formed steel needs to be developed to better reflect the behavior of cold-formed built-up sections.

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