Interdependence between Structural Engineering and Construction Management
Edited by Ozevin, D., Ataei, H., Modares, M., Gurgun, A., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-6-2

DEVELOPING A METHODOLOGY FOR USING THE CONTINUOUS STRENGTH METHOD FOR BUILT-UP I-SECTION

RAQUIBUL HOSSAIN, SHADMAN SAKIB, and MALEHA ALAM

[1]*Dept of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh*

Built-up steel sections are widely used in the construction industry due to their wide range of compression resistance. The main objective of the study is to introduce an efficient and economic design methodology for built-up I-sections by using the Continuous Strength Method (CSM) equations. These I-sections are made from two C-sections with bolts spaced at a specific interval. This methodology includes the calculation of individual capacity of C-sections using the CSM base curve and conversion that to bolted I-sections by using I-section properties. The predicted capacities show that the modified application of CSM equations can predict compressive resistance with high accuracy for built-up I-sections. Though the effect of bolt spacing is not considered in this study, the proposed methodology paves the path for deriving CSM equations for built-up sections.

Keywords: Bolted, Base curve, Cross-section, CSM, Steel.

1 INTRODUCTION

Built-up sections are comprised of two or more standard sections. They are required when the desired capacities and configuration cannot be achieved by a standard or hot rolled section. Besides, it is sometimes difficult to produce required sizes in standard sections. In that case, built-up sections offer alternative options against standard sections.

Built-up sections can be bolted or welded. For achieving economy and ease in construction, bolted sections are preferable compared with welded sections. It can provide acceptable strength, durability and safety. Besides, it is more effective in consideration of time, cost and installation.

This paper focuses on the study of compressive resistance of the bolted steel sections using the Continuous Strength Method (CSM) equations. This study may provide greater significance in increasing the design efficiency of bolted steel sections than standard CSM (Ahmed *et al.* 2016).

2 THE CONTINUOUS STRENGTH METHOD (CSM)

The Continuous Strength Method (CSM) is a strain-based design approach. Gardner (2008) first introduced the term 'Continuous Strength Method' and made the technique more generalized for easy applications. It has already been validated for stocky and slender standard sections (Gardner and Afshan 2013, Ahmed *et al.* 2016).

The CSM has two major parts: a base curve and a material model. A design base curve establishes a continuous relationship between the normalized cross-section deformation capacity

$\epsilon_{csm} / \epsilon_y$ and the cross-section slenderness ($\bar{\lambda}p$) (Gardner and Afshan 2013). It is suggested to determine the cross-section slenderness ($\bar{\lambda}p$) using the elastic buckling capacity $\sigma_{cr,cs}$ and 0.2% proof stress $\sigma_{0.2}$ (Gardner and Afshan 2013). To tackle the observed significant post-buckling of a slender cross-section, a new parameter called Equivalent Elastic Deformation Capacity $\epsilon_{e,ev}$ was also introduced recently by modifying the CSM equations by Ahmed *et al.* (2016). Equivalent elastic deformation capacity $\epsilon_{e,ev}$ is a function of ϵ_{csm}.

Material Model is used to determine the cross-section resistance in combining with the strain measure (Ahmed *et al.* 2016). Using the material model, the limiting buckling stress *fcsm* for the cross-section can be calculated. The final cross section resistance in compression *Nc,rd* is estimated as recommended in *EN 1993-1-4, Eurocode 3*.

3 CUFSM SOFTWARE

CUFSM (Li and Schafer 2010) is finite strip elastic buckling analysis application. The use of finite strip analysis has the unique capability to provide complete and relevant stability. Design and hand methods that are traditionally used for “plate” structures often ignore compatibility at plate junctures and usually provide no means to calculate a variety of important buckling modes such as distortional buckling. CUFSM allows all elastic buckling modes of a structure to be quantified and examined. This software was used by Ahmed *et al.* (2016) to obtain $\sigma_{cr,cs}$ in order to calculate f_{csm} for slender sections.

4 EXPERIMENTAL STUDIES

A total number of 21-collected test results (Stone and LaBoube 2005, Lue *et al.* 2006, Liu *et al*. 2009) for both stocky and slender I-sections (bolted) were used to conduct the study.

5 PROPOSED METHODOLOGY

The compression resistance $N_{standard\text{-}csm}$ of the built-up I-section was first calculated using the CSM formulas proposed by Ahmed *et al.* (2016). It was observed that there was large variation between test results and estimated values as shown in Figure 1 ($N_{standard\text{-}csm}/N_{test}$).

To improve the prediction capability, a new methodology is developed. Firstly, the critical stress $\sigma_{cr,cs}$ of each C-section is determined using CUFSM software (Li and Schafer 2010) instead of calculating the value for the I-section. Based on these $\sigma_{cr,cs}$, cross-section slenderness ($\bar{\lambda}p$), strain ratio $\epsilon_{csm}/\epsilon_y$, equivalent elastic deformation $\epsilon_{e,ev}$ and buckling stress f_{csm} were calculated based on CSM formulation (Ahmed *et al.* 2016).

Cross-section compression resistance for individual channel section $N_{c,rd\ (C-section)}$ was determined considering only C-section by multiplying f_{csm} and the area of C-section $A_{(c\text{-}section)}$. Then cross-section compression resistance for built-up I-section $N_{c,rd\ (I-section)}$ was calculated using Eq. (1).

$$N_{c,rd\,(I-\mathrm{section})} = 2 \times N_{c,rd\,(c-\mathrm{section})} \tag{1}$$

Buckling resistance of columns was calculated according to the proposed equations of *EN 1993-1-4, Eurocode 3*. Elastic critical buckling capacity N_{cr} was determined using the moment of inertia of the whole I-section using Eq. (2). $\bar{\lambda}csm$ was then calculated using the area of C-section $A_{(c\text{-}section)}$ and elastic critical buckling capacity N_{cr} using Eq. (3). The buckling reduction factor (χ) was calculated for both X-axis and Z-axis. Buckling resistance of the column $N_{b,rd\ (I-section)}$ was determined for both axis using Eq. (4). Minimum of $N_{c,rd\ (I-section)}$, $N_{b,rd-x\ (I-section)}$ and $N_{b,rd-z\ (I-section)}$ was taken as the cross-section resistance of the built-up section $N_{modified\text{-}csm}$.

$$N_{cr} = \pi^2 \times E \times \frac{I_{(I\text{-section})}}{L_e^{\,2}} \tag{2}$$

$$\bar{\lambda}_{csm} = \sqrt{\frac{A_{(c\text{-section})} \times f_{csm}}{N_{cr}}} \tag{3}$$

$$N_{b,rd(I\text{-section})} = \chi \times N_{c,rd(I\text{-section})} \tag{4}$$

6 PARAMETER SELECTION

In the modified CSM, the value of material partial safety factor γ_{M0} was taken as 1.0 that is less than 1.10 according to *EN 1993-1-4*, *Eurocode 3* and the imperfection factor α was taken as 3.0 that was proposed by Lecce and Rasmussen (2016). The values of a and b for calculating equivalent elastic deformation $\in_{e,ev}$ were taken as 3.05 and 3.00 for I-section under axial compression proposed by Ahmed *et al.* (2016).

7 DATA ANALYSIS WITH THE CSM

The collected test data mentioned in section 4 were used for evaluating the proposed methodology ($N_{modified\text{-}csm}/N_{test}$) as summarized in Table 1 and shown in Figure 1. Comparison between estimated compression resistance of built-up columns by respected method and test values in Figure 1 shows that variations are within 20% mostly that are more accurate and less scattered than the values calculated from standard CSM (Ahmed *et al.* 2016). In this study, effect of bolt spacing was ignored which may cause non-conservative result for proposed methodology. Further research will be conducted to include the effect of bolt spacing to make the methodology more accurate and reliable.

Table 1. Performance evaluation of proposed methodology.

Section ID	Specimen Description	$N_{modified\text{-}csm}/N_{test}$	$N_{standard\text{-}csm}/N_{test}$	Reference
1	2C75*6.9, bolted 4@52.5cm	1.03	0.59	*Liu et al.* (2009)
2	2C75*6.9, bolted 2@105.0cm	1.18	0.67	
3	2C100*9.4, bolted 4@52.5cm	1.03	0.71	
4	2C100*9.4, bolted 2@105.0cm	1.18	0.82	
5	2C180 × 21.4/B-B 4 bolted @ 50	1.01	0.88	*Lue et al.* (2006)
6	2C180 × 21.4/B-B 3 bolted @ 67	1.03	0.90	
7	1.372-152 @305	0.94	0.61	
8	1.372-152 @610	0.95	0.61	
9	1.372-152 @762	0.95	0.62	

Table 1 (contd). Performance evaluation of proposed methodology.

10	1.372-152 @914	1.10	0.72	
11	1.372-152 @1016	0.96	0.62	
12	1.372-152 @1067	0.95	0.62	
13	1.155-92 @305	1.06	0.73	*Stone and LaBoube* (2005)
14	1.155-92 @610	1.27	0.87	
15	1.155-92 @914	1.25	0.86	
16	0.88-92 @305	1.11	0.85	
17	0.88-92 @610	0.99	0.76	
18	0.88-92 @914	1.01	0.78	
19	0.84-152 @305	1.01	0.63	
20	0.84-152 @610	0.88	0.55	
21	0.84-152 @914	1.06	0.66	

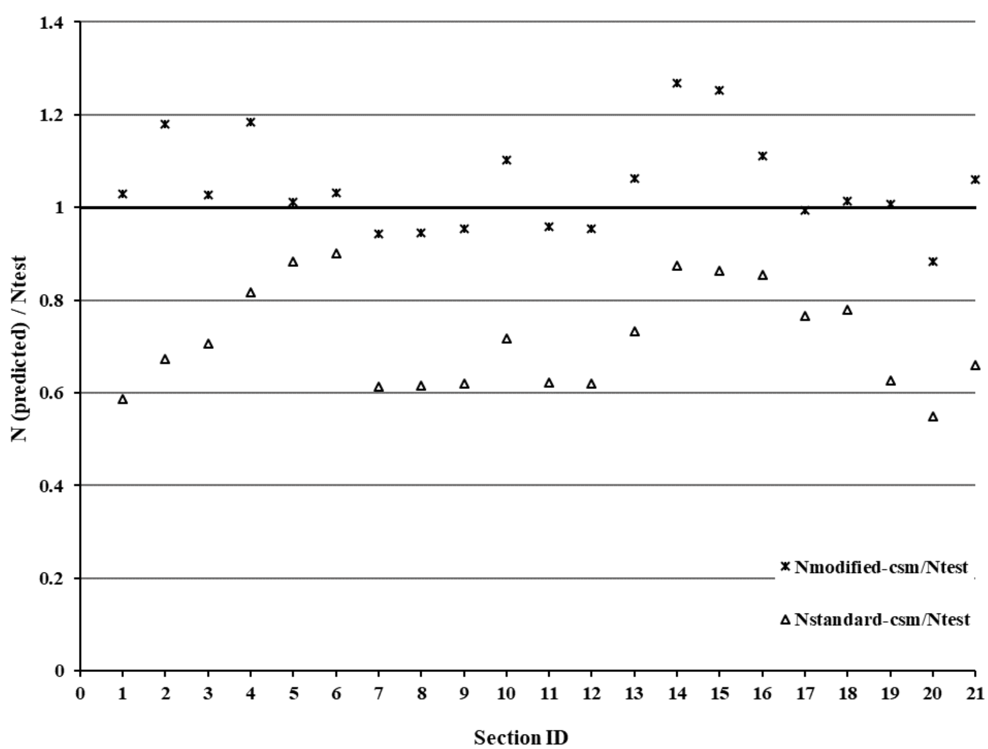

Figure 1. Performance evaluation of proposed methodology.

8 RELIABILITY ANALYSIS

A statistical analysis is presented in Table 2 to show the reliability of the standard CSM to calculate the compression resistance of built-up I-sections. The proposed methodology has the co-efficient of variance (COV) of 0.10 that indicates the better accuracy than standard CSM (Ahmed *et al.* 2016) having the COV of 0.16.

Table 2. Statistics of the predictions.

	$N_{modified\text{-}csm}/N_{test}$	$N_{standard\text{-}csm}/N_{test}$
Mean	1.05	0.72
Std. Deviation	0.10	0.11
COV	0.10	0.16

9 CONCLUSIONS

In this paper, a modified CSM methodology was proposed for built-up (bolted) I-sections. Comparison between test data and predicted values shows that the method offers improved cross section compression resistance than standard CSM. Though the effect of bolt spacing is not considered in this study, the proposed methodology paves the path for deriving CSM equations for built-up sections. Currently a study is being conducted to introduce bolt spacing consideration to make the proposed methodology more effective.

Acknowledgments

The authors would like to express their gratitude to Dr. Mahmud Ashraf, Associate Professor, School of Engineering from Deakin University, Melbourne, Australia and Dr. Shameem Ahmed, Assistant Professor, Department of Civil Engineering from Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh for their valuable suggestions in this research. The study was conducted as an undergraduate thesis in Bangladesh University of Engineering and Technology.

References

Ahmed, S., Ashraf, M., and Anwar-Us-Saadat, M., The Continuous Strength Method for Slender Stainless Steel Cross-sections, *Thin-Walled Structures*, 107, 362-376, October, 2016.

EN 1993-1-4: Eurocode 3: Design of Steel Structures - Part 1-4: General Rules - Supplementary Rules for Stainless Steels, *European Committee for Standardisation*, October, 2006.

Gardner, L., The Continuous Strength Method, *Proceedings of the Institution of Civil Engineers - Structures and Buildings*, ICE Publishing, 161(3), 127-133, June, 2008.

Gardner, L., and Afshan, S., The Continuous Strength Method for Structural Stainless Steel Design, *Thin Walled Structures*, 68, 42-49, July, 2013.

Lecce, M., and Rasmussen, K., Distortional Buckling of Cold-Formed Stainless Steel Sections: Finite-Element Modeling and Design, *Journal of Structural Engineering*, 132(4), April, 2006.

Li, Z., and Schafer, B., Buckling Analysis of Cold-formed Steel Members with General Boundary Conditions Using CUFSM: Conventional and Constrained Finite Strip Methods, Missouri University of Science and Technology, 2010.

Liu, J., Lue, D. M., and Lin, C. H., Investigation on Slenderness Ratios of Built-up Compression Members, *Journal of Constructional Steel Research*, Elsevier, 65(1), 237-248, January, 2009.

Lue, D. M., Yen, T., and Liu, J., Experimental Investigation on Built-up Columns, *Journal of Constructional Steel Research*, 62(12), 1325-1332, December, 2006.

Stone, T., and LaBoube, R., Behavior of Cold-formed Steel Built-up I-sections, *Thin-Walled Structures*, 43(12), 1805-1817, December, 2005.