Review on Impacts of Geometric Imperfections on Behavior of Cold-Formed Structural Members

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Abstract. Cold-formed structural members have been demonstrated to be highly sensitive to buckling modes due to their small thickness. Cold-formed sections have been identified to exhibit significant geometric imperfections which have been illustrated to significantly affect the stability and should be considered in structural analyses of such cold-formed structural members. Their effects were presented in a variety of previous investigations, but these obtained results were still discrete without general evaluations. Therefore, this paper will provide an overview on the impacts of various imperfection components on the behavior of cold-formed structural members. Subsequently, several previous investigations on structural behaviors of cold-rolled structural members were summarized and thoroughly analyzed to enhance understanding of the influence of each geometric imperfection component. It was found that sectional imperfection components should be considered in the analyses for short and intermediate structural members whereas global imperfection components should be included in the analysis of long structural members. Also, bucking behaviors of a structural member were governed by combinations of various imperfection components instead of any single component. These findings will be the base for future investigations of such members under the effects of geometric imperfections.

Keywords: Impacts · Geometric Imperfections · Behaviour · Cold-formed Structural Members

1 Introduction

Geometric imperfections can be observed in cold-formed structural members due to unavoidable factors in the manufacturing, transportation, and assembly processes. Considered as thin-walled structures, cold-formed structural members are highly sensitive to various forms of instability influenced significantly by geometric imperfections. Therefore, addressing geometric imperfections in the analysis of cold-formed structural components is essential. These geometric imperfections are categorized into global and sectional imperfections corresponding to different buckling modes. Global imperfections include initial twist (G_3) and flexural components (G_1 and G_2), while sectional imperfections involve deformations of flat sections, including local imperfections (d_1) and distortional imperfections (d_2) (refer to Fig. 1). The influence of geometric imperfections

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leads to a gradual buckling occurrence from pre-buckling, buckling to post-buckling, which makes the unclear buckling point.

These geometric imperfections are required to measure on the actual specimens for investigations. A variety of methods have been employed for this measurement, including the use of displacement gauges [1], optical observation [2], strain measurement devices [3], two-dimensional and three-dimensional laser scanning devices [4–6], and imaging devices [7]. The geometric imperfections are processed to incorporate them into structural analysis models. This processing procedure is detailed in the report by Pham et al. [8]. The results of integrating geometric imperfections into the analysis model are illustrated in Fig. 2.

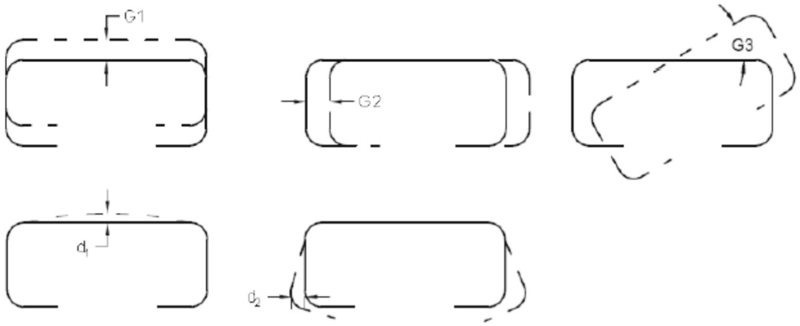


Fig. 1. The representatives of global and sectional geometric imperfections

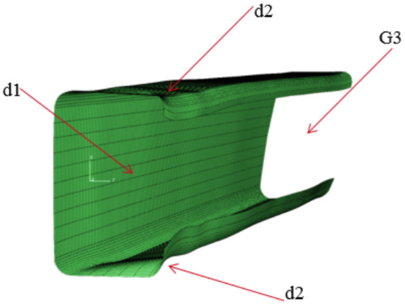


Fig. 2. Actual geometric imperfections of a specimen

Figure 2 illustrates that the geometric imperfections of cold-formed structural members are significant, impacting both their behavior and strength. Therefore, these parameters need to be carefully examined and incorporated into structural analyses in studies related to this type of structure.

The paper focuses on providing a comprehensive overview regarding the influence of geometric imperfections on the behavior of cold-formed steel or aluminum structural members. The aim is to enable readers to gain a deeper understanding of the impact of these parameters. Subsequently, the paper thoroughly presents the behavioral analysis of cold-formed aluminum columns influenced by geometric imperfections, based on the investigated results conducted by Pham [9–11]. Based on these results from the previous investigations, recommendations can be given for the consideration of geometric imperfection components in the buckling analyses of cold-formed structural members.

2 Overview on the Impact of Geometric Imperfections on the Behavior of Cold-Formed Structural Members

Numerous studies have examined geometric imperfections and their impact on the capacity and behavior of cold-formed steel structural members. Pi and Trahair's have investigated the influence of torsional geometric imperfections on cold-formed steel channel or Zed beams [5, 12–15]. These studies have highlighted the effect of the twist direction on the strength of investigated beams, whereas this twist direction was determined by the initial twist geometric imperfections (G_3). Dubina and Ungureanu's study [16] also explored the influence of the initial twist (G_3) and flexural imperfections (G_1); and it was found that these two components significantly affect the bending capacity of the examined structural members, while the sectional geometric imperfections have a negligible impact and can be disregarded. Subsequently, Dinis [17] investigated the separate impact of two sectional geometric imperfection components (d_1) and (d_2) on the post-buckling behavior of cold-formed steel channel columns. The study revealed that the imperfection component (d_2) significantly affects the capacity of the investigated sections. Schafer and Zeinoddini [18] examined the influence of geometric imperfection (d_1) on the strength of columns and provided design recommendations. Katarzyna and Andrzej [19] conducted a stability analysis of cold-formed steel sigma section columns influenced by both overall and local geometric imperfection components. The research results indicated a 20% reduction in the column capacities due to overall imperfections and only a 10% reduction due to local imperfections. Dominik et al. [20] developed a probabilistic approach to geometric imperfections to study the instability behavior of eccentrically loaded I-section columns. Andrei et al. [21] conducted sensitivity analyses to identify the most critical geometric imperfection shapes affecting the compressive strength of perforated steel columns.

Bassem and Hanna [22] conducted a study to examine how geometric imperfections affect the ultimate moment of cold-formed sigma section beams. The investigation indicated that compression flange sectional imperfections significantly influence the performance of short and medium-length beams, while longer beams are more critically affected by global imperfections Chao and Yong-Lin [23] examined the impact of imperfections (G_1) on the capacity of box-shaped columns. Random values were generated based on collected data, and these values were then input into the analytical model to obtain the limit load values. Unfavorable geometric imperfections were proposed to obtain detrimental capacities. Dinis et al. [24] studied the behavior of cold-formed steel channel columns influenced by global imperfections and sectional imperfections (d_2). The investigated results served as a basis for identifying the most unfavorable imperfections, which were subsequently used in numerical models. Additionally, studies also pointed out that the influence of geometric imperfections varies between beams and columns. Sectional imperfections have negligible effects and can be ignored in beam models [12, 16, 25, 26], whereas they should be considered in column models [27–32].

Regarding the geometric imperfections in aluminum cold-formed structures, research on the influence of geometric imperfections is still limited, as this type of structure is relatively new worldwide. Pham [33] investigated the impact of geometric imperfections on the strength of aluminum cold-formed members under compression or bending subject to global buckling. Detrimental modes of geometric imperfections were suggested for further extensive studies. Pham [9, 10] also examined the influence of various geometric imperfections on the behavior and capacity of short and intermediate lengths of aluminum cold-formed columns.

A review of research studies on geometric imperfections in cold-formed steel and aluminum members has been reported. This allows the readers to have an overview of the influence of geometric imperfections on the behaviors of cold-formed structural members. To better understand of these influences, the paper also analyses several research results from Pham [9–11], which explored the influence of various geometric imperfections on the behavior and capacity of cold-formed structural columns regarding their lengths as presented in Sect. 3.

3 Summary and Analysis of the Influence of Geometric Imperfections on the Behavior and Capacity of Cold-Formed Structural Columns

The paper summarizes studies conducted by Pham [9–11] on the impact of geometric imperfections. Geometric imperfection data were collected from the Cold-formed Aluminium Structure Project with the reference number ARC LP140100863, carried out at the University of Sydney, Australia. Based on the results of studies on the influence of geometric imperfections [27–32] as presented in Sect. 2, various sectional imperfection modes were examined for short and intermediate-length columns corresponding to local and distortional bucklings, while global imperfections were considered for long columns in the case of global buckling.

3.1 Short and Intermediate-Length Columns

The geometric imperfections considered in the study include local and distortional imperfection modes. These two types are combined to create various model shapes, as shown in Fig. 3 for short columns and Fig. 4 for intermediate columns, where L and D stand for local and distortional imperfection components respectively. The obtained results depicting the behavior of the members and average limit load values are illustrated in Figs. 5 and 6.

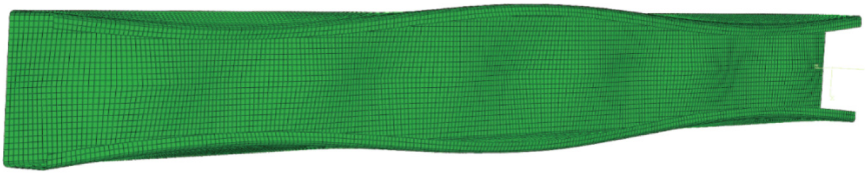
For short columns, the obtained results are reported as following:

- The results of models 1.2 and 1.3 are higher than the other two models, corresponding to cases where the signs of local and distortional imperfections are opposite. Models 1.1 and 1.4 provide detrimental results with both local and distortional imperfections having the same signs, exhibiting lower strength by up to 8% compared to the strength

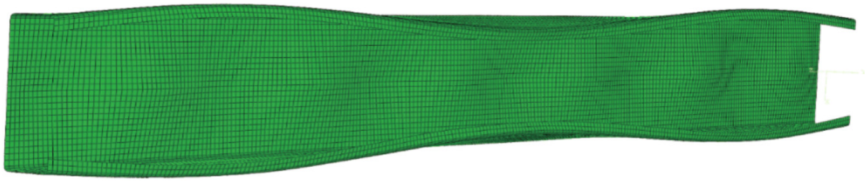
(a) Model 1.1: L (+) D (+) (b) Model 1.2: L (+) D (-)

(c) Model 1.3: L (-) D (+) (d) Model 1.4: L (-) D (-)

Fig. 3. Sign conventions of short column models. Note: L and D stand for local and distortional imperfection components respectively.



(a) Model 2.1: D (+)



(b) Model 2.2: D (-)

Fig. 4. Sign conventions of intermediate columns. Note: D stands for the distortional imperfection component.

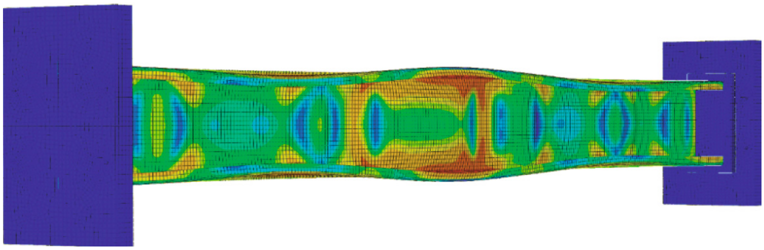
of the former models. Therefore, the later models are considered in the development of numerical investigations to propose design recommendations.

- Fig. 5 illustrates the sectional behavior depending on the direction of the local imperfection. These models exhibit the same deformation behaviors when they have the same direction of local imperfection.

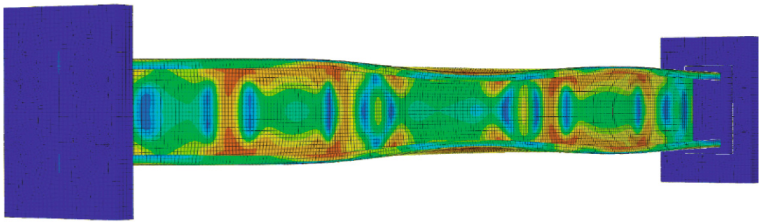
(a) Model 1.1: L (+) D (+) (Capacity: 129 kN) (b) Model 1.2: L (+) D (-) (Capacity: 137 kN)

(c) Model 1.3: L (-) D (+) (Capacity: 132 kN) (d) Model 1.4: L (-) D (-) (Capacity: 126 kN)

Fig. 5. Behavior and average strength of short columns.



(a) Model 2.1: D (+) (Capacity: 104 kN)



(b) Model 2.2: D (-) (Capacity: 102 kN)

Fig. 6. Behavior and average strength of intermediate columns.

- For intermediate columns, the obtained results are reported as following:
- Although the results of model 2.2 are slightly lower than those of model 2.1, the difference is not significant, being approximately 1%.
- Fig. 6 depicts the sectional behavior depending on the direction of the distortional imperfection. The model exhibits different behaviors as the directions of distortional imperfections changes.

The research results from Pham [10] also indicate that the influence of imperfection values on the capacity of short and medium-length columns is negligible and can be disregarded in the design recommendations. Further details can be found in Pham's work [10].

3.2 Long Columns

The configuration model of the long aluminum column is illustrated in Fig. 7 under boundary conditions allowing the column to rotate around the y-y axis. The geometric imperfection (G_1) attributed to this component is significant in the research model, as discussed in Pham [11]. For long columns, a nominal eccentricity value is determined as presented in Pham [11]. Due to the asymmetry of the cross-section about the y-y axis, two cases of eccentricity (E) and geometric imperfection (G_1) are defined as shown in Fig. 8.

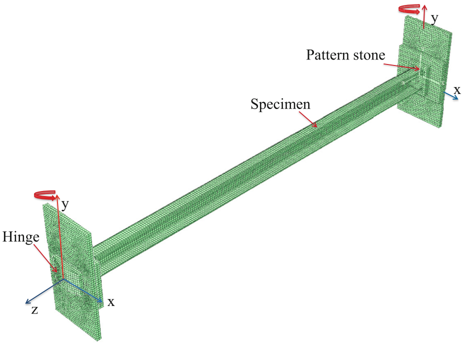


Fig. 7. Configuration model for long columns.

Based on the investigated results presented by Pham [11], several remarks are made as follows:

- The most detrimental loading condition is specified as the eccentricity E has a positive value E(+) and the flexural imperfection has a negative value G_1(-).
- The impact of imperfection should be considered in the proposed design according to the regulations of American Specification [34] with a coefficient of variation (CoV) equal to 0.2, as analysed in Pham's work [11].

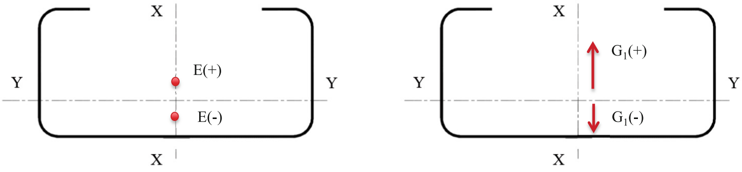


Fig. 8. Sign conventions of eccentricity and flexural imperfections.

4 Conclusions

The paper provides an overview of investigations and related studies on the influence of geometric imperfections on the behavior of cold-formed steel and aluminum structures. Also, several studies regarding the impact of various modes of geometric imperfections on the behavior and capacity of cold-formed aluminium columns are summarized and analyzed with a variety of column lengths. Remark conclusions can be given as follows:

Sectional imperfection components should be incorporated in the buckling analyses for short and intermediate structural members whereas global imperfection components can be included in the simulation models for long structural members.

A combination of geometric imperfection components should be considered in the buckling analyses to get the detrimental output instead of only using the single imperfection component.

These remarks are recommended for further investigations of cold-formed structural members with the consideration of geometric imperfections.

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