Available online at www.sciencedirect.com
SCIENCE DIRECT®

Journal of Constructional Steel Research 62 (2006) 605–613

JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH

www.elsevier.com/locate/jcsr

Buckling lengths of irregular frame columns

Konuralp Girgin*, Gunay Ozmen, Engin Orakdogen

Faculty of Civil Engineering, Istanbul Technical University, Maslak 34469, Istanbul, Turkey

Received 27 September 2004; accepted 28 September 2005

Abstract

In several design codes and specifications, simplified formulae and diagrams are given for determining the buckling lengths of frame columns. It is shown that these formulae may yield rather erroneous results, especially for irregular frames. This is due to the fact that the code formulae utilise only local stiffness distributions. In this paper, a simplified procedure for determining approximate values for the buckling loads of both regular and irregular frames is developed. The procedure utilises lateral load analysis of frames and yields errors on the order of 5%, which may be considered suitable for design purposes. The proposed procedure is applied to several numerical examples and it is shown that all the errors are in the acceptable range and on the safe side.

Keywords: Buckling load; Buckling length; Effective length; Sway mode; Unbraced frames; Irregular frames; Isolated subassembly; Design codes

1. Introduction

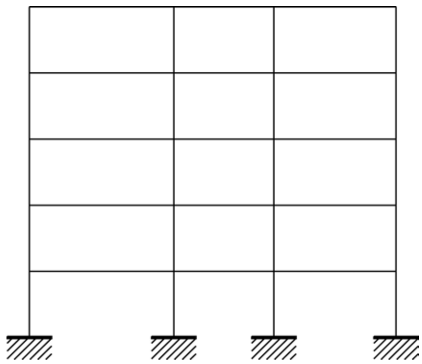
Determination of the buckling (effective) lengths of frame columns is one of the significant phases of frame design. Theoretically, the buckling length of an individual column is determined by calculating the system-buckling load of the frame. Since a full system instability analysis may be quite involved for frames encountered in practical applications, simplified formulae and diagrams are given for determining the buckling lengths of frame columns in most of the design codes and specifications [1,2]. The so-called "isolated subassembly approach" of specifications was originally developed by Galambos [3]. Similar formulae and diagrams exist in other widely applied specifications such as Eurocode 3 and DIN 18800 [4,5].

A major limitation of the methods based on the isolated subassembly approach is that they do not properly recognise the interaction effects of adjacent elements other than those in the immediate neighbourhood of the joints. Hellesland and Bjorhovde have shown that this approach may result in significant errors even for "regular" frames [6]. The errors encountered in the case of "irregular" frames are even greater, as will be shown. Efforts to improve the applicability of the subassembly approach include modifications made by Duan and Chen [7,8] and an iterative procedure developed by Bridge and Fraser [9]. Another method of improvement for unbraced regular frames is the so-called "storey buckling approach", which accounts for the horizontal interaction between columns in a storey [10,11]. White and Hajjar have shown that this approach may result in significant errors in asymmetrical cases [12]. The storey buckling approach has been the subject of several papers, among which the papers by Lui, Aristizabal-Ochoa, and Cheong-Siat-Moy may be highlighted [13–15]. The works of Aristizabal-Ochoa and Cheong-Siat-Moy provide solutions for both braced and unbraced frames as well as "partially braced frames". Aristizabal-Ochoa has further extended his studies to cover three-dimensional structures [16,17]. Another interesting improvement approach is proposed by Hellesland and Bjorhovde, which involves a post-processing procedure using weighted mean values of buckling lengths [18]. It has been stated that it is necessary to consider a wider range of unbraced frames in order to confirm the practical applicability of the proposed method. It is found that the Hellesland–Bjorhovde improvement approach is applicable to irregular frames as well.

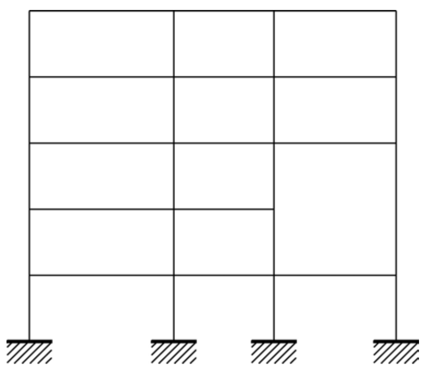
Apart from the above-mentioned improvement studies, certain independent methods for determining an approximate value for the overall buckling load of plane frames are also developed, whereby the lateral displacements due to a fictitious loading is utilised. Among these, the methods developed by

* Corresponding author.
E-mail address: kgirgin@ins.itu.edu.tr (K. Girgin).

0143-974X/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcsr.2005.09.006



(a) Regular frame.



(b) Irregular frame.

Fig. 1. Regular and irregular frames.

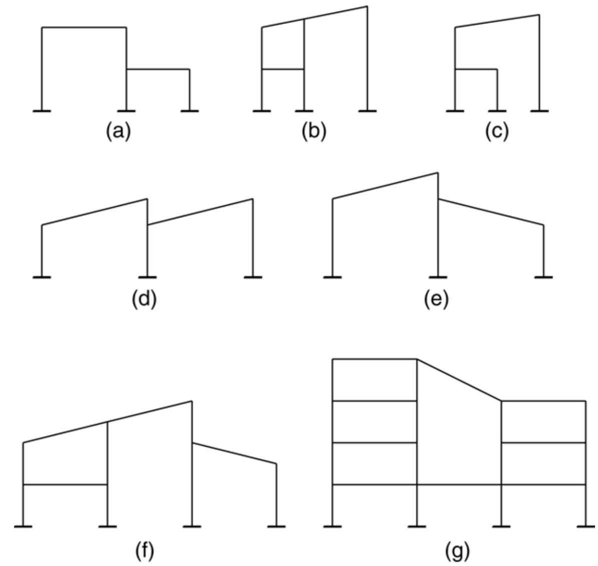
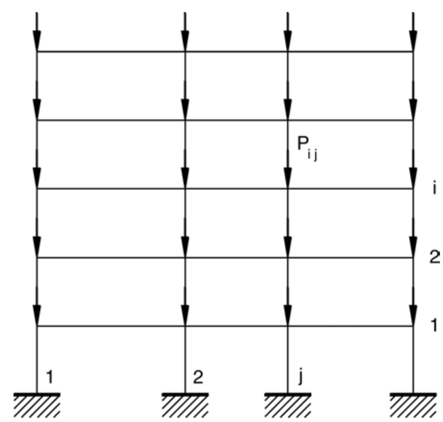
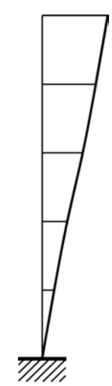


Fig. 2. Irregular frame examples.



(a) Frame and loading.



(b) Buckling mode displacements.

Fig. 3. Multi-storey frame and buckling mode.

Cakiroglu [19] and Stevens [20] are the earliest. The approach of Stevens was later improved by Horne [21]. All of these methods, which are developed for regular frames, are also applicable to irregular frames by means of slight modifications. It is interesting to note that all the fictitious load approaches yield better results compared with the isolated subassembly approach.

Recently, in AISC (1999), the isolated subassembly approach has been abandoned and it has been stated that "... the effective length factor K of compression members shall be determined by structural analysis" [22]. However in several widely used codes (such as Eurocode 3) the subassembly approach and related charts and formulae are still being used.

In this paper, a practical method that is applicable to both regular and irregular frames will be explained and applied to numerical examples. The method, which is developed by using the procedure given by Cakiroglu, is performed by applying a simple quotient based on the results of a fictitious lateral load analysis [19].

2. Irregular frames

A plane frame may be considered as being regular when all the beams are continuous along the width of the frame at all levels, as shown in Fig. 1(a).

The frame becomes "irregular" when the beams of at least one level are curtailed, as shown in Fig. 1(b). In other words, it is not possible to define a "storey" for certain levels of irregular frames. In practice, several frames of this nature exist, as shown in the examples in Fig. 2.

In the case of irregular frames, the error orders of code procedures are far greater, mainly because the isolated subassembly assumptions are hardly satisfied. Moreover, almost all of the improvement studies mentioned above hardly offer any remedy, since most of them use the storey buckling approach and it is not possible to define a storey at certain (or all) levels of an irregular frame. On the other hand, the method presented in this paper offers an approximate but simple solution for both regular and irregular frames.

3. System buckling load of unbraced multi-storey frames

A multi-storey frame that is composed of beams and columns made of linear elastic material is under the effect of vertical loads, as shown in Fig. 3(a).