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Interactive buckling of cable-stiffened steel columns with pin-connected crossarms

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ABSTRACT

Cable-stiffened steel columns can significantly enhance the stability behaviour of ordinary compression columns because of the additional stiffness offered by the pre-tensioned cables and crossarms. Most of the previous studies aimed to investigate the behaviour of stiffened steel columns with four branch crossarm systems; however, the current work focuses on investigating the interactive buckling of cable-stiffened steel columns with pin-connected three branch crossarm system via buckling analysis. The analysis shows that the crossarms remain straight in the antisymmetric buckling mode, which distinguishes them from stiffened columns with rigidly connected crossarms. In addition, the interactive buckling must be considered in nonlinear buckling analyses in some cases to obtain the actual capacities of the stiffened columns. The method to consider the interactive buckling is to introduce asymmetric initial geometric imperfections during buckling analysis; the principle to form the asymmetric initial imperfections is suggested.

1. Introduction

The slenderness ratio is one dominant factor determining the stability behaviour of compression columns. Thus, buckling can be commonly observed in ordinary columns due to the characteristic of the columns being slender. Introducing the pre-tensioned cables to ordinary columns has already been proved to be an efficient way to enhance the buckling behaviour of compression columns [1,2]. Cable-stiffened systems comprise horizontal crossarms placed along the column length and pre-tensioned cables between the crossarm ends and column ends. The horizontal crossarms in conjunction with the pre-tensioned cables offer lateral restraints to the column and potentially improve the buckling behaviour [3]. In this article, the cable-stiffened column, which is also named by prestressed stayed column in other literatures, is an ordinary column stiffened by pre-tensioned cables and crossarms (Fig. 1). In Fig. 1(a), four crossarms are placed in the mid-span of the column, whereas three crossarms are placed rotationally symmetric around the main column in Fig. 1(b).

A cable-stiffened column has been applied in practical engineering where slender supports are required (see Fig. 2) [4]. In addition to the practical application of cable-stiffened columns, intensive research has also been conducted. Hafez et al. explained the reason why the buckling strength of ordinary columns can be enhanced by the pre-tensioned cables [5]. Based on the results in reference [5], Wadee conducted research on the stability behaviour of cable-stiffened columns [6–9], including an interactive buckling analysis, an imperfection sensitive study and optimal prestressing research. Guo proposed a type of buckling-restrained brace based on cable-stiffened steel columns, and the formulas to calculate the elastic buckling load was deduced using the equilibrium method [10]. In addition to the above literature investigating the behaviour of cable-stiffened columns numerically and theoretically, experimental studies have also been conducted. Serra conducted a full-scale experiment to study the buckling strength of cable-stiffened columns [11]. Osofero investigated the buckling behaviour of cable-stiffened columns experimentally, and interactive buckling was observed in that experiment [12]. Martins studied the effect of crossarm layouts and steel strength on the buckling strength of cable-stiffened steel columns [13]. Zhou studied the behaviour of cable-stiffened columns under fire condition, and it was demonstrated that the size of external load considerably affected the fire response of the column [14].

Previous studies [15–18] primarily focused on determining the stability behaviour of stiffened columns with two or four branch crossarms (see Fig. 1(a)), except for work conducted by Li et al. [7]. Li et al. examined the buckling characteristics of cable-stiffened steel columns with three branch crossarms (see Fig. 1(b)). It has been proved that the post-buckling mode of this stiffened column with three branch crossarms is very different from that with two or four branch crossarms

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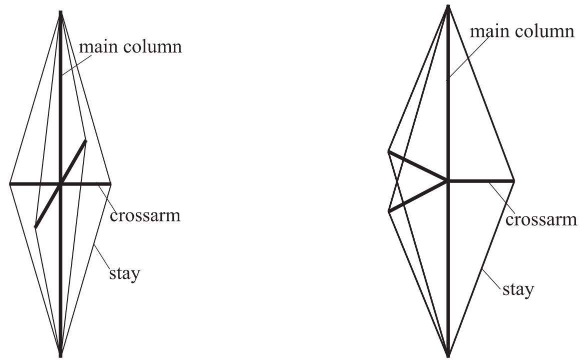

(a) Four branch crossarms (b) Three branch crossarms

Fig. 1. Cable-stiffened columns.

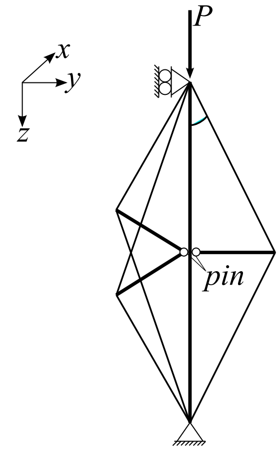

Fig. 3. Geometric configuration of cable-stiffened steel column.

[7]. However, it should be noted that the connection between the columns with the crossarms are rigid in reference [7]. In fact, pin connections between the columns with the crossarms are much simpler than the rigid connections in practical engineering. Meanwhile, it has been demonstrated that the pin connection stiffened column is also an effective system to stiffen ordinary columns [19]. Unfortunately, research on the stability behaviour of cable-stiffened steel columns with pin-connected three branch crossarm systems has not been attempted. As an extension of reference [7], this current work aims to examine the stability behaviour of this pin-connected stiffened steel column. Meanwhile, it should be noted that the interactive buckling of the stiffened steel column is the primary research of this study because the interactive buckling in some cases is the governing one to ensure structural safety.

2. Analytical model

As mentioned above, the analysis object in this study is cable-stiffened steel columns with pin-connected crossarms (see Fig. 3). In this model, three crossarms are rotationally symmetric around the main column; in other words, the angles between the adjacent crossarms are 120°. The two ends of the column are simply supported in this model, and the compressive load is assumed to be concentric. As illustrated in Fig. 3, the crossarms are pin-connected to the main column. Moreover, the connections between the cables and the column or crossarms are also assumed to be pins.

In the current work, circular hollow steel cross-sections are adopted for the main column and crossarms. The sectional and material characteristics of the cable-stiffened steel columns are presented in Table 1. Note that the main column length is selected to be 3000 mm for all the numerical analysis in this study, thus, it is not included in Table 1.

As mentioned before, the primary aim of the current research is to examine the interactive buckling behaviour of cable-stiffened steel columns in which the three branch crossarm systems are pin-connected. To study this interactive buckling behaviour systematically, the crossarm length and cable diameter are varied during the analysis. Table 2 illustrates that the selected crossarm length varied from 150 mm to 450 mm; these five crossarm lengths, represented by a1 to a5, are selected to cover the commonly adopted length range in practical engineering. Similarly, the cable diameters are varied from 1.6 mm to 8.0 mm, which are represented by the symbols F1 to F5.

3. Analytical methodology

3.1. Analysis procedure

Linear buckling analysis, which was aimed to obtain the critical loads and buckling modes, was performed firstly. The buckling modes and critical loads are essential to form initial geometric imperfection and determine the initial cable pretension. Moreover, linear buckling analysis

(a) Stiffened column in West London, UK (b) Stiffened column in Princeton, U.S.A

Fig. 2. Application of cable-stiffened columns.