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Stability of steel columns stiffened by stays and multiple crossarms

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A B S T R A C T

A pre-stressed stayed steel column (PSSC) can effectively enhance the buckling behaviour of compression columns. In the past, researchers have primarily concentrated on examining the behaviour of PSSCs with single-bay crossarms. However, research focused on PSSCs with multiple crossarms is limited. This article aims to investigate the stability behaviour of PSSCs stiffened with multiple crossarms according to geometric analysis in conjunction with finite element (FE) studies. The results show that the critical buckling modes can be complicated due to the introduction of multiple crossarms. Critical buckling deformation similar to three half sine waves can be observed. It has also been demonstrated that interactive buckling can be ignored when determining the actual buckling strength of PSSCs stiffened by multiple crossarms, though it must be considered for PSSCs with single-bay crossarms. The effects of stay diameter and pretension in the stay have been separately investigated, and the results show that the buckling strength of a steel column can be obviously enhanced even if the pretension in stays is quite small, because the stiffness of the stays can be automatically activated by column deformation.

1. Introduction

Global buckling tends to occur in compressed steel columns when they are slender. However, the buckling resistance can be drastically improved by introducing stays and crossarms. The compressed steel column, which is equipped with stays and crossarms, has been named prestressed stayed steel columns (PSSC). In the PSSC shown in Fig. 1, an additional restraint can be placed on the main column by the crossarms in conjunction with pre-tensioned stays.

Research on PSSC has been conducted since the 1960s, in which Chu and Berge first investigated the critical buckling loads in PSSCs [1]. Following the work of Chu and Berge, Hafez quantitatively examined the effect of pretension on the buckling load by theoretical derivation based on the assumption of small deformations [2]. With the development of computer technology, particularly over the last twenty years, nonlinear buckling analysis in PSSCs by finite element (FE) software became possible. Thus, geometric imperfections governing nonlinear buckling [3–5], evaluate the post-buckling behaviour [6,7], and investigate the optimum design method can be conducted numerically [8,9]. Experimental studies have also been conducted in parallel with FE analyses on PSSCs [10–14].

For practical application of PSSCs, the compressed steel columns are generally stiffened by spatial crossarm systems (see Fig. 2) around the main column and multiple crossarms along the main column length (see Fig. 2(b)). Unfortunately, most of the previous studies concentrated on investigating PSSCs with crossarms only set at the mid-span of the main column (see Fig. 2(a)), which are not typically found in practice. As far as the authors are aware, references [15, 16] are the only studies aimed at investigating the stability of PSSCs with multiple crossarms. However, the interactive buckling behaviour of PSSCs with multiple crossarms has not been investigated. In fact, research on PSSCs with single-bay crossarms shows that interactive buckling may become dominant when determining the actual buckling strength.

Based on the background information introduced above, this current work focuses on investigating the stability of PSSCs stiffened with multiple crossarms along the main column length. First, pretension was derived by geometric analysis, which corresponds to the maximum critical buckling load. This pretension level was used as the benchmark pretension value in the FE simulation. Subsequently, critical and nonlinear buckling analyses were conducted to explore the buckling strength of PSSCs stiffened with multiple crossarms. In addition, a discussion based on parametric analysis results was presented to quantitatively examine the effect of cross-sectional area of the stays and pretension in stays.

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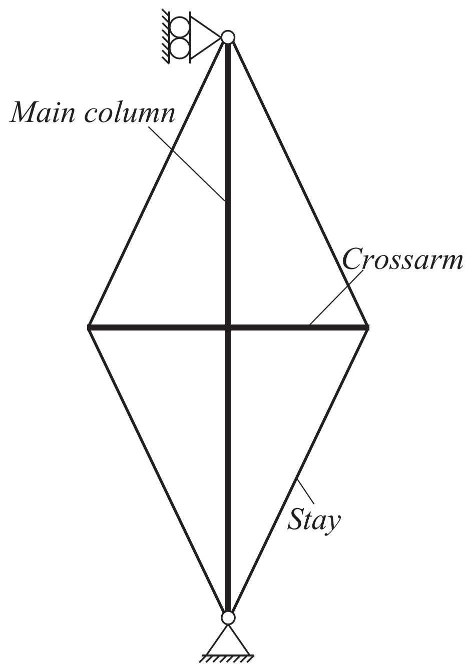

Fig. 1. Composition of PSSC.

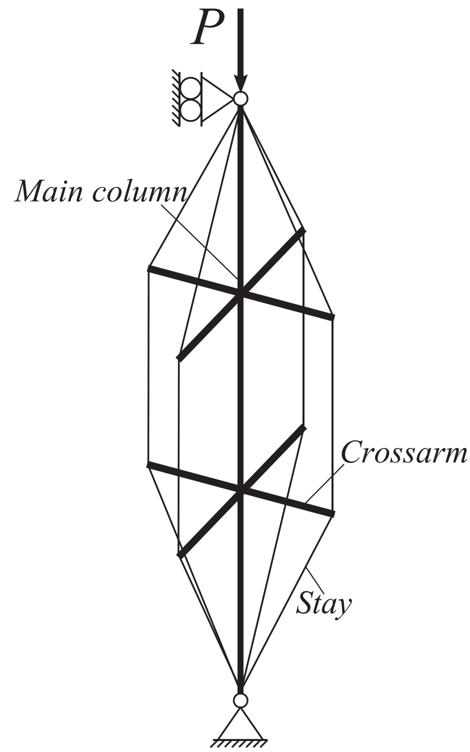

Fig. 3. Structural configuration of PSSCs.

2. Structural configuration and analytical methodology

2.1. Structural configuration

The number of crossarms along the column length can be different in PSSCs with multiple crossarms. As the simplest case of a steel column with multiple crossarms, the current work aims to investigate steel columns stiffened with two-bay crossarms along the column length (see Fig. 3). In this model, all crossarms have equal lengths and are set at the trisection points along the main column. Note that the crosssarms can be pinned or rigidly connected to the main column in practice. However, the pin-connected case is outside the scope of this study. In other words, the connections between the crossarms and main column are thought to be ideally rigid in this work. As for the boundary condition, it is assumed that the column is pin-supported at both ends.

It has been proven that the critical buckling mode is a crucial factor determining the post-buckling behaviour of PSSCs. Thus, the structural parameters, including the crossarm length and stay diameter, should be varied to activate different critical buckling modes in a systematic analysis. To achieve this, a series of different crossarm lengths and stay diameters (see Table 1) was selected in the following FE analysis. However, it must be noted that the column length was fixed at 5100 mm during the numerical analysis performed in this study. Circular steel tubes with outer and inner diameters of 38.1 mm and 25.4 mm, respectively, were adopted for both the main column and crossarms. Thus, the Young's modulus of the main column and crossarms are 201,000 N/mm^2. Note that the stays in this work are bars, which are the same as those in Hafez's model [2]. Thus, the Young's modulus is assumed to be 202,000 N/mm^2.

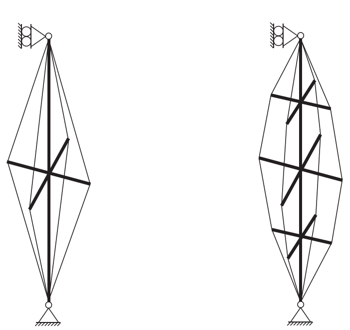

Fig. 2. Different spatial crossarm layouts along the main column length.

2.2. Analytical methodology

As mentioned above, this study focuses on investigating the behaviour of two-bay stayed PSSCs. For the PSSCs stiffened with single-bay crossarms (see Fig. 2(a)), it has been demonstrated that interactive buckling could dominant the buckling strength in some cases. This study would check whether interactive buckling can determine the actual buckling strength for two-bay stayed PSSCs using nonlinear buckling analysis. Note that the initial geometric imperfection must be considered in the nonlinear buckling analysis. Thus, linear buckling analysis should be conducted to obtain the buckling modes, which can be used to construct an imperfect model for nonlinear buckling analysis. It should also be noted that the initial pretension in stays is another crucial factor that can affect the buckling behaviour of PSSCs. To make the numerical analytical results comparable, a benchmark must be defined for the initial pretensions in stays. In this work, pretension corresponds to the maximum critical buckling load is adopted as the benchmark for pretension in stays. Based on these statements, the analytical process in this study can be summarised as follows:

Table 1
Analytical parameters.

Crossarm length (mm)	255	382.5	510	637.5	765
Stay diameter (mm)	1.6	3.2	4.8	6.4	8.0