Structures 12 (2017) 227–241

Contents lists available at ScienceDirect

Structures

journal homepage: www.elsevier.com/locate/structures

Stability of Multiple-crossarm Prestressed Stayed Columns With Additional Stay Systems

Luke Lapira, M. Ahmer Wadee*, Leroy Gardner

Department of Civil and Environmental Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK

ARTICLE INFO

Keywords:
Prestressed stayed columns
Steel structures
Analytical modelling
Structural stability
Finite element analysis
Nonlinearity
Cables

ABSTRACT

Prestressed stayed columns have an enhanced resistance to buckling through the effective use of crossarms and pretensioned stays when compared to conventional columns. An analytical derivation of the minimum, linear optimum and maximum initial pretension forces for configurations of prestressed stayed columns with multiple crossarms and additional stays is presented for the first time. The findings are validated through comparisons with finite element models developed in the commercial package ABAQUS. The influence of the initial pretension on the load-carrying capacity of the configurations considered is also analysed, providing insight into the actual optimum initial pretension force for the configurations accounting for the significance of geometric nonlinearities.

1. Introduction

Prestressed stayed columns, the composition of which includes a main column element, a system of crossarm members and pretensioned cable stays, offer an aesthetic, innovative and practical solution to enhancing the buckling strength of slender columns. Their enhanced resistance to buckling arises from the effective provision of intermediate supports through the crossarms and the stay system. The net result is that the column buckling length is reduced thereby increasing the critical buckling load. Although not currently covered by design codes explicitly, prestressed stayed columns are often found in construction owing to their structural efficiency and aesthetic value. Fig. 1 shows an example in practice from the development at Chiswick Park in London, whereby a triple-crossarm stayed column with additional stays is used to support a shading structure at roof level.

Prior to the mid 1970s [1], research on prestressed stayed columns focused on cases where a small amount of residual tension in the stays was present prior to buckling. However, the detailed effect of different levels of pretension on the mechanical behaviour had not been explored. Subsequently [2], three zones of behaviour were demarcated by the following pretensioning force levels: T_{min}, T_{opt} and T_{max}, as shown in Fig. 2 where:

- T_{min} is the minimum initial pretension force that ensures the buckling load is higher than the classical Euler load P_{E} of the bare, unstayed, main column element. This denotes the transition between Zones 1 and 2 where the pretension force begins to affect the buckling load significantly.
- T_{opt} is the initial pretension force at which all the stays lose their tensile force simultaneously at the maximum possible buckling load, denoted as P_{max}. This denotes the transition between Zones 2 and 3 where, in the latter, there is a residual tension in the stays when buckling is triggered.
- T_{max} is the pretension force that causes buckling without the application of any external load.

However, from later studies [3–7] it was determined that the zonal behaviour is only part of the story. Although, the identified zones provide important insight into the behaviour as a function of the initial pretension, in reality the ultimate load is greater than the Euler load at low pretensioning levels and rises with increasing pretension beyond T_{opt}, before reaching a peak and finally reducing with increasing T. It was shown in Refs. [6] and [7] that T_{opt} is significantly below the initial pretension force that truly maximizes the load-carrying capacity when large deflections are considered. This effect is primarily due to the nonlinear post-buckling behaviour where bending of the main column reactivates stays that had gone slack during the triggering of critical buckling [8]. However, since T_{opt} demarcates between distinct linear buckling behaviours, it is considered to be the benchmark initial pretension in the current work; it is henceforth termed the 'linear optimal' initial pretension force to distinguish it from the true optimal value.

A significant volume of research has been carried out on prestressed stayed columns where the theory underpinning the ultimate resistance has been investigated [4,6,9,10], the post-buckling behaviour has been

* Corresponding author.
E-mail addresses: luke.lapira15@imperial.ac.uk (L. Lapira), a.wadee@imperial.ac.uk (M.A. Wadee), leroy.gardner@imperial.ac.uk (L. Gardner).

http://dx.doi.org/10.1016/j.istruc.2017.09.010
Received 2 June 2017; Received in revised form 29 September 2017; Accepted 29 September 2017
Available online 02 October 2017
2352-0124/

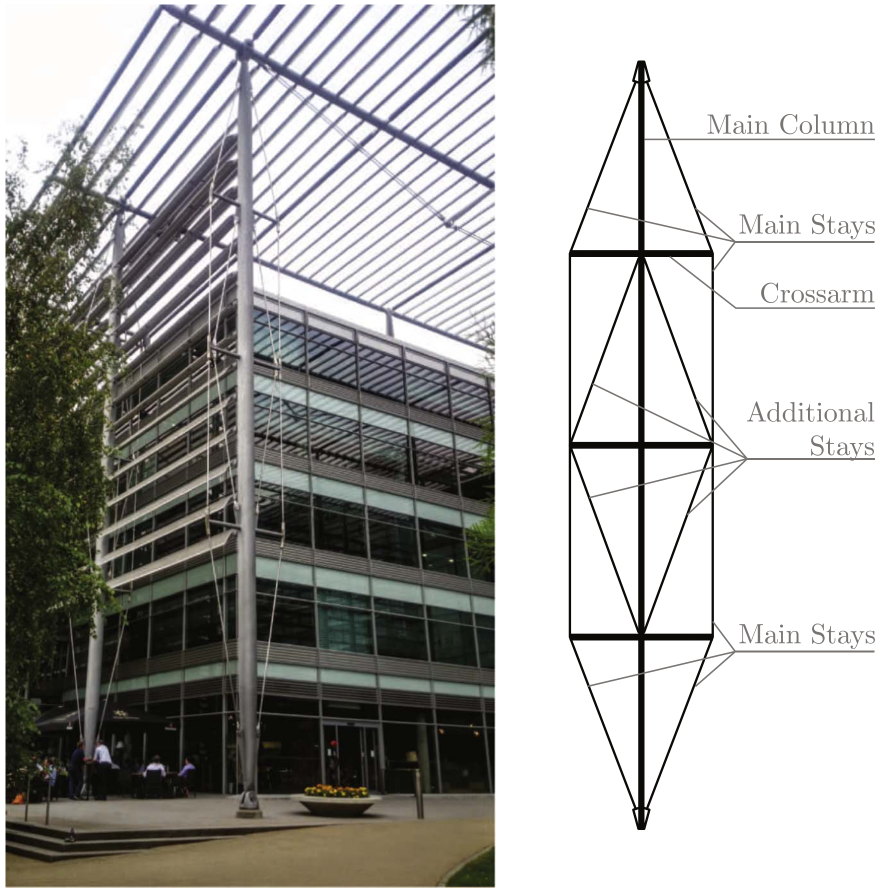

Fig. 1. Triple-crossarm stayed column with additional stays at Building 5, Chiswick Park, London, UK.

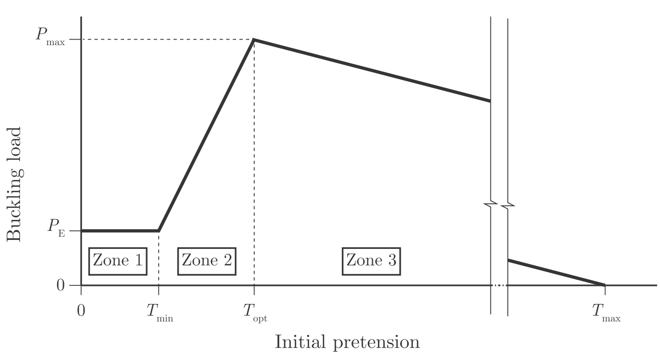

Fig. 2. Critical buckling load versus initial pretension force *T*, as determined in [2].

established [8,11-13], interactive buckling has been studied [14,15] and experiments have been conducted [16–18]. As far as the authors are aware, there is very little published research that considers the behaviour of multiple crossarm stayed columns with additional stays. Temple [19] considered multiple crossarm configurations including additional stays to determine the adequacy of the finite element (FE) method for predicting the linear buckling loads. Van Steirteghem et al. [20] analysed stayed columns with bipod configurations, determining that a significant increase in efficiency may be achieved by using a split crossarm, as opposed to the single crossarm. More recently, Martins et al. [21] presented findings from full-scale experiments conducted on 18 metre long double-crossarm configurations.

The current work focuses on the effects on having additional stays on the behaviour of prestressed stayed columns with multiple crossarms along the length. The derivations of the linear optimal prestress, as determined in [2] for single-crossarm stayed columns, are extended to such configurations first. A parametric FE study to validate the key prestress levels obtained is then presented. Finally, the behaviour of the configurations under different degrees of initial pretension is explored and conclusions are then drawn.

2. Analytical modelling

The restraint introduced by the stays in prestressed stayed columns at the location of the crossarms is dependent on the initial geometry and the level of the initial pretension within the stays. Fig. 3 shows a sequence of increasingly sophisticated configurations of prestressed stayed columns from a single and a double crossarm stayed column with only one stay-group (Configuration 1) to a double and triple crossarm case with two stay-groups (Configurations 2 and 3 respectively). Upon application of the external load, the elastic pre-buckling deformations result in the shortening of the stays causing a reduction in the lateral restraint provided. The influence of the additional stay-group on the behaviour of the stayed column is therefore determined by considering such deformations. The discussion first examines the more complex deformation relationships of Configuration 3 and then for Configuration 2 since the former introduces the majority of terms and relationships. The improvements in load-carrying capacity for these configurations with two stay-groups are then compared to the results from the reference case of Configuration 1, which contains only one stay-group.

2.1. Assumptions

As in the work presented in [2], the following assumptions are made in deriving the key prestress levels for the configurations considered.

1. The member has reflective symmetry and is axially loaded with no initial imperfections.