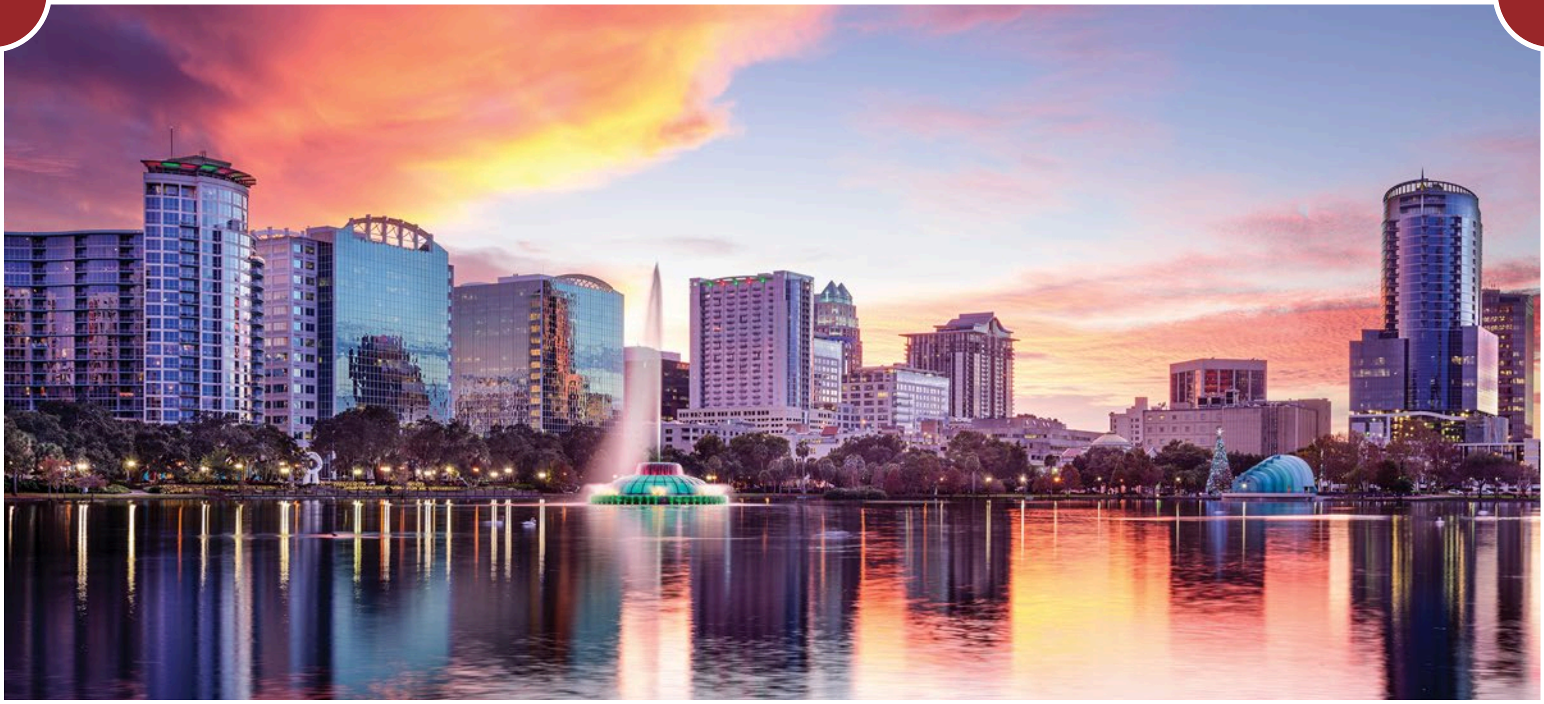

Structures Congress 2019

Bridges, Nonbuilding and Special Structures, and Nonstructural Components

Proceedings of the
Structures Congress 2019

Orlando, Florida

April 24–27, 2019

ASCE

Edited by
James Gregory Soules, P.E., S.E., P.Eng.

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Preface

The Structures Congress has a robust technical program focusing on topics important to Structural Engineers.

The papers in the proceeding are on the following topics

- Blast & Impact Loading & Response of Structures
- Bridges, Tunnels and other Transportation Structures
- Disproportionate Collapse
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- Natural Disasters - Moving Toward Improved Resilience
- Nonbuilding Structures and Nonstructural Components
- Special Topics in Structures
- Transformation in SE Education

Acknowledgments

Preparation for the Structures Congress required significant time and effort from the members of the National Technical Program Committee, the Local Planning Committee and staff. Much of the success of the conference reflects the dedication and hard work by these volunteers.

The National Technical Program Committee, the Local Planning Committee and staff would like to acknowledge the critical support of the sponsors, exhibitors, presenters, and moderators who contributed to the success of the conference through their participation.

Thank you for spending your valuable time attending the Structures Congress. It is our hope that you and your colleagues will benefit greatly from the information provided, learn things you can implement and make professional connections that last for years.

Sincerely,

J. G. (Greg) Soules, P.E., S.E., P.Eng, SECB, F.SEI, F.ASCE
McDermott International
Chair, National Technical Program Committee

Contents

Bridges, Tunnels, and Other Transportation Structures

Nonbuilding and Special Structures

Performance of Thin-Walled Steel Tubular Circular Columns with Graded Thickness under Bidirectional Cyclic Loading

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ABSTRACT

Thin-walled steel tubular circular columns are an attractive choice for elevated highway bridge piers due to both their structural advantages, and ease and speed of construction. However, local buckling, global buckling, or a combination of both are considered a main reason for a significant loss of strength and ductility in these columns, or possibly a full collapse under severe earthquakes. This paper investigates the hysteretic behavior of circular thin-walled steel columns with uniform and graded thickness under constant axial and bidirectional cyclic lateral loading. The paper's analysis is carried out using a finite-element model (FEM) which considers both material and geometric nonlinearity. The accuracy of the employed FEM is validated based on experimental results. Then, five different configurations of graded-thickness thin-walled columns with the size and volume of material equivalent to a uniform column are investigated. The graded-thickness columns are found to make significant improvements in ultimate strength, ductility, and post-buckling behavior as compared to their counterpart uniform column, emphasizing the sectional configuration in the graded-thickness columns.

INTRODUCTION

In regions with severe seismic activities, the integrity of civil engineering structures is exposed to an increased earthquake risk (Jaiswal et al., 2017; Miller, 1998; Nakashima et al., 1998). In response to these risks, thin-walled steel columns are becoming an attractive choice in modern buildings, elevated storage tanks, transmission towers, and onshore and offshore structures (Bedair, 2015; Tao et al., 2005; Ucak and Tsopelas, 2014). In addition, these columns are commonly used for elevated highway bridge piers (Goto et al., 2012) and wind turbines (Guo et al., 2013) in regions with severe earthquakes due to their structural efficiency, attractive aesthetic appearance, high earthquake resistance, and potential for concrete infilling (Yang et al., 2017; Zhao et al., 2015). However, thin-walled steel columns are vulnerable to damage when subjected to severe earthquakes (Aoki and Susantha, 2005; Bedair, 2015; Ge et al., 2000; Mamaghani et al., 1996, 1997; Ucak and Tsopelas, 2014). Local buckling behavior causes overall strength loss, ductility reduction, and even full collapse of these columns under constant axial and unidirectional cyclic lateral loading (Al-Kaseasbeh and Mamaghani, 2018). The strength and ductility of circular thin-walled steel columns depend on the radius-to-thickness ratio parameter (R_t) and slenderness ratio parameter (λ). Moreover, decreasing R_t and λ improve the strength and ductility of these columns (Al-Kaseasbeh and Mamaghani, 2018; Gao et al., 1998; Mamaghani and Packer, 2002). In the past few decades, unidirectional cyclic lateral loading has been considered to study the hysteretic behavior, ductility, and strength of thin-walled steel columns. However, the nature of earthquakes is complex and multidirectional rather than a unidirectional loading pattern. The earthquakes excitation consists of 3D loading components acting simultaneously (Anderson and Mahin, 2004; Okazaki et al., 2003). Moreover, hysteretic behavior of thin-walled steel columns under multidirectional cyclic lateral loading is expected to be more severe than the unidirectional loading of the same amplitude. Accordingly, many researches were initiated to study the behavior of thin-walled steel column behavior under multidirectional cyclic lateral loading. These studies concluded that multidirectional cyclic lateral loading causes extensive degradation of strength and ductility in the thin-walled steel columns in comparison with unidirectional loading, and should be considered in the seismic design process (Goto et al., 2006; Onishi et al., 2005; Oyawa et al., 2004; Watanabe et al., 2000). Thin-walled steel bridge piers are key in bridge seismic design and acceptable to be modeled as a cantilever column (Jiang et al., 2002). In addition to R_t and λ; cross-sectional configuration, cyclic lateral loading, and different parameters must be considered in the seismic behavior of the thin-walled steel columns (Goto et al., 2006). Up to date research focuses on the investigation of the uniform circular thin-walled steel columns under uni/multidirectional cyclic lateral loading.

As revealed in the literature, local buckling usually occurs near the column base (Nishikawa et al., 1998; Tang et al., 2016). To address this limitation, circular thin-walled steel columns with graded-thickness have been recently proposed and investigated by the authors to eliminate and delay the local buckling behavior under unidirectional cyclic lateral loading (Al-Kaseasbeh and Mamaghani, 2018). The authors' study concluded that graded-thickness circular thin-walled steel columns offer improvements on the strength and ductility capacity under constant axial and unidirectional cyclic lateral loading. This current study aims to extend the basic knowledge of the effect of the unidirectional cyclic lateral loading on the strength and ductility of graded-thickness circular thin-walled steel columns, to that of using bidirectional cyclic lateral loading. To achieve this goal, a uniform circular thin-walled steel column has been numerically analyzed under constant axial and bidirectional cyclic lateral loading. The accuracy of the adopted FEM has been verified based on the experimental results in the literature (Goto et al., 2006). Then, a graded-thickness circular thin-walled steel column with size and volume of material equivalent to a uniform column is investigated. The study results indicate that graded-thickness columns show significant improvements in ultimate strength, ductility, and post-buckling behavior as compared to their counterpart uniform column, emphasizing the effect of the plate thickness and sectional configuration in the graded-thickness columns. The main reason for the improved overall behavior of the graded-thickness columns is their ability to mitigate and/or eliminate the local buckling that commonly occurs near the base of the column.

NUMERICAL FINITE ELEMENT MODEL

Finite element analysis is carried out using the finite-element software Abaqus/Standard where material and geometric nonlinearities are considered (Hibbit et al., 2014). The accuracy of the employed FEM is validated in comparison with the experimental results available in the literature (Goto et al., 2006). The analyzed cantilever column is fixed at the base and subjected to constant axial load (P) and bidirectional cyclic lateral displacement at its top, as shown in Figure 1. The two-node beam element (B31) is employed for the upper part of the column, whereas reduced integration four-node shell elements (S4R), which accurately consider the local buckling behavior, are used for the lower part of the column. All used elements are available in the Abaqus/Standard library. The interface between S4R and B31 elements is modeled using MPC (multi-point constraint). For computational time efficiency, the mesh density of the bottom section of the lower part, where the local buckling usually occurs, is finer than the remaining part. Forty S4R elements are used in the circumferential direction. The above stated mesh sizes