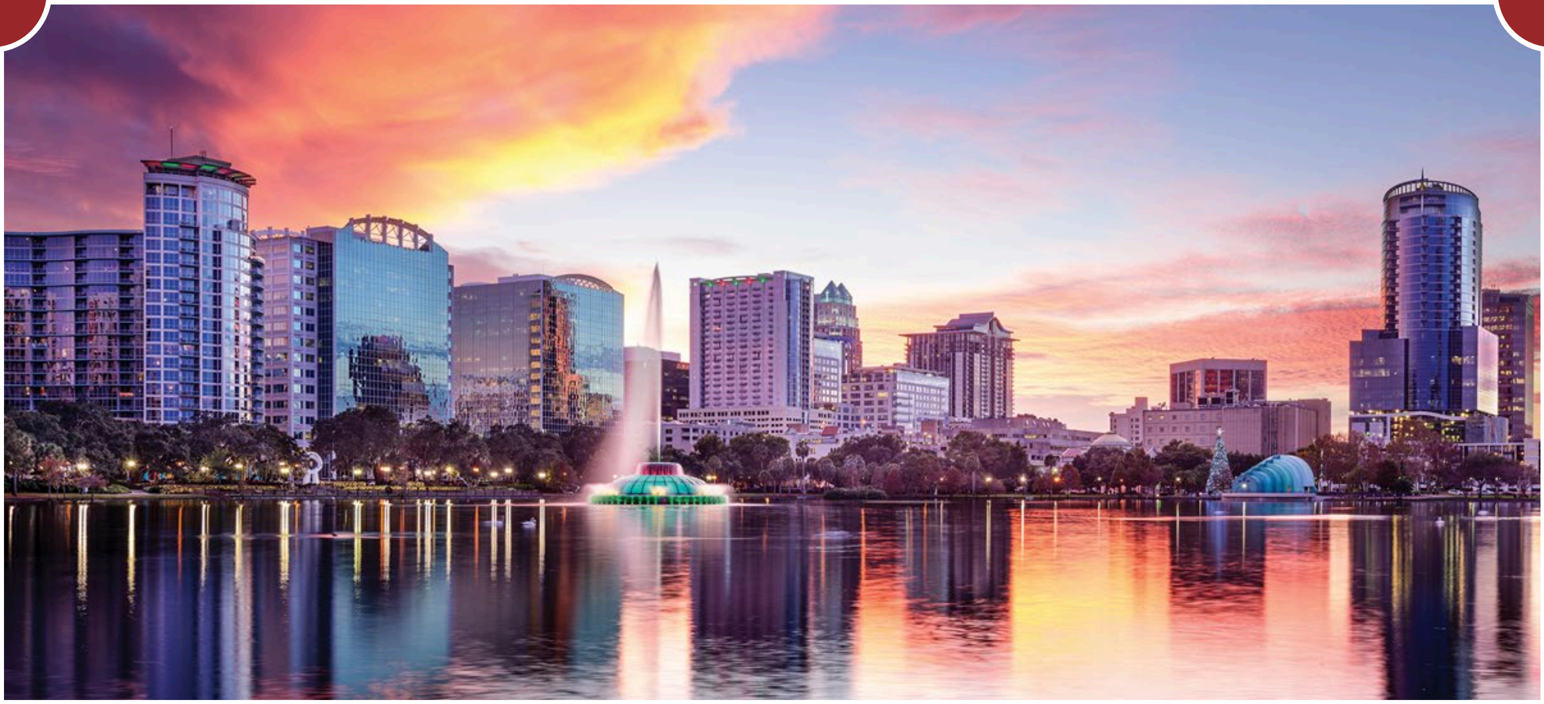

Structures Congress 2019

Blast, Impact Loading, and Research and Education

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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SELECTED PAPERS FROM THE STRUCTURES CONGRESS 2019

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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

Blast and Impact Loading and Response of Structures

Education

Research

Damage Analysis of Reinforced Concrete Piers under Vehicle Collision

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ABSTRACT

In recent years, increasing attention has been paid to the safety of bridges affected by vehicle-pier collisions. Up to date, the vehicular impact demand, dynamic responses, and damage characteristics of reinforced concrete (RC) piers under vehicle collisions have been studied, but few studies discussed the damage quantifications of RC piers in this circumstance with full consideration of their specific damage characteristics. This study aims to provide a framework used to quantify and classify the damage of RC piers under vehicle collision, where a damage index is proposed taking both the shear and flexural damage into account. Finite element (FE) simulations are further conducted to study the section-level deformation and damage characteristics of a three-column type of RC piers under vehicle impact. The simulation results reveal that the vehicular impact energy, stirrup diameter, and the bottom constraint location of the piers all affect the damage of the piers. It is found that the damage features of RC piers observed from the FE simulations are generally consistent with the damage indices, although future work is also required to make them more accurate and effective.

INTRODUCTION

Vehicle crashes on bridge piers occur occasionally but could lead to damage or even collapse of bridges resulting in serious secondary disasters. Buth et al. (2010) and Chen and Xiao(2012) documented a series of such crashes, where tremendous economic loss and lives were reported. Along with the increase of the amounts of vehicles and bridges, the risk of bridges subjected to vehicle collisions is growing. It is of great significance to take full consideration of potential vehicle collisions when designing bridge piers.

Nowadays, many bridge design codes have included anti-collision measures and design method regarding to vehicle collisions on bridge piers, e.g. the *AASHTO LRFD Bridge Design Specifications* (AASHTO 2016) and *Eurocode 1-Part 1-7* (British Standards Institution 2006). However, they usually adopt a design method based on a single or multiple equivalent static forces, which do not take full consideration of the dynamic characteristics of both vehicle and piers. El-Tawil et al. (2005) demonstrated that the then-current AASHTO code is not always conservative in this regard. Recent simulation work conducted by Abdelkarim and Elgawady (2017) obtained similar arguments with respect to the current AASTHO code (AASHTO 2016), although the design force in the code had been increased from 1800 kN to 2670 kN. Clearly, developing a reliable design method for piers against vehicle collision is still challenging.

In contrast to the traditional force-based design, performance-based design (PBD) is recognized to be the next generation of the design methodology in seismic engineering. The Pacific Earthquake Research Center developed PBD approaches, which can be divided into four parts: a) hazard scenarios analysis, b) structural response analysis, c) structural damage analysis, and d) consequence and loss analysis (Porter 2003). In fact, several researchers such as Sharma et al. (2012), Agrawal et al. (2013), Abdelkarim and Elgawady (2017), and Zhou et al. (2017) have already tried to develop the PBD approach for RC piers under vehicle collisions, where the performance objectives, damage classifications of the piers, and structural responses were preliminarily discussed. On the other hand, Chen et al. (2016; 2017) established a reduced model for simulating truck collision with bridge piers, which could be used in the structural response analysis within the PBD framework. Do et al. (2018) numerically simulated the truck impact on RC piers and discussed the damage characteristics of the piers. Up to date, there are few studies discussing the damage quantifications of RC piers with full consideration of their specific damage characteristics. Generally, the PBD approach for RC piers against vehicle impact is still at its initial stage.

Table 1 Proposed damage and performance levels for RC piers under vehicle collision

Damage level	Damage description			Performance levels	Damage index
	Local crushing	Flexural	Shear		
Minor damage (D1)	Some scratches; no spalling	Flexural cracks (<2 mm); limited yielding; no spalling	Hairline-minor shear cracks (<0.5 mm)	Fully operational with no significant damage (P1)	0.0-0.2
Moderate damage (D2)	Minor to moderate spalling of concrete in impact area	Minor to moderate spalling of concrete cover due to flexural deformation	Moderate shear cracking (>0.5 mm)	Operational with damage (P2)	0.2-0.5
Severe damage (D3)	Significant spalling of concrete in impact area	Significant spalling of concrete cover; buckling of longitudinal reinforcement, yielding of transverse reinforcement because of core expansion	Severe shear cracking (>1 mm), stirrup yielding	Collapse prevention (P3)	0.5-0.9
Collapse (D4)	Loss of axial load capacity due to severe erosion of concrete in impact area	Loss of axial load capacity due to significant amount of buckling or fracture of longitudinal reinforcement	Loss of axial load capacity due to severe shear cracking or fracture of transverse reinforcement	N/A	≥1.0

In view of that, this paper aims to provide a framework used to quantify and classify the damage of RC piers under vehicle collision based on their specific damage characteristics and then make an in-depth analysis of the damage of the piers through nonlinear finite element (FE)