

Structures Congress 2019

Blast, Impact Loading, and Research and Education



Proceedings of the Structures Congress 2019

Orlando, Florida

April 24–27, 2019



SE

STRUCTURAL

ENGINEERING



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



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SELECTED PAPERS FROM THE STRUCTURES CONGRESS 2019

April 24–27, 2019 Orlando, Florida

SPONSORED BY The Structural Engineering Institute of the American Society of Civil Engineers

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
- Advances in Structural Engineering Research
- Analysis, Design & Performance
- Avoiding Disproportionate Collapse
- Forensic Investigation
- Building Structures- Case Studies & Concepts
- Buildings Special Topics in Structures
- Codes and Standards Learn from the Experts
- Design for Lateral Loads/Systems
- Extreme Bridge Loads
- Long Span Bridges & Vibrations
- Materials- Design & Construction
- 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
Damage Analysis of Reinforced Concrete Piers under Vehicle Collision1 Lin Chen and Tao Liu
Dynamic Behavior and Resistance Mechanism of RC Pier Columns under Lateral Impact Loading
Residual Behavior of Sandwich Panels with Flax FRP Faces and FoamCores after an Impact Event
Computer Predictions of Tunnel Response to Blast
A Pragmatic Design Approach for Internal Blast Scenarios
A Numerical Study on the Structural Response of Steel Structures under Post-Blast Travelling Fires
Numerical Simulation of Vehicle Collision with Reinforced Concrete Piers Protected by FRP-Foam Composites
Full Scale 13-Story Building Implosion and Collapse: Effects on Adjacent Structures
Kanchan Devkota, Christine E. Wittich, and Richard L. Wood Application of Absolute Nodal Coordinate Formulation for Dynamic Progressive Collapse Analysis
Dynamic Behavior of Multi-Bay Beam-Slab Substructures to Resist Progressive Collapse Caused by Close-In Blast Detonation 106 Kai Qian, Xi Huang, Pan He, and Xiao-Fang Deng
Effect of the Post-Peak Behavior on Collapse of Structural Systems

Experimental Study of Disproportionate Collapse Resistance
Mechanisms for Mass-Timber Buildings
Hercend Miplul Bita, Marjan Popovski, and Thomas Tannen
Design and Analysis of Unretrofitted and Retrofitted Glulam Beams
and Columns under Blast Loading137
Daniel N. Lacroix and Ghasan Doudak
Parametric Evaluation for Relanced Design Considerations of
Resistant Windows 147
J. Mikhael Erekson and Kenneth W. Herrle
Effectiveness of Progressive Collapse Resistance Criteria against
Blast Loading
Sam Noli, Devon Wilson, Deborah Blass, and Will Wholey
A Blast Mitigation Technique for Unreinforced Masonry: An
Experimental and Computational Analysis
Bowen G. Woodson, Bradley W. Foust, Jorge O. Torres,
Grady A. Wingard, and Steven W. Alves
Mitigation of Glass Hazards in High Inreat Environment
Using Cable Calcii Systems
1. Sisson and A. Montaiva
Petrochemical Facilities—Blast and Fire Considerations193
Yousef Alostaz and Asher Gehl
Education
Luncanon
Improved Learning through In-Class Assessment
Aaron T. Hill Jr. and Michael Campbell
A Readman to the Implementation of the ASCE Policy
Statement 465: First Professional Degree 215
Camille A. Issa
Posegrah
Keseurch
Assessment of the Applicability of Recycled Rubber Fiber Reinforced
Bearings (RR-FRBs) as Base Isolators of Residential Buildings in
Developing Countries
A. Calabrese and N. Kumawat
Design of Experimental Apparatus for Real-Time Wind-Tuppel
Hybrid Simulation of Bridge Decks and Buildings
Oh-Sung Kwon, Ho-Kyung Kim, Un Yong Jeong, You-Chan Hwang,
and Moniruzzaman Moni

3D Collapse Simulation of Concrete-Filled Steel Tube Columns through Multi-Axis Cyclic and Hybrid Simulation 246
M. Javad Hashemi, Hamidreza A. Yazdi, Riadh Al-Mahaidi, and Emad Gad
Mixed Formulation of Steel-Concrete Sandwiched Beams with Partial
Shear Shp
Behavior of Fiber Reinforced Cementitious Matrix Elements under
Combined Thermo-Mechanical Loads
Lateral Load Resistance of a Novel Connection Detailing for Structural
Wall-Floor Slab Joint Region 279 Surumi Rasia Salim and Jaya Krishnan Prabhakaran
Performance of Steel Grain Silos and Rural Communities to Windstorms291 Lianne Brito and Christine Wittich
Effects of Shear Studs in Composite Columns' P-M Interaction Diagrams
A New Generation of Metallic Dissipaters for Low Damage Seismic Design of Structures 314
Mustafa Mashal and Alessandro Palermo
Predicted Slip of Ballasted Solar Arrays on Angled Roofs Due to Seismic Motion 326
Tonatiuh Rodriguez-Nikl, Sergio Cedano, Edwin Martinez, and Francisco Ojeda
Performance of Precast Connections on a Moment Resisting Frame
Ines Torra-Bilal, Mustafa Mahamid, and Kamel Bilal
Generation of Strut-and-Tie Models and Stress Fields for Structural
Concrete
Probabilistic Model for Rebar-Concrete Bond Failure Mode Prediction
Considering Corrosion
Data-Driven Risk-Based Assessment of Wind-Excited Tall Buildings
A Scalable Framework for Assessing Seismic Resilience of Communities

Camera-Based Imperfection Determination of Cold-Formed Steel Members	95
Burcu Guldur Erkal, Rafet Aktepe, Alper Can Alkoyak, Merve Bayraktar,	
Berkan Demir, and Zeynep Unsal	
The Design of an Ultra-Transparent Funicular Glass Structure4	05
Masoud Akbarzadeh, Mohammad Bolhassani, Andrei Nejur, Joseph Robert Yost,	

Cory Byrnes, Jens Schneider, Ulrich Knaack, and Chris Borg Costanzi

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

1

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.

Damage level	Local crushing	Damage description Flexural	Shear	Performance levels	Damage index
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

	Table 1 Pro	posed damage	e and performant	nce levels for	RC pie	rs under vehicl	e collision
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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)