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Frameworks and Life Cycle Assessment for Reinforced Concrete Bridges for Sustainability in Transportation

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Introduction

Because of its position along the San Andreas fault and other active fault systems, California is vulnerable to seismic activity, including damaging major earthquakes, which put the state's transportation system at risk. Reinforced concrete (RC) bridge structures are essential components to transportation networks throughout California, and there is an urgent need for seismic retrofitting and bridge maintenance to extend the life span of these bridges to make them safer. Additionally, retrofitting uses significantly less energy and thus reduces environmental impacts.

This study uses advanced computer models called fiber-based nonlinear finite element models with section damage indices to assess how a bridge would be damaged during an earthquake and then identify any structural weaknesses and suggest retrofit and maintenance solutions to help the bridge last longer. In addition, the proposed Life Cycle Assessment (LCA) method in this research highlights the need to retrofit RC bridges rather than to rebuild to reduce environmental impacts.

Study Methods

In this research, fiber-based nonlinear finite element models together with section damage indices are used for damage prediction for RC bridges' seismic performance damage assessment. The selected RC highway bridge underwent nonlinear dynamic analysis subjected to ten different earthquakes, as well as Life Cycle Assessment. The proposed LCA method includes Product stage, Construction Process stage, Use stage, End-of-Life stage, and Beyond Building Life stage. Due to global warming potential, the environmental footprint of the RC bridge is recorded under each of the stages. To investigate the seismic performance and LCA of the RC bridges, the Canyon Road Overcrossing RC highway bridge was selected for model use. The Canyon Road Overcrossing RC highway bridge is located about 5.5 miles south of Los Banos in California. This bridge is over Interstate 5 (I-5) and serves to connect transportation and promote mobility between Los Banos City and the Los Banos Reservoir.

Findings

Based on the fiber-based nonlinear finite element models together with section damage indices for seismic performance assessments, the research indicates that the selected RC highway bridge needs to be repaired and retrofitted prior to the design basis earthquake (DBE) and the maximum credible earthquake (MCE) as well as to prevent collapse in the event of MCE to avoid the needs to be rebuilt and could result in negative impact to the environment. The results from the proposed life Cycle Assessment (LCA) methods indicated that the Product stage and the Beyond Building Life stage were the prominent causes of environmental impact in the selected RC highway bridge. Although bridges are a crucial transportation medium where vehicles emit considerable amounts of CO2, the Use stage had zero contribution in all stages of all areas as the structure itself does not emit any CO2. The Construction Process stage and the End-of-Life stage contributed similar amounts of CO2. Therefore, retrofitting existing RC bridge structures to extend their life span would be better than rebuilding new bridges to reduce the environmental impact to improve sustainable bridge structures under seismic risks.

Using fiber-based nonlinear finite element models and section damage indices for seismic performance assessment, this research recommends that the selected reinforced concrete (RC) highway bridge be repaired and retrofitted prior to a design basis earthquake (DBE), which is the earthquake for which safety systems are designed, or maximum credible earthquake (MCE), which is a low probability, intense earthquake. Early intervention is necessary to prevent collapse during an MCE, avoid costly reconstruction, and reduce environmental harm.

The study's Life Cycle Assessment (LCA) reveals that the Product and the Beyond Building Life stages are the primary contributors to environmental impact. Additionally, the Construction Process and the End-of-Life stages also contributed to CO_2 emissions and global warming potential. Therefore, extending the lifespan of existing RC bridges through retrofitting offers a more sustainable and environmentally responsible alternative to rebuilding after seismic damage.

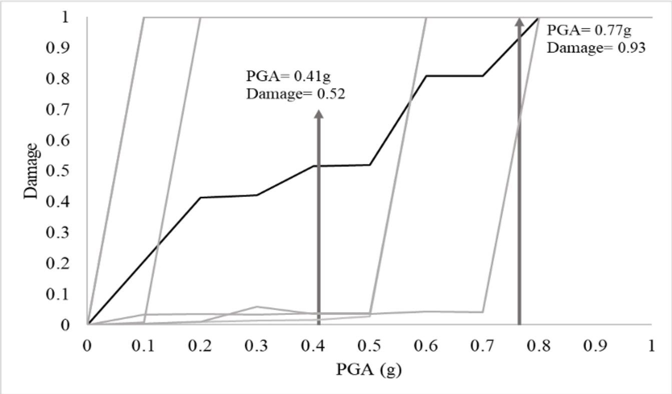
Retrofitting existing RC bridge structures to extend their life span would be better than rebuilding new RC bridges to reduce the environmental impact to improve sustainable bridge structures under seismic risks.

Policy Recommendations

Life cycle assessment (LCA) should be implemented to allow reinforced concrete bridge structures to maintain a more sustainable transportation system. LCA impacts can play a role in engineering design and maintenance to mitigate environmental impacts. Good design practice and code specifications will ensure RC bridge structures can achieve a long service life and minimize environmental impact. Incorporating LCA into seismic retrofit planning further strengthens the case for proactive maintenance, aligning structural resilience with environmental responsibility and safety.

About the Authors

Dr. Yu-Fu Ko, PhD, PE, is a Professor in the Department of Civil Engineering and Construction Engineering Management at California State University Long Beach (CSULB). He received his MS and PhD (outstanding PhD award recipient) degrees in Civil Engineering, focusing on Structural Mechanics and Structural Engineering/Dynamics, from the University of California, Los Angeles. He is a registered Professional Civil Engineer in the state of California. Dr. Ko's areas of research interest include micromechanical damage mechanics modeling and associated applications, damage assessment and experimental mechanics of structural materials, nonlinear/linear structural dynamic analysis of structures subjected to earthquake motions, finite element method code-based and performance-based structural design of structures, and seismic retrofitting of existing structures.



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To Learn More

For more details about the study, download the full report at transweb.sjsu.edu/research/2440

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