# Effects of Low-Cycle Fatigue Fracture of Longitudinal Reinforcing Steel Bars on the Seismic Performance of Reinforced Concrete Bridge Piers

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Project 2328
October 2024

## Introduction

Earthquake-damaged bridges have major impacts on transportation systems. The tremendous local stress and strain caused by earthquakes can cause reinforced concrete (RC) bridges to collapse due to the concrete cracking and fracture of the steel reinforcement rebars. Concrete bridges account for more than two-thirds of all extant California bridges constructed prior to 1960 and more than 90% of the bridges constructed from 1960 to the present. The fracture of longitudinal reinforcing steel due to low-cycle fatigue is one of the main causes of failure in RC structures under earthquake loading. Plastic deformation in each cycle and low-cycle phenomenon (materials have finite endurance for this type of load) are the characteristics of low-cycle fatigue. The term "cycle" refers to repeated applications of stress that lead to eventual fatigue and failure. "Low-cycle" pertains to a long period between applications. The low-cycle assessment results will allow us to better understand the behavior of RC bridges under seismic motions. The purpose of this research is to include the effects of low-cycle fatigue fracture of longitudinal reinforcing steel bars on the seismic performance of RC bridge piers as well as to assess the seismic damage of bridge columns accurately and effectively. It is imperative to propose numerical models that could accurately predict the seismic behavior of RC bridges as well as assess the damage states of RC bridges. Effective models would allow engineers and other transportation professionals to take action to prevent and repair this essential infrastructure.

## Study Methods

The steel reinforcement bars within RC bridge piers experience strain reversals under seismic loadings. The prominent causes of failure and damage to steel reinforcement bars include rebar global buckling, tensile strain damage, and low-cycle fatigue fracture. Rebar global buckling refers to rebar failure due to large lateral deformation under compressive loads. Tensile strain damage is rebar yielding and fracture under tensile loads. Low-cycle fatigue fracture refers to repeated long periods between applications of stress that lead to eventual fatigue and failure.

In addition, the cracking and spalling of cover concrete and the bond-slip between concrete and longitudinal steel bars are also major causes of failure to RC bridge piers. Bond-slip is related to the interaction between the longitudinal steel rebars and the concrete for load bearing and coordination deformation. Thus, these damage parameters are considered in this study of seismic performance of RC bridge piers. To effectively assess the seismic performance of RC single-column pier-supported bridges subjected to ground motions, four numerical models are developed with fiber-based nonlinear beam-column elements to conduct the seismic assessment. The four numerical models were developed with different considerations of low-cycle fatigue and bond-slip: Model 1 (without bond-slip and without fatigue), Model 2 (without bond-slip and with fatigue), Model 3 (with bond-slip and without fatigue), and Model 4 (with bond-slip and with fatigue). The models underwent nonlinear time-history analyses. The models consider different damage parameters such as low-cycle fatigue, tensile strain damage, global buckling of longitudinal steel bars, the cracking and spalling of cover concrete, and the bond-slip between concrete and longitudinal steel bars.

## Findings

The simulated section damage index $D_{section}$ of all four numerical models align well with experimental test results as well as the National Cooperative Highway Research Program Synthesis 440 for bridge performance assessment. In addition, the predicted seismic responses of all four numerical models are in good agreement with experimental test results. Therefore, all four numerical models are optimal to assess the seismic performance of RC single-column pier supported bridges. The proposed damage indices can reflect the damage states in accordance with the experimental results. When compared with experimental testing results, the numerical models considering the damage indices proposed in this study could capture the damage states and failure of RC single-column pier-supported bridges reasonably. Besides, the damage values reflect the damage development states in accordance with the experimental test results. The effects of bond-slip, cover concrete damage, steel strain damage, global buckling, and low-cycle fatigue damage of steel rebars would impact and influence the seismic behavior of RC bridge columns. The proposed models have shown to be able to capture the evolution of damage to RC bridge piers under seismic ground motion.

During the 1971 San Fernando earthquake in California, more than 60 bridges on the Golden State Freeway in California were damaged. The San Fernando earthquake cost the state approximately $100 million in bridge repairs. The Loma Prieta earthquake in 1989 damaged more than 80 bridges in California and caused more than 40 deaths in bridge-related collapses alone. The cost of bridge damage by Loma Prieta earthquake was about $300 million. Earthquake-damaged bridges have major impacts on transportation systems. Earthquakes don't only destroy the physical, mental, and emotional wellbeing of local communities, but also damage their financial wellbeing. The proposed models can help to predict the damage states and seismic behavior of RC bridge columns and could be available and beneficial to users for non-linear analysis and performance assessment of RC bridge structures.

## Policy/Practice Recommendations

The research findings provide insight on the effects of low-cycle fatigue fracture of longitudinal reinforcing steel bars on the seismic performance of RC bridges under near-fault ground motion. The effects of bond-slip, cover concrete damage, steel strain damage, global buckling, and low-cycle fatigue damage of steel rebars would impact and influence the seismic behavior of RC bridge columns and should be considered in numerical modeling. This study will mitigate risk and improve earthquake resilience for RC bridges. Therefore, this study will not only benefit the engineering community, but will also benefit the publicwith enhanced safety, economy, and transportation security.

## About the Authors

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## To Learn More

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