Transportation Consortium of South-Central States (Tran-SET)

Sustainability-based Long-term Management of Bridges under Multi-Hazard Exposure

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Developing a sustainability-based management approach for bridges under multiple hazards

Bridges are under deterioration due to various mechanical and environmental stressors. Hydraulic-related hazards (e.g., flood and scour), aggressive environmental conditions, and seismic events (i.e., earthquakes) are recognized as the most significant threats to the safety of bridges. In traditional risk assessment methods for structures susceptible to damage due to floods and other natural hazards (e.g., corrosion and seismic events), future hazard predictions are conducted using historic return periods and climate records. However, the recent increase in seismicity and flood intensity in central-southern states indicates that the future hazard occurrence rate may not necessarily follow past trends. Accordingly, current design, assessment, and management methodologies should adapt to these changes in order to ensure the satisfactory performance of bridges under the combined or cumulative action of hazards. This project addresses this need by presenting a framework for optimum management of bridges susceptible to damage due to floods, earthquakes, and other gradual deterioration mechanisms (e.g., corrosion and fatigue). Downscaled climate data, adopted from the global climate models, are employed to predict future flood hazard at a given location. Probabilistic simulation is used to quantify the time-dependent failure probability, which subsequently helps quantify the long-term sustainability through the systematic integration of economic, social, and environmental metrics associated with bridge failures or interventions. These profiles are next used to obtain optimum times and types of interventions required to extend the service life while maintaining the structural performance above prescribed thresholds.

Problem Statement

The increase in flood frequency and intensity, which may be attributed to climate change, is adversely affecting the safety of our Nation? s bridges and imposing devastating consequences to our transportation systems and the communities which they serve. As an indication of the severity of this problem, the 2015 flooding in Texas and Oklahoma led to at least five reported complete or partial bridge failures. In 2017, Hurricane Harvey caused severe flooding which led to the failure of several bridges in Texas. This 2017 flooding in Houston was considered the third 500-year flood to occur within the preceding three years. These events highlight the extent of increase in the occurrence rate of high intensity weather-related extreme events.

On another front, seismicity rates in Oklahoma and Northern Texas have increased considerably in recent years. The seismic hazard corresponding to 1% probability of exceedance in one year has increased by three times compared to the 2014 national seismic hazard predictions in Oklahoma. Accordingly, the chance of having a damaging earthquake (i.e., earthquakes with Modified Mercalli Intensity VI or greater) in these regions is predicted to be 5-12 % per year, which is comparable to the chance of having a natural earthquake in some regions in California. A bridge with foundations that have been weakened under the cumulative action of successive floods may experience a significant drop in its ability to resist seismic loads. Therefore, the risk of failure due to seismic events may increase considerably.

In order to prevent failure of bridges due to these extreme events, bridge design and management approaches should account for the increase in the hazard occurrence rates in affected states. Retrofit and maintenance activities should be optimally planned to reduce the failure risk and minimize the impact of bridge interventions on the economic, social, and environmental systems.

Summary

The research team is developing a framework for identifying optimum repair, maintenance, and/or retrofit activities required to improve the sustainability of bridges constructed in a multi-hazard environment. The procedure starts by quantifying the increase in the bridge failure risk during flood events considering the expected change in climate conditions. Climate scenarios extracted from global climate models appropriate for the location of interest, along with different carbon emission scenarios, are used to predict the future climate trends. The predicted temperature, streamflow, and time-dependent scour depths based on these climate scenarios are integrated into a probabilistic framework to perform multi-hazard risk analysis considering flood, scour, corrosion and seismic hazards. Probabilistic simulations coupled with finite element modeling establish a multi-hazard risk profile for the structure of interest. Figure 1 presents a general layout of the risk analysis framework. Probabilistic simulations also assist in accounting for the uncertainties associated with hazard occurrence, load effects, and structural resistance. Multi-objective optimization is used next to establish the best intervention schedules required to fulfill the management goals.

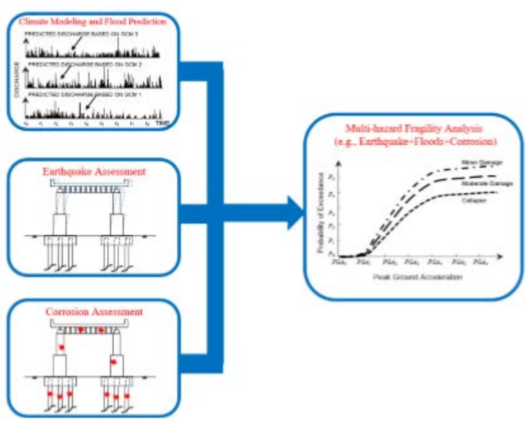

Figure 1. Multi hazard risk analysis approach.

Findings

Preliminary flood hazard analysis considering future climate predictions for several locations of interest indicates that although the mean annual discharge may have a general decreasing trend, the maximum annual discharge (i.e., flow peaks) can show a steady increase. This indicates a potential increase in the flood hazard and highlights the importance of proper climate modeling for bridge risk assessment. Preliminary multi-hazard analysis also suggests that the cumulative flood action can significantly reduce the seismic capacity of bridges.

Impacts

Deteriorating bridges require maintenance and repair activities to extend their service life and maintain a satisfactory performance level. The developed framework could be implemented by bridge officials to manage the existing stock of deteriorating bridges while reducing the associated life-cycle costs and maintain the desired performance level throughout the service life of bridges. In particular, the proposed framework can provide a better understanding of the system performance under multiple hazards. Accordingly, bridge managers can take corrective actions to prevent structural failures under extreme events. This will eventually improve the durability and extend the service life of existing bridge infrastructure and subsequently reduce the economic and social consequences of the bridge failure. In addition, the results of this study can be used for real-time decision-making for traffic control during natural disasters or disaster evacuation operations. Therefore, the project? s outcomes will lead to a better budget allocation and significant societal, environmental, and economic benefits can be achieved. In addition, this tool will be useful for preventing unnecessary expenditures on infrastructure management.

Tran-SET

Tran-SET is Region 6’s University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 “to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes”.

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For more information about Tran-SET, please visit our website, LinkedIn, Twitter, Facebook, and YouTube pages. Also, please feel free to contact Mr. Christopher Melson (Tran-SET Program Manager) directly at transet@lsu.edu.

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