MPC-448
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Project Title:
Reducing flood vulnerability of communities with limited road access by optimizing bridge elevation

University:
Colorado State University

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Research Needs:

The collapse of several key road bridges by flood waters can result in the isolation of an entire community when these structures are located at key, or critical points or junctures. This scenario was dramatically illustrated by the deadly 2013 floods in Colorado, which affected the counties of Larimer, Weld and Boulder among others. Residents of Drake, a community near Estes Park, had no exit routes and had to be evacuated by helicopter. Other towns and communities in the area were left with few or no routes for delivering help or exiting the site.
The current approach for determining the elevation of a road bridge over waters at flood stage considers the location of the structure in isolation. The importance of the structure relative to the entire network for accessing the served community is not formally considered as a design criterion and bridge elevations are typically determined for the same flood recurrence. However, the failure of a bridge in a locality with few or no access alternatives carries significantly more negative consequences than the failure of another bridge that can be bypassed. This approach results in an uneven vulnerability of many road systems in the protection offered to their served communities.

Research Objectives:

This research project will provide a prototype tool for the determination of the appropriate elevation of bridges in a road network serving a community with access compromised by a flood event. A holistic and systematic determination of safe elevations will help decision makers to prioritize resources for road bridge retrofitting, as well as designers in the engineering of these structures. This will be a reliability-based approach that accounts for the consequences of bridge failure rather than just the structural reliability.

The hypotheses tested in this research are:

1. Road bridges in a network of roads providing access to a community need to be concurrently examined to assess the consequences of their individual failure to the accessibility of the community after a flood event, as opposed to their isolated design or retrofitting.
2. The location of a bridge within the road network providing access to a community affects the safety level of the entire network after a flood event.
3. The accessibility of a community with limited access after a flood event is significantly improved by applying higher safety criteria to the elevation of a small proportion of bridges in its road network.

Research Methods:

This project introduces an innovative dimension to road bridge design by addressing the relative criticality by the application of a concept known as consequence-based engineering to each of these structures in a given road network. The functionality of the network is considered as a whole, instead of retrofitting or designing each part independently of the sensitive of the served community to a combined failure.

Monte Carlo simulation will be used to determine the probability of a community becoming significantly isolated from road access by the failure of bridges in key locations. The simulation will be performed on a network consisting of interconnected nodes and links, modeling bridges and roads, respectively. Flood stages for various recurrence scenarios will be applied from existing or derived data, which in turn will depend of the location and hydrology of each node. Individual bridge failure will be considered as the point at which the flood stage at the location surpasses the bridge elevation. Consequences and their unit costs will be determined based on several key metrics identified during the project.

The method will be tested using a community selected for the project.

Expected Outcomes:

This research project will result in a prototype tool (Excel Marco) for the determination of standard consequence-based height assessment method for road bridge elevation determination. Determining improved elevations above flood stage will lead to a safer, more uniform access and exit traffic in the event of a flood capable of isolating the community.

The rationale and mathematical solution provided by this tool can, in theory, be extended to other transportation scenarios in which urgency for accessing or exiting a site is of crucial relevance and access means have been compromised. Natural disasters such as hurricanes and earthquakes, and man-made disasters such as war or acts of terrorism are examples of such circumstances, which is in fact where the term consequence-based engineering originated.

The Case Study will contribute practical considerations for the application of the methodology introduced here.

Relevance to Strategic Goals:

This project will directly address the central issues set forth in the USDOT Strategic Plan FY 2010 – FY2015 in its State of Good Repair strategic goal. This goal is captured in the Strategic Plan's Executive Summary by the statement that "It is essential that we be good stewards as good stewards and apply asset management principles proactively to maintain and modernize our critical infrastructure to maximize its productivity and performance and minimize full life cycle costs." This project will allow a proactive management of road bridges by providing a holistic view of their relative mutual importance for retrofitting and expansion.

Educational Benefits:

A graduate student will develop his or her MS thesis based directly on this project. There is also the potential for the student to develop a fundamental approach which may develop into a Ph.D. dissertation through additional MPC (or other) funds.

Work Plan:

The proposed study will include following tasks:

Task 1. Literature review (Months 1-3)
This task is already underway as part of the process of identifying the research problem. However, a more comprehensive literature review to identify all relevant studies on this topic will be conducted in the first quarter of the project. This will include the process of identifying metrics that affect the consequence.

Task 2. Selection of the Case Study community (Months 2-3)
The selected community will be selected as outcome of this task. The community should have sufficient hydrology, geography and road network information available, including recent flood frequency curves and updated Digital Flood Insurance Rate Maps (DFIRMs). Moreover, it should have limited road access and be located in Colorado. This may be Drake, CO or Estes Park, CO or another community based on Task 1.

Task 3. Collection of hydrology, geographical and road network data (Months 4 -7)
Information available at FEMA, CDOT and local counties, among others, will provide the data required to complete this project.

Task 4. Development and execution of simulation model (Months 4-8)
The Monte Carlo simulation model will be developed using MATLAB, Simulink or similar simulation modeling software. The simulation will provide the flood recurrence interval

appropriate to the design of each bridge so that the viability of the road network to provide access to the community is optimized and consequences minimized based on a set of financial (or other) constraints. The model will be developed and applied to the community selected in Task 2.

Task 5. Dissemination of project results
This Task will consist of dissemination the Annual Meeting of the Transportation Research Board (TRB) and relevant journals. In addition, a final report and an MS thesis based directly on this work will be written and made available to the public.

Project Cost:
Total Project Costs: $116,850
MPC Funds Requested: $57,000
Matching Funds: $ 59,850
Source of Matching Funds: Salary Cost share and hard match from discretionary funds

TRB Keywords: bridge; safety; resiliency; design