Rapid and Robust Evaluation of Bridge Load-Carrying Capacity Post-Disaster

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Overview

- Importance of transportation networks and bridge structures
- Types of damage for bridge structures
- Rapid assessment of partially damaged bridges
- Proposed assessment framework
- Conclusions & future testing

Importance of Transportation Networks

- **Transportation networks are critical to economic prosperity and everyday life**

Importance of Bridge Structures

- **Bridge structures, while only one piece, serve as critical & susceptible links in the transportation network**

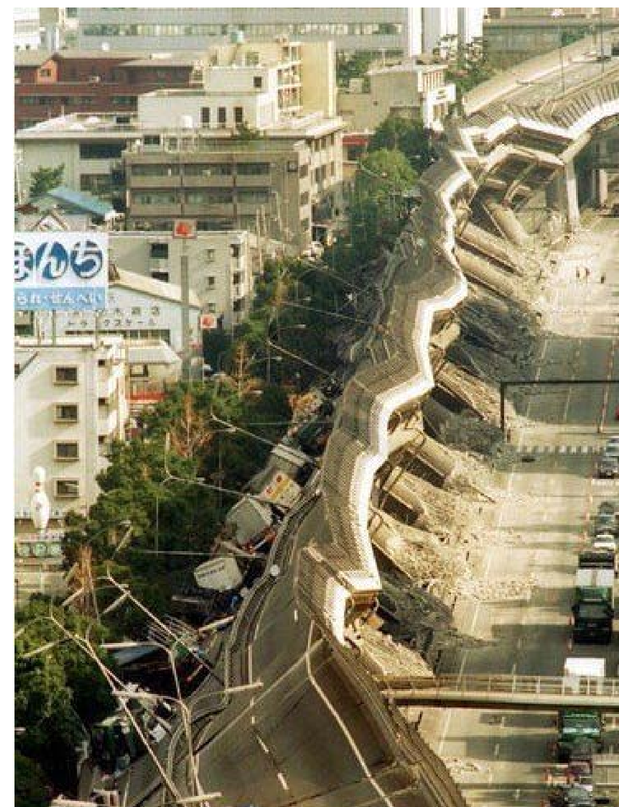
- **Providing more resilient transportation infrastructure implies providing safe and reliable bridge structures**

Importance of Bridge Structures

- Much research has focused on initiation & prevention of damage during extreme loading
- There is a need for research on rapidly assessing bridges immediately following a disaster

Types of Damage for Bridges

- Bridges can be subjected to various types of dynamic loads including: blast, earthquake, tsunami, hurricane, fire, barge impact
- This research will focus on two very different types of severe dynamic loading, earthquake and blast loading



Extreme Loading

- Earthquake loading
  - ✓ periodic and occurs over seconds
  - ✓ multiple modes of vibration in the response
  - ✓ damping in the structure is important
- Blast loading
  - ✓ pulse with a loading of milliseconds
  - ✓ response approximated by single mode analysis
  - ✓ loading so quick that damping does not play a role

Failure Modes

- **Potential failure modes include:**
  - ✓ **footing failures caused by soil liquefaction & differential settlements; abutment back-fill settlement and erosion; plastic hinges of RC columns inadequate confinement; shear failures; lap splices; compressive failures with rebar buckling/ruptures; failure of seismic restrainers; inadequate anchorage bridge foundations/piers; pounding/unseating; local buckling of columns; brittle fracture of welds; bolt breakage in tension and/or shear; and section loss.**

Types of Damage

- Column failure imperative in protective designs
- Failure modes of Reinforced Concrete (RC) columns considered in this research
  - ✓Flexural Failure Mode (earthquake)
  - ✓Lap-Splice Failure Mode (earthquake)
  - ✓Loss-of-Section Failure Mode (blast)

Proposed Framework

- Assessment tools include a novel scheme and algorithm development that allows the direct extraction of bridge equivalent stiffness and mass
- Using only the vibration measurements, the stability and bridge load-carrying capacity might be identified.
- The tools being developed within this research will be able to provide a foundation for the new technology of rapid and robust evaluation of bridge load-carrying capacity in disasters.

Proposed Framework

- **Limited to tools available to first responders**
- **Proposed assessment based on rapid and robust identification of structural properties**
- **Identify the load-carrying capacity of a damaged highway bridge**
  - **stability of bridge in current state (no prior test)**
  - **predict additional load before stability diminished and structure completely fails.**

Methodology Illustration

- **Introduce added mass and perform real-time experimental modal analysis**
  - **The added mass can lead to inverse identification of bridge element stiffness, without prior analysis results**
  - **The added mass can move to different places and help assess stability boundary**

Inverse modal analysis generally cannot determine the actual stiffness/mass. Introducing a known added mass can solve this problem!

$$\left\{K-\omega^2\left(M+\begin{bmatrix}0 & & & & \\ & \ddots & & & \\ & & \Delta m_j & & \\ & & & \ddots & \\ & & & & 0\end{bmatrix}\right)\right\}X=F$$

$$\begin{bmatrix}B_1(\omega_1) & B_2(\omega_1) & . & . & . & B_N(\omega_1)\\ B_1(\omega_2) & B_2(\omega_2) & . & . & . & B_N(\omega_2)\\ . & . & & & & .\\ B_1(\omega_i) & B_2(\omega_i) & . & . & . & B_N(\omega_i)\\ . & . & & & & .\\ B_1(\omega_N) & B_2(\omega_N) & . & . & . & B_N(\omega_N)\end{bmatrix}\begin{Bmatrix}1/M_1\\ 1/M_2\\ .\\ 1/M_i\\ .\\ 1/M_N\end{Bmatrix}=\begin{Bmatrix}A(\omega_1)\\ A(\omega_2)\\ .\\ A(\omega_i)\\ .\\ A(\omega_N)\end{Bmatrix}$$

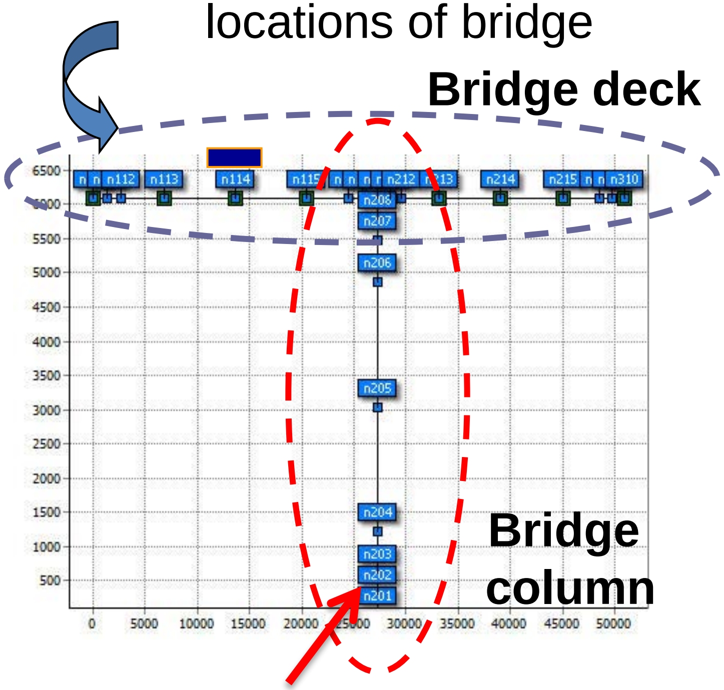
$$\det\left|P-\omega^2\Delta m_j Q\right|=0$$

After finding the equivalent bridge mass, we can obtain the corresponding bridge stiffness.

Methodology Illustration

- **Inverse identification approach has been established, by using Zeus-NL bridge analysis software**

Δm added to different locations of bridge



Damage = 50%
loss of cross-section

Damage introduced as reduced column section

	1st	2nd	3rd	4th	5th	6th	7th
Healthy	3.13	6.49	9.95	23.48	30.21	45.33	56.32
Damaged	2.15	6.40	9.89	23.31	29.70	44.68	55.50

Using bridge natural frequencies and mode shapes, we can identify directly the stiffness of healthy and damaged bridges

	114Δm=5	114Δm=20	114Δm=50
Healthy	3.29e10	3.26e10	3.19e10
Damaged	1.84e10	1.79e10	1.71e10
Change	43.9%	45.0%	46.2%

The results obtained under different Δm at different locations provide insights of the bridge stability and load carrying ability

Conclusions

- **Analytical studies indicate using only vibration measurements the proposed methodology can identify structural characteristics**
- **The failure modes can be assessed by observing the stiffness change with different added masses**
- **Rapid assessment given the constraints of first responders is possible within the proposed framework**

Future Testing

- University of Connecticut Structures Lab
  - Hybrid simulation of scaled RC bridge column subjected to earthquake and subsequent system identification

- US Army Engineering Research and Design Center (ERDC)
  - Blast load simulator with scaled RC bridge column