Proposed Pooled Fund Study

Problem Title: Validation of Numerical Modeling and Analysis of Steel Bridge Towers Subjected to Blast Loadings

Research Problem Statement

Background

Most major long span bridges in the United States are vulnerable to terrorism. They are high visibility structures, with a potential for extensive media exposure and public reaction if an incident were to occur. As a result of the long spans, complicated designs, site locations, etc., these bridges have very high replacement costs, and multi-year replacement construction periods. The potential for impacting regional and national economy is also greater because of the increased time for reconstruction. Many of these bridges serve as transportation arteries critical for emergency evacuation and for carrying lifelines besides vehicular traffic. Depending on the location, there is potential for mass casualties because of the volume of traffic it can carry at any given time. Most if not all of these long span bridges cross rivers, bays or other navigational channels. Damage resulting from an attack could impede navigation in addition to disrupting vehicular or other lifeline traffic flows.

Although surveillance and security systems such as cameras and sensors can be used to deter and detect terrorists, in the long run this might prove uneconomical and ineffective. It is also not practical to assume that society will be able to continuously inspect every truck that crosses these bridges. Building a strong structure, which can handle extreme event loadings, produces less chance of catastrophic failures and lessens the consequence of an event. The greatest threat is bombs, which constitute a high percentage of terrorist attacks worldwide. A vehicular delivered bomb allows a terrorist to bring an explosive device to a bridge with practically no time on target. A truck can deliver a large quantity of explosives anywhere traffic is allowed. A long span bridge offers a target that makes a high visibility statement for the terrorist. It represents the opportunity to destroy a landmark.

Bridge tower legs are critical bridge components for suspension and cable stayed bridges. Several long span bridges have traffic lanes adjacent to the tower that presents limited standoff distances (sometimes only one foot). There is a need to develop retrofit strategies for these critical towers and to have these incorporated upfront into designs of new structures. Routine large scale experimental testing of bridge and/or bridge components to determine vulnerability to blast loadings, and to determine effectiveness of retrofit schemes is unrealistic because of the time and cost associated with building and conducting experimental tests. Therefore it is essential to develop numerical analysis capabilities, which can be used to determine behavior of structures subjected to varying degrees and types of blast loadings both with and without retrofit schemes.

The United States military has developed multiple tools to calculate blast loadings from low resolution prediction to high resolution hydrodynamic codes. Following the bombing of the Alfred P. Murrah building in Oklahoma City, and of embassies overseas, a great deal of work has been done on terrorist threat protection of buildings. Research has gone into numerical simulations and small- and large-scale experiments on the effects of blasts on buildings with subsequent improvements in building design. There is greater understanding of how blast pressures decay with distance resulting in recommendations for standoff distances and how these can be used to mitigate blast effects. The transfer of blast data from other industries and from the military to civilian use highlights several important data gaps regarding the application of this information to bridges. The experimental data and computer codes on the affects of blast on concrete walls/bunkers and steel plate/ship hulls arising from explosive devices may not realistically simulate the effect of blast on bridge towers. Analysis done using these programs has given questionable results of the tower and retrofit behaviors. Validity of these types of analysis is questionable due to lack of experimental data. A research approach for critical highway structures that parallels the effort for improving building design needs to be undertaken.

Project Description

There is a gap in the current knowledge of blast phenomenology associated with large explosive devices (truck bombs) detonated close-in or almost in contact with steel cellular structures, specifically bridge towers. It is proposed that several numerical models be developed and analysis validated through the construction of physical models subjected to large explosive devices detonated to determine the actual behavior of such towers. For long span double-decked bridges, numerical and physical models shall also consider the blast resistance of the tower at both deck levels. It is further proposed that several hardening concepts be similarly tested so that performance of these long span bridges can be well understood in the event of such an attack occurring after the hardening has been implemented.

Literature Search Summary

A list of related research is given below. In addition, the terrorist attacks of September 11, 2001 fueled a number of studies on structural performance of the WTC and Pentagon buildings during the attack and structural vulnerability towards other similar attacks. The reconnaissance and analysis on the WTC and Pentagon site (Berman et. al. 2002, Mlakar et. al., 2003) indicated that the damage and collapse were results from a combined effects of impact, fire, and explosion. The various performance of the Pentagon and WTC complex buildings suggested that redundancy, continuity, and ductility are the keys to the survival or delay of collapse of the buildings. A number of numerical analysis tools have been utilized in the post-9/11 building studies. Results from these tools were compared to those from reconnaissance reports to verify their effectiveness for building performance evaluations (Berman et. al. 2002).

Bridges have significantly different structural systems than buildings involved in the 9/11 attacks. The optimal strategies are yet to be determined. The tower base and tower deck level are among the most vulnerable components of typical long-span bridges (Blue Ribbon Panel on Bridge and Tunnel Security workshop, 2004). Not much work has gone into validation of numerical tools for bridge towers against airblasts.

Research Objective

The objectives of this study are to develop better analytical modeling and numerical analysis capabilities of steel bridge towers subjected to airblast, and to develop retrofit schemes for the towers. The numerical analysis, both with and without retrofits are to be verified through large scale experimental testing.

Scope of Work

The scope consists of analytical and controlled explosive tests on large-scale steel tower sections representative of typical towers in both their as-built and retrofitted configurations to determine performance under various blast scenarios and for verification of numerical analysis techniques. Section sizes and detailing will be carefully determined to insure realistic boundary conditions and applicability to actual towers. It is envisioned that this work will consist of, at the minimum, following tasks done in several phases:

- **Phase I – Selection of Steel Bridge Towers and Numerical Analysis of As-Built Towers**
  Task 1 - Select steel bridge towers from existing population of bridges for computer modeling and numerical analysis
  Task 2 - Develop drawings for the selected towers to be used in Task 3
  Task 3 - Utilizing various levels of tools developed by the military from low resolution prediction code (CONWEP), to medium resolution code (BlastX), to high resolution hydrodynamic code (SHAMRC and FEFLO), and one suitable commercial program, develop models and analyze selected towers to determine behavior in response to a large explosion both in close proximity and with stand-off distances.

- **Phase II – Experimental Testing of As-Built Towers**
  Task 1 - Develop experimental test plans, to include determination of representative tower sections, model designs, testbed layout, required bomb sizes, instrumentation plan, etc.
  Task 2 - Conduct experimental tests of as built towers for validation of numerical analysis with towers subjected to both close in detonation and with stand-offs
  Task 3 - Analyze the experimental results and refine numerical modeling and analytical procedures as necessary

Task 4 - Prepare Report I that summarizes the work from phases I and II including the numerical modeling, test results and correlation of these results to the numerical models.

- **Phase III – Numerical Analysis and Experimental Testing of Retrofitted Towers**
  Task 1 - Select blast resistant retrofit schemes for the bridge towers tested in phase II,
  Task 2 - Conduct computer modeling and analysis of the retrofit schemes using programs from Phase I
  Task 3 - Develop experimental test plans, to include determination of representative tower sections, model designs, testbed layout, required bomb sizes, instrumentation plan, etc.
  Task 4 - Conduct experimental tests of retrofitted towers subjected to close in detonation and with stand-offs for verification of the retrofit schemes and validation of numerical analysis.
  Task 5 - Analyze experimental results and refine modeling and analytical procedures as necessary
  Task 6 - Prepare Report II that summarizes the work under Phase II, including the test results and correlation of these results to the numerical models. The report should provide an analysis of the effectiveness of the tested retrofits and should discuss possible improved retrofit schemes.

- **Phase IV – Final Report and Executive Summary**
  Task 1 - Prepare a final report synthesizing the findings of all phases
  Task 2 - Prepare an executive summary

Estimate of Problem Funding and Research Period

Recommended Funding: $1,500,000

Suggested minimum contribution: $100,000

Research Period: 24 months (Work under Phase I, II and III can overlap and therefore considerably shorten the timeframe. Because of the urgency of the subject area, it is the intent to fast track the study as much as reasonably possible)

Contractor: It is proposed this study be conducted by the U.S. Army Corp of Engineers (COE) under an existing Memorandum of Agreement between the FHWA and the COE Engineer Research Development Center (ERDC). Due to the nature of the study, the expertise existing at the ERDC, and their access to classified programs working with the ERDC is seen as the optimal means of completing the study in relatively shortened timeframe.

Urgency, Payoff Potential, and Implementation

The majority of the nation's 600,000 bridges do not satisfy the terrorist's goals. The destruction of one freeway overcrossing may not make a high visibility statement. Long span bridges represent more likely terrorist targets. The replacement cost for any of these bridges exceeds billion dollars, and would require years to replace with a potential for severe economic impact. Published news reports indicate terrorist interest in long span bridges. The 1993 World Trade Center bombers also had a plot to detonate a bomb on the George Washington Bridge. The Al Qaeda members arrested in Spain in July 2002 had detailed videotape shots of the Golden Gate Bridge towers. This documented interest necessitates action.

Experimental testing of each new retrofit scheme to determine its effectiveness is costly and unrealistic. There is an urgency in having validated computational tools available to determine efficacy of proposed retrofit schemes to blast loadings. The results of this project would benefit bridge owners by providing validated tools that are more economical than experimental testing, and which can be adapted to other structure types.

Person(s) Developing the Problem

Denis Mulligan
Chief Engineer, Golden Gate Bridge
Highway and Transportation District
Box 9000, Presidio Station
San Francisco, CA 94129-0601
Telephone: (415) 923-2250
Fax: (415) 563-0809
Email: dmulligan@goldengate.org

Sheila Rimal Duwadi, PE
Team Leader, Bridge Safety, Reliability and Security
Turner Fairbank Highway Research Center
Federal Highway Administration
6300 Georgetown Pike
McLean, VA 22101
Telephone: (202) 493-3106
Fax: (202) 493-3442
Email: sheila.duwadi@fhwa.dot.gov

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Myint Lwin
Director, Office of Bridge Technology
Federal Highway Administration
400 7th St. SW
Washington, DC 20590
Telephone: (202) 366-4590
Email: myint.lwin@fhwa.dot.gov

Richard Land
State Bridge Engineer
California Department of Transportation
1801 30th Street, West Building
P.O. Box 942874
Sacramento, CA 94274-0001
Telephone: (916) 227-8115
Email: richard_land@dot.ca.gov

Mary Lou Ralls, P.E.
Chair, AASHTO HSCOBS T-1,
Technical Committee for Security
State Bridge Engineer
Texas Department of Transportation
125 E. 11th St.
Austin, TX 78701
Phone: 512-416-2183
Fax: 512-416-3144
Email: mralls@dot.state.tx.us

List of Reports on Relevant Research

[1] National Needs Assessment for Ensuring Transportation Infrastructure Security: Preliminary Estimate, NCHRP Project 20-59(5)
[2] Recommendations for Bridge and Tunnel Security, Report of Blue Ribbon Panel, AASHTO, September 2003.
[3] Department of the Navy, “Structures to Resist the Effects of Accidental Explosion,” NAVFAC P937 (June 1969).
[4] National Defense Research Committee (1946), “Effects of Impact and Explosion: Volume 1,” Office of Scientific Research and Development.
[5] Department of the Navy (1990), “Structures to Resist the Effects of Accidental Explosions, Revision 1,” NAVFAC P-937.
[6] Wright, S.J., Hobbs, B. and Watson, A.J. (1992), “Analysis of Bridge Testing Results,” Denver Research Institute.
[7] Houlston, R. and Slater, J.E. (1985), “Structural Response of Panels Subjected to Shock Loading,” 55th Shock and Vibration Bulletin, 2/3, pp. 149-163.
[8] Protecting Buildings from Bomb Damage. National Research Council, National Academy Press, 1995.
[9] Making the Nation Safer – The Role of Science and Technology in Countering Terrorism, National Research Council (2002)
[10] Wright et al (January 1992). “Analysis of Bridge Testing Results”, NAWC-WPNS TM 7245, Naval Air Warfare Center, China Lake, CA.