Problem Title: Steel Suspension Bridge Vulnerability and Countermeasures

Research Problem Statement

Background

For all of their importance, suspension bridges are relatively under-represented in counterterrorism research. Physical modeling in this area has mainly been conducted on buildings, protective structures, and girder and truss bridges. Because of the latter, modeling the behavior of suspension bridge plate and truss elements would require only a small departure from established analytical models. Modeling the behavior of multi-cell towers, main cables, and main cable-suspender rope interaction – although done on actual vulnerability assessments -- is less firmly established in experience. Part of this deficiency is being addressed in an FHWA National Pooled-Fund study on steel multi-cell towers being conducted by the Eastern Research and Development Center of the Army Corps of Engineers. Physical testing, however, employs specimens built specifically for the study, that is, specimens constructed with modern steel alloys and bolted or welded connections. The specimens, because they are new, are also in pristine condition at the time of testing. A useful extension of this test program would encompass early 20th Century alloys, riveted connections, gusset plates, built-up cross-sections, and the uneven effects of corrosion.

Project Description

The study shall consist of physical, full-scale testing of steel suspension bridge elements, their connections, and, where practical, assembled groups of bridge elements, subjected to simulated attack. Attack methods include the use of vehicle bombs or other standoff charges; hand-emplaced breaching charges, cutting charges, and mechanical cutting. Direct impact by airplane, vessel, or truck is beyond the scope of this study. The proposed program is based on the availability of a particular suspension bridge to be demolished, the Waldo-Hancock Bridge, near Bucksport, Maine, and the availability of a test facility where full-scale explosive demolition testing may be conducted in a secure environment. The main testing phases of the study will be conducted in two parts: 1) A limited on-site study, followed by removal of the structure; and, 2) A more extensive off-site study. The earliest phase of the study will consist of the overall study design, obtaining information on existing loads, stresses, strains, and displacements, design of the on-site study, coordination with the demolition and salvage operation and of transportation of structural elements to the off-site study location, and design of the off-site study.

The On-Site study will consist mainly of a Suspender Cutting Charge study; Dynamic Effects on Stiffening Truss and Main Cables, Main Cable Shear study, and Dynamic Effects of Stiffening Truss Demolition on the Towers and Main Cable. Note that any or all of the testing in this phase may be reconfigured for the Off-Site phase or eliminated altogether for any of the following reasons: environmental impact, worker safety, security, physical impediments in the existing structure, interference with the demolition schedule, or cost.

The Off-site study will consist of a continuation of the Suspender Cutting Charge study, a Tower Section Standoff Attack study, a Main Cable Standoff Attack study, and a Main Cable Cutting Attack study. If sections of main cable remain, a fire heat transmission study will also be conducted off-site. After the behavior of the unprotected structure has been calibrated, the behavior of several retrofits will be studied in the Off-site phase. These will include: Main cable wrapping; Tower plate thickening; Internal tower reinforcement; Suspender replacement materials; Energy-absorbing suspender sockets; and any other retrofit identified as suitable for inclusion in this study.

Research Objectives

1. Verify and calibrate analytical predictions of the behavior of multi-cell steel towers, main cables, and main cable-suspender rope interaction on steel suspension bridges for specified attack methods.
2. Verify and calibrate analytical predictions of the behavior of currently-used and proposed retrofits for these structural elements.

Scope of Work

The scope of work consists of the verification of blast loading and structural response phenomena, previously identified by analytical modeling, and further refined on scaled specimens. It shall further consist of the development of retrofit solutions validated through analytical work and experimental testing to determine performance of retrofit elements on bridges constructed with early-to-mid 20th Century materials and subjected to decades of environmental and traffic loading.

Delineation of Tasks

The project will consist of the following tasks:

PART A – BRIDGE BASELINE STUDY and OVERALL STUDY DESIGN

<u>Task 1 – Bridge Baseline Information</u>
Obtain information from existing sources on loads, stresses, strains, and displacements in the structure. Perform a structural analysis on this information as necessary to support the work in Task 5a and Task 6b of the On-Site Study. [NOTE: A detailed set of plans, inspection reports, and photographs for the existing structure has already been provided by Maine DOT.]

<u>Task 2 – Design On-Site Study</u>
Develop a detailed plan for the on-site phase of testing, including the tasks listed under PART B. The plan shall consider and accommodate the following: Maine DOT's demolition work and schedule; The impact on surrounding buildings, and on the new Penobscot Narrows Bridge; The prevention of debris falling into the Penobscot River; The safety of study personnel and subsequent demolition workers; Security from hostile observation.

<u>Task 3 – Planning for Post-Demolition Salvage, Storage, and Transportation</u>

a. Obtain information from the Maine DOT's demolition contractor -- if available at the time this task is scheduled – on the demolition contractor's design of the demolition and salvage operation.
b. Identify number and type of structure sections required for the <u>off-site</u> study. Develop criteria, for later use, on acceptable limits for damage caused by demolition or salvage, especially to main cable, truss, and tower sections (e.g., length of undamaged sections of cable, size and distortion limits for sections of trusses and towers).
c. Arrange for the temporary storage and security of salvaged bridge sections in the Bucksport area, if needed.
d. Arrange for the transportation of salvaged bridge sections to the Off-site study test site(s), and for storage at that site until needed.

<u>Task 4 – Design Off-Site Study</u>
Develop a detailed plan for the off-site phase of testing, including the tasks listed under PART D. The contractor shall schedule testing at this time for available periods at the Off-site study test site(s). The contractor shall develop a contingency test schedule if the arrival of specimens at the test site(s) is delayed because of the demolition schedule.

PART B – ON-SITE VULNERABILITY TESTING

Conduct the following tests, subject to restraints imposed by the site or structure:

Task 5 – Main Cable

a. Determine cable response, including damping, from localized lateral loadings (pendulum tests simulating blast loadings). This includes the effects of lateral shear and longitudinal waves in producing damage in the cable itself, and to anchorages and saddles.
b. Determine load redevelopment around cut strands by comparing the response of the main cable to loading in areas where the main cable section is in relatively good condition and where it is heavily-damaged by corrosion.

Task 6 – Suspenders

a. Analytically determine the number of suspenders that need to be destroyed in order to initiate progressive failure in the other suspenders. Determine this for various longitudinal positions on the bridge.
b. Determine the dynamic effect on the stiffening truss and main cables of progressive suspender removal.
c. Determine placement times for mock charges or deployment times for mechanical/thermal attack on suspenders. Design and perform this subtask as a "Red Team" exercise, involving groups with varying training and skill levels.

PART C – REMOVAL and TRANSPORT of SPECIMENS

Task 7 – Identify Sections for the Off-Site Study

Coordinate with the demolition contractor and Maine DOT to rapidly identify and mark, after each phase of demolition, those bridge sections useable for the off-site study that meet the criteria developed in Task 3b.

Task 8 – Section Storage and Removal

Store or Remove the sections identified in Task 7 as useable for the off-site study. This is an implementation of the plans developed in Tasks 3c and 3d, making any necessary adjustments for the demolition contractor's schedule and safety.

Task 9 – Effects of Stiffening Truss Demolition on the Towers and Main Cable

Instrument the towers and main cable prior to demolition to record dynamic effects of sudden removal of the stiffening truss.

NOTE: PHASE I OF THE MAINE DOT DEMOLITION CONTRACT IS EXPECTED TO TAKE PLACE AT THIS POINT IN THE STUDY.

Collect data during demolition.

NOTE: PHASE II OF THE MAINE DOT DEMOLITION CONTRACT IS EXPECTED TO TAKE PLACE AT THIS POINT IN THE STUDY.

NOTE: This is an optional task, and will be conducted only if it does not interfere with the demolition contractor's operations.

PART D – OFF-SITE VULNERABILITY and COUNTERMEASURE TESTING

Task 10 – Main Cables and Suspenders

a. Continue Task 6c, the Suspender Cutting Charge study, for any attack methods not feasible at the Maine site (e.g., overall cutting times for a torch (Thermal Lance) attack). **Develop and Test Countermeasure Options.**
b. Conduct a full-charge weight Main Cable Standoff Attack study. Determine the effect of blast loadings on circular main cable sections. [Optional] Continue Task 5b (Main Cable Strand Load Redistribution) to determine these effects on cables of varying condition. **Develop and Test Countermeasure Options.**
c. Perform a Main Cable Cutting Attack study (similar to the Suspender Cutting subtasks listed previously). **Develop and Test Countermeasure Options.**
d. [Optional, if there are still remaining sections] Determine the effects of Fire and Heat Transfer in Main Cable sections, Suspenders, Bands, and Sockets. **Develop and Test Countermeasure Options.**

Task 11 – Trusses

a. **Develop and Test Countermeasure Options** for protection of truss systems against blast loads.
b. **Develop and Test Countermeasure Options** for protection of truss systems against fire effects / heat transfer.

Task 12 – Tower Sections

Perform a partial replication of the test program from the FHWA Pooled-Fund Study on Blast Loading and Countermeasures for Steel Bridge Towers, **Including Countermeasures developed in that study.** Record effects and develop modified resistance factors to account for the items noted previously: Pristine vs. pattern-corroded tower sections; A36 Steel specimens vs. early 20th Century alloys; High-strength bolts with drilled holes vs. riveted connections with punched holes; Welded, uniform sections vs. built-up sections, with corner angles, gusset plates, etc.

PART E – ANALYSIS and REPORTING

Task 13 – Analysis

Conduct analysis. **Modify existing analytical models where necessary.**

Task 14 – Draft and Final Reports

Prepare draft and final reports, executive summary, and presentations in accordance with FHWA and DHS guidelines.

Estimate of Problem Funding and Research Period

Recommended Funding: $5,000,000

Suggested minimum contribution: $30,000 per year

Research Period: 5 years

Urgency, Payoff Potential, and Implementation

The vulnerability of steel suspension bridges to terrorist attack is a major concern for transportation agencies. The bridges, typically, carry much higher volumes of traffic than other structures, and are critical links in the transportation network of the regions in which they are located. The loss of such a structure would, in many cases, necessitate long detour routings over the regional network for months or years. Replacement would require Federal assistance – the costs would overmatch the emergency funds of most State DOT's or toll authorities. In addition, many are landmark structures. They have already attracted the attention of potential terrorists. One jihadist website mentions them specifically as targets, and individuals linked to terrorist groups have been caught making notes on the Brooklyn and Chesapeake Bay bridges. Currently there are no detailed guidelines or standards available specifically for bridges beyond the ones being developed by the current limited research being sponsored by FHWA and others.

The recommendations developed in this study would ultimately reduce the risk to life and economic losses from a terrorist attack against the infrastructure. Like many natural disasters, terrorist attack against a specific target is considered a "low-probability / high-consequence event." As with any natural disaster, the transportation system must be operational in the aftermath of an attack, and available for evacuation, response, and recovery efforts. Because major terrorist attacks against infrastructure targets have generally occurred in highly populated areas, and because the impact on communities from a bridge out of service can be ruinous, the payoff from any investment in counterterrorism retrofits would have local, regional and national benefits.

The solutions recommended and standards developed under this project will be available for immediate implementation by the States and other bridge owners, and for adoption into AASHTO specifications as appropriate.

Person Developing the Problem Statement

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