SUMMARY OF TECHNICAL REPORTS completed under TPF 5(216) Study Steel Suspension Bridge Vulnerability and Countermeasures

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Blast Loading of Steel Bridge Towers Constructed with New and Vintage Materials

(Also funded under DHS IAA HSHQDC-09-X-00320)

Previous work has developed blast mitigations for steel suspension bridge towers using surrogate tower structures fabricated from modern A36 steel. However, many landmark suspension bridges in the United States have towers fabricated from pre-1940s A7 steel. The primary objective of the current work was to determine if scaled suspension bridge tower specimens constructed with vintage (A7) bridge steel behaved significantly differently under blast loads than those constructed with modern (A36) steel. Vintage and modern steel specimens were constructed at 1:2.33 scale and subjected to airblast loading. These results extended work performed by Walker et al. (2011a, 2011b, 2011c, 2011d) under Transportation Pooled Fund Study TPF 5(110) to actual historic structures created with plate steels cast prior to 1940.

Citation: C. Kennan Crane, Christopher P. Rabalais, Vincent P. Chiarito, Jared C. Minor, and James C. Ray. 2022. Blast Loading of Steel Bridge Towers Constructed with New and Vintage Materials. ERDC/GSL TR-22-13. Vicksburg, MS: U.S. Army Engineer Research and Development Center. [Limited Distribution Document. CUI Category: CTI, Distribution Statement: C.]

Suspension Cable Response to Explosive-Like Loading Conditions: A Report on Diagnostic Field Test Procedures Conducted at Fort Steuben Bridge

(Also funded under DHS IAA HSHQDC-09-X-00320)

Abstract: Previous testing on the Waldo-Hancock Bridge indicated that 40% to 60% of transient loading energy could be absorbed across the cable system. However, the presence of a supplementary cable system at Waldo-Hancock raised concern over whether a typical bridge with only one suspension cable system would provide comparable attenuation capacity. Therefore, further investigation was carried out on Fort Steuben Bridge, a suspension bridge constructed in 1928, to observe the response of a 'typical' bridge.

A series of tests was completed in which impulsive loading conditions were applied to the main cable system. Excitation by a cold gas thruster device produced peak force levels ranging from 4,800 lb to 20,000 lb over a broad frequency band (1 Hz to 1000 Hz). Responses were measured along the cable, on one of the support towers, and in the anchorage for the purpose of identifying attenuation capacity in the cable system. Cable Attenuation Factors (CAFs) having both spatial and frequency dependency were computed for the cable system. Results indicated attenuations of 40% or more were present in the cable system. Companion studies have also been conducted in which detailed numerical models of the cable system and its primary components were used to replicate the field tests performed and gain insight into the attenuation behavior observed at Fort Steuben.

Citation: Ziyad H. Duron, C. Kennan Crane, Vincent P. Chiarito, Katherine Lownsbery, Nick Hill, Ethan Ritz, Diana Chen, Martha Cuenca, and Sydney Hanson. 2022. Suspension Cable Response to Explosive-Like Loading Conditions: A Report on Diagnostic Field Test Procedures Conducted at Fort Steuben Bridge. ERDC/GSL TR-22-19. Vicksburg, MS: U.S. Army Engineer Research and Development Center. [Limited Distribution Document. CUI Category: CTI, Distribution Statement: C.]

UNPUBLISHED DRAFT REPORTS

The following reports are in the process of review to determine appropriate distribution limitations, if any, and will be published by the ERDC.

Advanced Cementitious Materials for Blast Protection

(Also funded under FHWA IAA DTFH61-13-X-30049)

Abstract: Advanced cementitious materials, commonly referred to as ultra-high performance concretes (UHPCs), are developing rapidly and show promise for civil infrastructure and protective construction applications. Structures exposed to blasts experience strain rates on the order of 10^2 s^{-1} or more. While a great deal of research has been published on the durability and the static properties of UHPC, there is less information on its dynamic properties. The purpose of this report is to (1) compile existing dynamic property data--including compressive strength, tensile strength, elastic modulus, and energy absorption--for six proprietary and research UHPCs and (2) implement a single-degree-of-freedom (SDOF) model for axisymmetric UHPC panels under blast loading as a means of comparing the UHPCs. Although simplified, the model allows identification of key material properties and promising materials for physical testing. Model results indicate that tensile strength has the greatest effect on panel deflection, with unit weight and elastic modulus having a moderate effect. $CEMTEC_{multiscale}$® deflected least in the simulation. Lafarge Ductal®, a commonly available UHPC in North America, performed in the middle of the five UHPCs considered.

Draft Citation: Andrew B. Groeneveld and C. Kennan Crane. Advanced Cementitious Materials for Blast Protection. ERDC/GSL TR draft. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Numerical Model Performance of the Fort Steuben Bridge Suspension Cable System

(Also funded under DHS IAA HSHQDC-09-X-00320)

Abstract: The performance evaluation of large civil structures increasingly relies on the use of modern and sophisticated numerical modeling and analysis techniques. Models that include a wide range of non-linear energy absorption mechanisms and are subject to hazard loading conditions challenge even the most experienced analyst to arrive at informed and appropriately conservative performance evaluations. There exists a need for field investigations that produce observed behavior and that capture important characteristics of the structure's ability to withstand hazard loading conditions. Performance Based Testing (PBT) is an innovative field testing technique that employs a cold-gas-thruster device to create impulsive loading conditions in large civil structures and measure the transient response of these structures. This study is focused on the use of PBT responses acquired at Fort Steuben to develop and validate simplified cable models for evaluating vulnerabilities. Significant results include the finding that simplified cable models are capable of reproducing dominant transient behavior, and these field-validated models can be used to identify potential failure modes or vulnerabilities in the anchorage of bridges. Recommendations are provided for the development of diagnostic procedures which combine PBT with simplified numerical models and analysis techniques, and that could lead to enhanced assessments and evaluations of the nation's inventory of critical infrastructure.

Draft Citation: C. Kennan Crane, Vincent P. Chiarito, Ziyad H. Duron, Diana Chen, Martha Cuenca, and Sydney Hanson. Numerical Model Performance of the Fort Steuben Bridge Suspension Cable System. ERDC/GSL TR draft. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Analysis of Bolt and Rivet Structural Fasteners Subjected to Dynamic and Quasi-Static Shear Loadings

(Also funded under DHS IAA HSHQDC-09-X-00320)

Abstract: Non-pre-tensioned bolted, pre-tensioned bolted, and riveted lap-spliced specimens were tested to observe how the fasteners' shear strengths were affected by (1) loading type, (2) fastener type, (3) number of shear planes, and (4) joint configuration. A 200,000-lbf capacity dynamic loader was used to fail the specimens under a monotonic dynamic or quasi-static load. The applied force and acceleration were measured by load cells and accelerometers above and below the specimen.

The test data were normalized by the number of shear planes loaded in each test, actual cross-sectional area per shear plane, and ultimate static tensile strength of the respective fastener type. Statistical analyses were conducted on data sets from the 224 tests.

Results from the analyses conclude that loading type has the most significant effect on shear capacity. A fastener's shear strength is increased by a ratio of 1.72 to 1.78 over its quasi-static shear capacity regardless of fastener type due to dynamic loading effects. The joint configuration and shear type generally did not significantly affect, in an engineering sense, the shear capacity of bolted fasteners. Shear type did affect riveted specimens under quasi-static loadings. Joint configuration only affected the response of riveted specimens under dynamic loadings.

Draft Citation: Christopher P. Rabalais, C. Kennan Crane, and Lennie A. Gonzalez-Roman. Analysis of Bolt and Rivet Structural Fasteners Subjected to Dynamic and Quasi-Static Shear Loadings. ERDC/GSL TR draft. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Bridge Retrofit for Blast Mitigation using Fiber Reinforced Polymer (FRP) Materials

(Also funded under FHWA IAA DTFH61-13-X-30049)

Abstract: Historically, blast-resistant designs were implemented only on government, military, petrochemical, and nuclear facilities. Recent developments within the past two decades have shown that our transportation infrastructure may also benefit from blast effects mitigation. This report discusses recent developments in fiber reinforced polymer (FRP) materials and using them to retrofit aging bridges to improve blast resistance. One way to improve a bridge's blast resistance is by applying externally bonded reinforcements to the existing structure. These techniques are most attractive because they provide improved strength and chemical resistance, little increase to a bridge's dead load, and ease of application. This report also summarizes the different types of FRPs, i.e., carbon-fiber, glass-fiber, aramid-fiber, etc., and discusses whether their individual mechanical and high-strain rate properties are suitable for this type of application.

Draft Citation: Dylan A. Scott, Wendy R. Long, and Charles K. Crane. Bridge Retrofit for Blast Mitigation using Fiber Reinforced Polymer (FRP) Materials. ERDC/GSL TR draft. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

State-of-Practice on the Mechanical Properties of Metals for Armor-Plating

(Also funded under FHWA IAA DTFH61-13-X-30049)

Abstract: This report presents a review of quasi-static and dynamic properties of various iron, titanium, nickel, cobalt, and aluminum metals. The physical and mechanical properties of these materials are crucial for developing composite armoring systems vital for protecting critical bridges from terrorist attacks. When the wide range of properties these materials encompass is considered, it is possible to exploit the optimal properties of metal alloys though proper placement within the armoring system, governed by desired protective mechanism and environmental exposure conditions.

Draft Citation: Wendy R. Long, Zackery B. McClelland, Dylan A. Scott, and C. Kennan Crane. State-of-Practice on the Mechanical Properties of Metals for Armor-Plating. ERDC/GSL TR draft. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Vulnerability of Suspension Bridge Suspender Ropes to Explosive Threats

Abstract: A series of twelve tests was performed on tensioned wire ropes to determine their vulnerability to hand-emplaced explosives. Tensions ranged up to 40% of ultimate capacity, including one un-tensioned test. The residual capacity and stiffness of damaged wire ropes were also determined. Varying tension was shown to affect the number of wires cut. Residual capacity and stiffness decreased with increasing loss of wires, though there does not appear to be a simple linear relationship. Results suggest that the location of wires lost is also a factor. Based on the test results, it is recommended to test tensioned wire with mitigations to reflect in-service conditions and avoid possibly unconservative results.

Draft Citation: C. Kennan Crane, Rudolph A. Andreatta, Andrew B. Groeneveld, and Tyler N. Temple. Vulnerability of Suspension Bridge Suspender Ropes to Explosive Threats. ERDC/GSL TR draft. Vicksburg, MS: U.S. Army Engineer Research and Development Center.