Assessment, Repair, and Replacement of Bridges Subjected to Fire

Submitted To:

Research Program Manager
Iowa Department of Transportation
Research and Analytics
800 Lincoln Way
Ames, IA 50010

PROPOSAL

Project Title:	Assessment, Repair, and Replacement of Bridges Subjected to Fire	
Submitted by: **Organization/Institution:**	Iowa State University Institute for Transportation Bridge Engineering Center 2711 South Loop Drive, Suite 4700 Ames, IA 50010	
Principal Investigators	Justin Dahlberg, PE (PI) Research Engineer Bridge Engineering Center Telephone: 515-294-5664 Email: dahlberg@iastate.edu ORCID: 0000-0002-6184-4122	Brent Phares, PE, PhD (CoPI) Research Engineer Bridge Engineering Center Telephone: 515-294-5879 Email: bphares@iastate.edu ORCID: 000-0001-5894-4774
Authorized Agent:	Marva Ruther, Senior Award Administrator ISU Office of Sponsored Programs Administration 1138 Pearson Hall Ames, IA 50010 Telephone: 515-294-5225 Email: grants@iastate.edu	
Submission Date:	January 31, 2020	
Estimated Project Cost:	$199,573 – SPR	

Executive Summary

Recently, a bridge on I-29 near Sioux City, IA caught fire causing various levels of damage to multiple pre-stressed girders. Visual inspection and load testing of the bridge were completed to aid in the development of a response. However, the lack of available information on fire damage created a situation where the decision makers were left without many tools or guidelines to follow for such cases. Research to develop guidelines is needed. This research will assess the condition and structural behavior of precast pre-stressed concrete fire-damaged bridge girders. Additionally, repair, and replacement options will be explored.

Keywords:

Concrete precast pre-stressed girder, Fire damage

Problem Statement

There is very little technical information available on "what to do" following a bridge fire. As such, bridge owners do not have much guidance as to how to assess the amount of damage resulting from a fire nor do they have information as to how to repair or replace structures identified as "too damaged". Recently, a bridge on I-29 near Sioux City caught fire causing various levels of damage to multiple pre-stressed concrete girders. Visual inspection and load testing of the bridge were completed to aid in the development of a response. However, the lack of available information on reacting to bridge fire damage leaves more questions than answers.

Fortunately, fire damage of bridges is a rare occurrence. However, this should not be construed to mean fire-damaged bridges do not require tools for assessment and repair. As was the case near Sioux City, those charged with making the decisions for the bridge, both immediate and long-term, are without any real clear tools to aid their decision. Research to develop guidelines is needed.

Figure 1 Bridge Fire on I-29 near Sioux City, IA

Background Summary

While not an overly common occurrence, bridges can be subject to fire damage for several reasons including vehicle accidents (on or below), arson, and other accidents as on I-29 near Sioux City, or even wildfires. In more extreme cases, a bridge can be permanently weakened and potentially collapse. Given the probability of bridge fires is continually increasing with ever-growing traffic volume and bridge numbers, guidelines for timely damage assessment and repair options should be researched and developed.

A brief internet search of "bridge fires" yields several instances in recent history of highway bridges where fires have occurred. Similar to the I-29 Bridge in Sioux City, within the past couple of weeks the Memorial Bridge in Danville, IL was subject to fire damage caused by a homeless encampment when a propane tank caught fire. Fortunately the damage was limited and the Illinois DOT deemed the bridge safe to reopen to traffic, however this situation could have been much worse had the response not been so immediate [1].

Not more than three years ago, a bridge located on I-85 in Atlanta, GA caught fire when HDPE and fiberglass materials stored beneath the bridge by the Georgia DOT were set on fire. The fire was so intense it lead to the eventual collapse of the bridge and created a major disruption to the lives of those traveling around Atlanta as nearly two miles of interstate highway were closed for more than 40 days before the replacement of the collapsed span [2]. Just recently, another fire under this same bridge was extinguished, this time without damage to the bridge. This instance was attributed to a debris fire from a homeless encampment [3].

In 2015, in Oakland, CA a tanker truck flipped and exploded while traveling a major interstate interchange. The fire quickly engulfed a three-lane, steel girder section of I-580 leading to its collapse [4]. The transport of highly flammable cargo is a necessity, and fortunately accidents are rare, yet the risk it poses on bridges and other transportation features is not insignificant and should be addressed.

These cases not only highlight the unpredictable nature of bridge fires, their cause, and their damage, but also gives reason for further research to mitigate their effects immediate to the bridge and also to the bridge users. Regardless of the reason, intentional or accidental, the hardship is for the traveling public to bear as a bridge removed from commission unexpectedly can be cause for traffic delays and overall economic strain.

Some research studies have been completed with respect to fire-damage assessment and their causes, but are generally limited to what can be concluded from visual observation and paper studies. Damage assessment completed through visual observation followed by strength and serviceability testing is rare.

In 2016, ASCE published a paper titled *Detailed Analysis of the Causes of Bridge Fires and Their Associated Damage Levels* [5]. The researchers studied the damage levels sustained at 154 bridge fire locations and proposed a method for information collection and classification of damage levels. The damaged levels were described as 1) Superficial Damage, 2) Slight Damage, 3) Partial Damage, 4) Massive Damage and 5) Structural collapse. In addition, the collected data were statistically analyzed to identify the factors that most influenced the damage levels (e.g., vehicle type, vertical clearance of bridge, and bridge deck material composition). Many conclusions with respect to these factors were made, though two conclusions are of specific interest; of the 154 bridge fires studied, the most severe levels of damage commonly involved tanker trucks carrying combustible materials (e.g., gasoline) and most of the bridge superstructures that collapsed or suffered severe damage resulting from tanker fires were constructed with I-girders. This research proves to be a valuable resource, though it should be mentioned the focus of the research was aimed to assess vulnerabilities of existing and new bridges and also to provide preliminary assessment of damage levels based on visual observation. Physical testing of damaged bridge members and methods of repair were not addressed.

NCHRP Project No. 12-85, *Highway Bridge Fire Hazard Assessment,* [6] similarly aimed to identify vulnerabilities and risk to bridge structures based on causes of fires and bridge characteristics (geometry and materials). It was concluded that catastrophic fires causing permanent loss of service are rare and most often caused by high-fuel vehicle crashes (i.e., tanker trucks), and smaller fires are more common but cause lesser damage resulting in repairable areas and temporary loss of service. Also, the certainty of strength and load rating being effected is higher with more intense fires and visual geometric changes. Whereas, the certainty of structural impacts is lessened with smaller fires and no evidence of visual global geometric changes; smaller fires can result in cracked concrete, localized bucking or distortion, or damage to joints and bearings, but these are considered repairable. With respect to superstructure material, it was concluded steel girder bridges in comparison to concrete girder bridges are more vulnerable to large deflections and collapse due to the speed at which the structural member temperatures rise; concrete has a lower rate of thermal conductivity and acts to delay the temperature rise of internal strands and reinforcing steel. However, steel may be less likely to sustain long-term strength reduction effects if deformation did not immediately occur; concrete is more likely to sustain long-term strength reduction and serviceability effects.

Objectives

The primary objective will be to gain technical information related to the evaluation, repair or replacement of concrete girders after being damaged by a fire. Specifically, the goals will be to:

- Document the condition of fire-damaged girders by visual inspection
- Evaluate the fire impact on serviceability and strength through load testing
- Evaluate repair options
- Evaluate replacement options

Research Plan

The research plan for this work is presented below. Given the national need for research in this area and for the development of better guidance on the topic, the research team presents the proposed plan in two parts. Part A is work primarily focused on the I-29 Bridge including testing of damaged girders from the bridge and providing options for repairing and replacing fire damaged bridges based upon available information. Part B extends the work to include evaluation of other materials with more in-depth testing and development and evaluation of repair options. The Part B work is offered as a suggestion for work that could be completed via a Transportation Pooled Fund (TPF) project involving other states and federal agencies.

Part A

Task 1 – Literature Review

The research team will gather and review available literature addressing the characteristics and performance of bridge structures which have been subject to fires. The team will review books, agency guidance manuals, technical reports, together with papers published in journals and at scientific meetings for any information which may prove useful to the overall objectives and goals of this project. It should be noted bridge fires are an international issue and other valuable information will be sought from international resources.

Task 2 – Remove damaged bridge girders from fire-damaged bridge

The Iowa Department of Transportation has arranged for the removal, preservation, and shipment of three selected precast/pre-stressed concrete girders from the I-29 Sioux City burned bridge during the spring or summer of 2020 to the Iowa State University Structural Engineering Laboratory. As needed, the research team will work with the contractor selected to replace the bridge to ensure safe, efficient, and timely removal and delivery of the girders.

Task 3 – Evaluate damage levels and the impact on serviceability and ultimate strength

Visual/NDE Condition Assessment

A detailed condition assessment of the fire-damaged girders from the I-29 Sioux City Bridge will occur at the Iowa State University Structural Engineering Laboratory. This assessment will include the documentation of the visible condition of the girders through photographs, sketches, notes, and Nondestructive Evaluation (NDE) as warranted.

Girder Load Testing

Additionally, the three girders (low damage, medium damage, high damage) will undergo load testing for the sake of comparison to the calculated behavior (serviceability and strength) of non-fire-damaged specimens of the same size, shape, configuration, and strand patterns. It is anticipated each girder will first undergo two-point bending tests while equipped with deflection and strain transducers which will allow for comparison of strain and deflection values to the induced moment. Likewise, since the fire was more intense near the east end of the girders resulting in a higher level of damage, shear tests will then be completed at these ends with similar instrumentation.

The varying levels of fire damage among the girders received from the I-29 Bridge presents an opportunity to compare the residual strength and behavior among each of the girders and to assess how the visible conditions may be indicative of the overall structural detriment. For the shear testing, the applied loads will be limited to that which will not permanently damage the girders, whereas, the applied loads will be increased to that which causes ultimate failure for the bending tests. The exception will be for the one girder selected for advancement to Task 4; the applied loads will be limited to that which will not permanently damage the girder.

Materials Testing

Material testing will be conducted using samples obtained from each of the two girders loaded to ultimate bending failure. Multiple concrete core and steel strand samples will be extracted from near each end of the girders where additional damage due to load testing is not expected. The goal is to capture the material properties from where the fire damage was more extensive (east end) and from where the fire damage was limited (west end). Concrete cores will undergo compression tests, while the steel strands will undergo tension tests to obtain stress-strain curves and ultimate strength values.

The samples will be comparatively analyzed in two ways: First, the samples will be compared to those extracted from the same location on the other side of the beam (e.g., bottom flange, web, etc.) and second, the samples will be compared to those on the same end of the beam but at different locations (bottom to top). The assumption is the fire and temperature intensity was greatest at the bottom of the girder and the material properties will reflect the temperature gradation. Though the actual temperatures of the bridge fire are unknown, the material strength properties coupled with the observed damage at respective sample locations will provide a means to visually assess the condition of girders subjected to fire.

Task 4 – Evaluate possible options for repairing girders

Once Task 3 is complete and the data have been reviewed, possible options for repair can be devised. Several options will undergo desk-level exploration and then be presented to the Technical Advisory Committee (TAC) for discussion and comment. Following this exercise, the girder selected to undergo repair will be re-tested once the repair is complete. Results of the pre- and post-repair load tests will be compared to evaluate structural changes. Upon completion of all load tests, selected cross-sections not visible prior to the testing of the girders will be cut to investigate their internal condition, specifically with regards to bond loss between the pre-stressed strands and the concrete.

Task 5 – Evaluate possible replacement of girders when evaluations indicate damage levels are too extensive for repair

In the event where results of the load tests indicate certain levels of damage are beyond repair, replacement of fire-damaged elements is required. For this task, the research team will explore and evaluate possible replacement options that both restore the structural integrity of the bridge and provides an economical solution. A table of possible solutions will be presented to the Technical Advisory Committee for discussion and comment. It is anticipated the solutions will be adaptations of previously employed techniques for replacing bridge girders damaged in other ways.

Task 6 – Final Report

A final report documenting the steps, outcomes, and recommendations of each task will be completed following Iowa DOT publication guidelines. This report will first be presented in a draft form along with an executive summary to the project sponsors for technical and editorial review three months prior to the project end date. Once comments have been addressed and final approval has been received, the document will be redistributed to the project sponsors in its final form. A supplementary document specifically guiding the decisions of engineers with respect to evaluation, repair, or replacement of pre-stressed concrete girder bridges will also be developed. This guide document with be formatted similarly to the Emergency Response Manual for Over Height Collisions to Bridges. It will include tools to assess the integrity of the structure post-fire and methods and guidelines for repair or replacement.

Part B

While the State of Iowa has a particular opportunity and interest in what can be learned from the I-29 Bridge near Sioux City, the inclusion of other states via a Pooled Fund project can multiply the efforts of this research team. The scope of Part A is limited to precast/pre-stressed concrete girders, but bridges of all types are subject to fire damage and thus research beyond the scope of Part A is warranted. Additional focus on other materials will provide more comprehensive instruction for steps to take once a bridge fire occurs. Even more, the research plan outlined to this point is focused on proper identification of damage and repair options. Opportunities exist to complete additional research focused on the prevention of fire damage and/or protection of bridge members during fire events.

The following sections outline a potential research plan that could be pursued with the collaboration of additional partners.

Phase 1: Literature Review

An expansion of the literature review completed in Part A will be completed. To add to the attention previously paid to precast/pre-stressed concrete girders, any available information will be gathered respective to fire damage of other girder materials, primarily steel. The effects of temperature and exposure time on the residual strength will be the concentration of the review. In addition, protection and fire suppression measures and their potential integration to bridge structures will be investigated.

Phase 2: Investigation of material properties during fire exposure

A program of laboratory tests will be established to visually assess and quantify the effects of fire damage within three separate areas of focus: 1) concrete-only, 2) concrete with pre-stressing strands, and 3) steel. Numerous small-scale specimens will be fabricated for each of the three categories using materials commonly specified for bridge girders. The specimens will then go through testing under variable conditions; the temperature and duration of exposure will be controlled while the load and geometric changes are measured. When combined the data will quantify and illustrate the material property changes as a function of temperature and duration of exposure. As is the case in actual bridge fires, the intensity can be variable. This testing program is aimed to emulate the conditions to which a bridge may be exposed ranging from small to extreme fires.

For the concrete-only specimens, the capacity to withstand a compression load while being exposed to various elevated temperatures will be investigated. It is envisioned a sustained compression load, measured with an inline load cell, will be applied to the specimen prior to the heating phase. The load cell will be used to measure the consistency of the load while the specimen is exposed to a given temperature; geometric changes will be recognized as changes in measured load. All load, temperature and time data will be recorded for any given test.

For the second set of samples where pre-stressed strands are encased in concrete, vibrating wire strain gages will be used to measure pre-stress losses during the heating phase. These gages will be attached to the strands once they have been pre-tensioned and prior to placement of the concrete.

The steel specimens will be placed under tensile load during the heating phase. Similar to the concrete specimens, a load cell will be used to evaluate the change in load with respect to time and temperature. In addition, the elongation of the steel specimens will be recorded.

Upon completion of each test, empirical observations of the condition and quality of the specimens will be recorded.

Phase 3: Prediction of residual capacities of fire-damaged bridges using finite element analysis

Finite element models of 1) concrete girder and a 2) steel girder bridges much like those commonly in use today will be developed using the material strength results obtained in Phase 2. By modifying the parameters of the bridge models, the residual capacity of most standard concrete or steel girder bridges can be enveloped. Various iterations of the models will undergo numerous simulations resulting in an extensive database of information from which conclusions to the effects of fire damage can be made. The simulations will aim to emulate bridge fires of varying intensity and duration. The resulting analysis will culminate in the development of an interactive tool for the prediction of residual capacity and ultimate decision regarding the bridge adequacy. The duration and relative intensity of a bridge fire can frequently be estimated based on witness and first-responder testimony. Using this information coupled with the observable post-fire damage, the interactive tool will help guide the final decisions of bridge adequacy.

Phase 4: Exploration of girder repair options for concrete and steel girder bridges

The level of repair required will be determined based on the condition assessment and prediction of residual capacity. The research team will explore various repair options for concrete and steel girder bridges where the capacity has been reduced but long-term adequacy is not a concern with properly completed repairs. Economic feasibility will be a major consideration for any repair options identified; repairs exceeding the cost of complete removal and replacement would simply be impractical. Options will be presented in tabular format and be categorized by material and level of damage to ensure clear conveyance of the information.

Phase 5: Development of guidelines for repair options of concrete and steel girder bridges

A supplementary document specifically guiding the repair options for concrete and steel girder bridges will be developed. This document will incorporate the information and tables from Phase 4, but will provide summaries, commentary, and other important information that will clearly guide the decision for repair of fire-damaged girders.

Phase 6: Evaluation of protection methods

For new and existing bridges considered to be at a higher risk of sustaining fire damage, the potential exists to provide additional protection measures. The research team will investigate options for fire-proofing or fire-resistance and assess the efficacy of these options.

Concrete is inherently a fire resistant material, but improvements to the mix design or overall assembly with steel reinforcement can be improved. The type of aggregate, free moisture, and concrete cover thickness are all examples of factors affecting the overall fire resistance of reinforced concrete members. Another option for improved fire resistance is to apply intumescent surface coatings to better control the rise in internal temperature. It is the rapid increase in temperature that most attributes to spalling and fractures due to the free water quickly changing from liquid to highly pressurized steam. These factors and others will be investigated by the research team to devise best practices with respect to fire resistance.

Steel is also a fire resistance material, in that it is noncombustible. When exposed to prolonged elevated temperatures, however, material properties can change and strength losses occur. Intumescent coatings have been used for fire protection of building and industrial structures. This will be one option the research team will explore with respect to the fire protection of steel girders.

Products – Part A

Research results and deliverables will be as follows:

- Quarterly progress reports to the Technical Advisory Committee
- Draft of final report to the Technical Advisory Committee for review and comment
- Final report incorporating committee comments
- Executive summary or technology transfer technical brief
- Guide document that provides bridge engineers with the tools to evaluate, repair, or replace fire damaged pre-stressed concrete girder bridges

Implementation

In the unfortunate events when bridges are damaged by fire, the results of this work will aid principal decision makers in their decisions regarding the structural adequacy of fire-damaged bridges and the repair and/or replacement thereof.

Benefits

Bridge engineers and transportation officials in Iowa and beyond with need to assess fire-damaged bridges will benefit from this research. Most importantly, the decisions vital to the safety of the traveling public, both on and below, fire-damaged bridges will be more informed. This research may reveal the potential exists to allow for temporary solutions other than the complete closure of damaged bridges until a more permanent solution is devised. This can benefit the public by eliminating detours and reducing travel delay. With respect to final solutions regarding long-term bridge adequacy, there is potential cost savings by showing how bridge girders may be repaired in lieu of complete removal and replacement. Where replacement is required, an informed decision can be made for the most economical solution.

References

[1] 2020, January 14. *Crews battle afternoon fire under bridge.* Retrieved from https://www.wcia.com/news/crews-battle-afternoon-fire/

[2] 2018, March 13. National Transportation Safety Board Highway Accident Brief: Fire Damage to Bridge and Subsequent Collapse, Atlanta, Georgie, March 30, 2017. Retrieved from https://web.archive.org/web/20180818211755/https://www.ntsb.gov/investigations/AccidentReports/Reports/HAB1802.pdf

[3] 2020, January 23. *Small fire breaks out near I-85 bridge that collaped in 2017.* Retrieved from https://www.wsbtv.com/news/local/brush-fire-shuts-down-buford-spring-connector/SOS2OGSG2NAFBCNBNJV5YOZKHA/

[4] McKinley, Jesse and Carolyn Marshall. 2007, April 30. Tanker Truck Fire Collapses Bay Area Overpass. Retrieved from https://www.nytimes.com/2007/04/30/us/30collapse.html

[5] Peris-Sayol, G., et al. "Detailed Analysis of the Causes of Bridge Fires and Their Associated Damage Levels." ***Journal of Performance of Constructed Facilities***, ASCE, ISSN 0887-3828. 2017 10.1061/(ASCE)CF.1943-5509.0000977.

[6] Wright, William et al. "Highway Bridge Fire Hazard Assessment Draft Final Report." Virginia Polytechnic Institute and State University, Blacksburg, VA NCHRP Project No. 12-85. Transportation Research Board, 2013