Assessment, Repair, and Replacement of Bridges Subjected to Fire

tech transfer summary

This project studied assessment, repair, and replacement of concrete girder bridges subjected to fire using concrete girders from an actual fire-damaged bridge.

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RESEARCH PROJECT TITLE
Assessment, Repair and Replacement of Bridges Exposed to Fire Damage

SPONSORS
Iowa Department of Transportation (InTrans Project 20-734)
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Project Overview

The overall goal of this study was to determine the effects on girder strength and serviceability resulting from an actual fire below a concrete girder bridge and to determine potential repair options if replacement is not required.

Problem Statement

Although bridge fires are not frequent events, they pose impacts on safety, traffic flow, and the economy given bridge repairs or replacement can be costly. A lack of information and the tools needed to evaluate fire damage to concrete bridges and aid in decisions for both immediate and long-term use of fire-damaged bridges was the impetus for this research.

Project Background

On October 30, 2019, multiple items within a homeless encampment were set on fire beneath the I-29 northbound bridge over the Perry Creek conduit in Sioux City, Iowa. The fire was exacerbated when a propane tank became engulfed by the flames. The bridge girders and deck were particularly vulnerable to the ground fire because of the minimal ground clearance (about 6 ft) in comparison to that of most other bridges.

I-29 Bridge fire north side of bridge looking toward west abutment

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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I-29 burned bridge girders over homeless encampment in Sioux City, Iowa

Despite this unfortunate incident, it provided an opportunity to learn more about the residual condition and strength of the bridge girders through this research study. The Iowa Department of Transportation (DOT) elected for the removal and replacement of the bridge, which allowed for three girders to be removed to undergo testing.

The stay-in-place polycarbonate deck forms caught on fire, which aided the spread of the fire along the deck. Spalling was extensive on the concrete prestressed girders where the fire was concentrated, resulting in the exposure of steel reinforcement strands and stirrups. Per the initial condition assessment (HDR 2019), a loss of camber was observed in three girders.

Research Objectives

The objectives of this research study were as follows:

- Develop a greater understanding of the effects on prestressed concrete girders from fire events in order to develop recommended practices for bridge owners
- Conduct a condition assessment of three girders removed from an in-service fire-damaged bridge
- Evaluate the impact of fire on the serviceability and strength for the girders through load and materials testing
- Evaluate potential repair and replacement methods
- Provide recommendations for fire prevention measures or management strategies that can be implemented for bridges

Research Description

The Iowa DOT arranged for the removal of the three selected prestressed concrete girders from the I-29 Sioux City fire-damaged bridge. The girders were brought to a test site at the Iowa DOT maintenance yard in Ames to begin visual and nondestructive evaluation (NDE) condition assessment.

Spalling on concrete girder

Melted polycarbonate stay-in-place forms

HDR 2019

Melted polycarbonate formwork between two girders

Girder transport to maintenance yard in Ames for testing

Girder placement in Iowa DOT maintenance yard in Ames

Visual Assessment

Visual assessment included documenting all visible fire damage using images, notes, and sketches. Girder length, deck width, deck thickness, concrete cracks, spalling, large areas of missing concrete, color changes, and any exposed reinforcement were documented in the notes prior to load testing.

Materials Testing

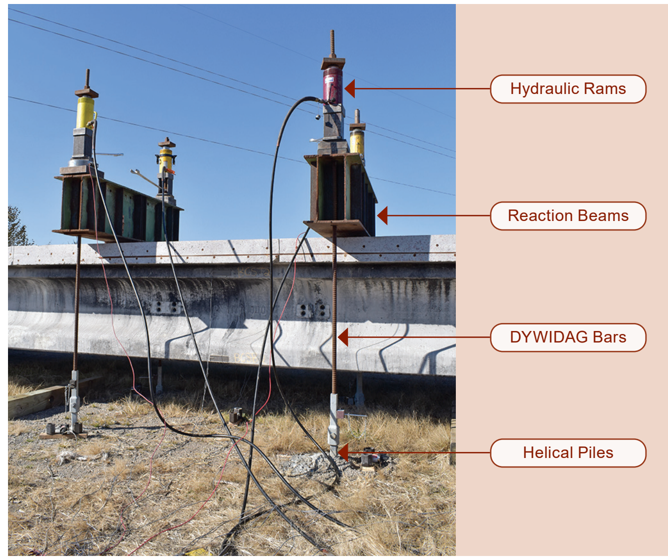
Materials testing was conducted from samples extracted from one girder. Several concrete core samples were obtained to undergo compression tests, and steel strands were obtained to undergo tension tests.

Each of the samples was taken from an area near the bottom of the girder, which is an area presumably more susceptible to greater heat-related damage. The goal was to capture stress-strain curves as well as ultimate strength values to understand the material properties of the more-damaged end of the girder.

Two-Point Bending Load Tests

The three concrete girders underwent load testing to compare their serviceability and strength to the calculated behavior of the non-fire-damaged girders. Each girder underwent a two-point bending test with deflection and strain transducers in place to compare the strain and deflection values from the applied load to the calculated strain and deflection values based on the girder properties. To set up the two-point bending test, four helical piles were installed to anchor the load frame to the ground.

Once the piles had been placed, four Dyckerhoff & Widmann AG (DYWIDAG) threaded bars were connected to each of the piles. Reaction beams were placed over the DYWIDAG bars 4 ft on either side of the girder cross-section midspan, leaving 8 ft between the two bars on either side of the girder. Each reaction beam across the girder had a hollow core hydraulic cylinder ram at each end.



Reaction frame

The hydraulic rams were connected to a single hydraulic pump so that the load could be applied uniformly and incrementally. Two load cells were used to measure the induced force. One was placed on each reaction beam between the ram and a reaction plate. Below each reaction beam, a steel plate was centered on the girder providing a single point at which the girder would be loaded. This setup ensured a constant moment region in the middle 8 ft section of the girder.

Shear Capacity Load Testing

Upon completion of the bending tests, testing of the shear capacity was completed for one girder in the laboratory at Iowa State University. The end of the girder nearer the fire epicenter was used to evaluate if reductions in shear capacity resulted from the fire.

The end section of the girder was placed on two roller supports 10 ft apart on top of two reaction blocks.

Installation of helical piles in the maintenance yard for testing

Girder end shear test configuration in the laboratory

The two reaction beams were used similarly to those in the bending tests with a hollow core hydraulic cylinder ram at each end. Each reaction beam was placed 1.5 ft from midspan, resulting in a 3-ft distance between the two.

Deflection data were collected at midspan during loading of the girder. Visual observation for the formation of shear cracks was also completed.

During the third cycle, the goal was to fail the girder in shear; however, the hydraulic jacks did not have enough capacity to continue the test to that point. The girder was observed for cracking during each of the three cycles of shear testing. Although occasional audible pops could be heard, no cracks were observed.

Exploration of Girder Repairs

For the girders tested in this research project, it was shown that the strength and stiffness were not significantly reduced despite the apparent damage sustained, including concrete spalling along the girder length. Given that the structural integrity remained intact, the purpose of the repairs was to focus on protecting the remaining concrete and reinforcement to ensure service life is not lost rather than on restoring any lost capacity.

Of the three girders subjected to load testing, only one girder was used to undergo repair using three different methods. The loading of the girder in its previous test was limited to that which maintained its elastic properties throughout the girder length. (The other two girders were loaded past their yield points or even to failure and, thus, repairs would not have been suitable using them).

The repairs were evaluated for simplicity, the effectiveness of protecting the remaining girder, and durability under a sustained load. The following materials/methods were chosen for demonstration with each option occupying a 10 ft length of the girder near midspan:

- Self-consolidating concrete (SCC)
- Ultra-high performance concrete (UHPC)
- SCC in combination with fiber-reinforced polymer (FRP) wrap

In each case, forms were constructed around the bottom flange to create a cast around the most damaged portions of the girder. The three repair methods were completed near midspan to maximize the load effects when tested, and the final report for this project details this work.

Economic Analysis for Girder Repair vs. Girder Replacement

Economic feasibility is a key factor when it comes to deciding how to approach repairing a fire-damaged bridge. Repairs or partial replacements exceeding the cost of complete removal and replacements are not practical. Therefore, to aid repair decision making, a breakdown of typical costs for different repairs and girder replacements were investigated and are documented in the final report.

Key Findings

The final report for this project includes detailed findings from the assessment, analysis, and testing.

The girders had varying levels of damage that coincided with the epicenter of the fire. At a minimum, each of the girders was soot-covered and experienced some spalling of the concrete. At worst, large concrete spalls that reached the depth of reinforcement, primarily from the bottom flange of the girder, were observed.

Each of the girders, despite the visual differences in levels of damage, performed nearly equally when tested in bending. The measured deflection and strain magnitudes were within an expected range as determined by analysis of plan-documented material properties and geometric configuration. Per visual observation and load testing, the effect of the fire on the girders appeared to have been limited to the surface-level concrete and to no greater depth than the reinforcement.

Samples of the primary strand reinforcement were selected for testing, and each sample was within specifications, indicating the material properties were not ill-effected by the temperatures achieved at that level.

The level of fire effect on the concrete strength was not conclusive. Concrete core samples taken from one of the girders showed a greater concrete strength than what was specified in the plan documents.

While two of the girders were loaded in bending beyond the elastic range, the load on the third girder was reduced to remain within the elastic range to accommodate the repair methods. The ultimate capacity of the girder end that was tested for shear capacity could not be determined because the available equipment could not generate enough shear force. Despite this fact, the girder exhibited the shear capacity required to function in service.

The primary repairs completed were necessary along the bottom flange of the girder where spalling of concrete was most significant and reinforcement had become exposed. Each repair method performed sufficiently well to protect the remaining structure during the load test and limited time of evaluation.

The simpler repair option to complete was the use of SCC only when evaluated from the perspective of constructability. Cracking of the SCC repair resulted from a sustained high load, while service loads are not likely to cause the same cracks.

The completed UHPC protection resulted in a good, durable product, but the expense and additional construction efforts present some disadvantages.

The FRP wrap provided a means for additional protection and strength if that was required; however, the workability in an overhead application and the need for a very smooth surface for full adherence presented some challenges.

Girder replacement is more expensive than girder repair; however, new girders are accompanied with a well-known structural performance and service life. The cost can vary depending on the level of damage, location, construction risks, etc. However, the largest economic impact during bridge closure is due to traffic delays and detours. The cost of construction alone does not capture the total cost of a project.

Implementation Readiness and Benefits

Different levels of fire damage require different repair methods for prestressed concrete bridges. The severity of the damage a bridge has incurred from fire greatly varies and needs to be evaluated on a case-by-case basis. In situations where the extent of damage compromises the structural integrity of a concrete bridge, replacement of partial or all components of the bridge is needed.

The longevity of repairs or undetected structural degradation due to the fire provide a level of uncertainty for long-term performance. In the event of girder replacement, bridge owners and engineers should also consider the economic impact bridge closures can have on a city or state. This must be considered in the overall decision to repair or replace damaged girders.

Being proactive to put measures in place to prevent, assess, and repair damage in case of fire occurrence is recommended. An assessment of susceptibility to fire damage during initial design and construction is recommended for new bridge projects.

Also, an assessment of in-service bridges to determine high levels of vulnerability is a good idea. Where highly vulnerable bridges are identified, specific plans for permitting or re-routing of certain vehicle types can be established or plans for the removal of storage materials can be developed if storage of flammable materials is the cause of elevated vulnerability, for example.

A fire-damage-assessment team can be formed with the goal to create guiding documents and tools for the rapid assessment of fire-damaged bridges.

Recommended Fire and Damage Prevention Measures and Management Strategies

Based on review of previous literature and case studies, the following preventive measures and management strategies are recommended to prevent damage on bridges from fire:

- A risk assessment should be required during the design phase for bridges. This can include qualitative analysis methods, quantitative analysis methods, and relative risk ranking methods.
- Different factors (deck material, location, type of bridge, cause of fire, etc.) typically involved in bridge fires should be ranked in terms of damage levels that could occur during a fire. This can help engineers and bridge owners to design against fire damage early on (e.g., proper design of bridge drainage systems to prevent the accumulation of fuel from tanker-truck incidents).
- Due to high damage levels resulting from tanker-truck fires on bridges, coordination between bridge management, fire control, engineers, DOTs, and government officials should be required through the establishment of an emergency rescue group, with a specific focus on fire incidents.
- For certain vulnerable bridges, it is recommended that tanker-truck operators use designated lanes to reduce damage levels during an incident (e.g., center lanes so other bridge users may escape safely and quickly). Through logging and reporting, some trucks may be restricted from traveling over or under a specific bridge with high fire risks dependent on the amount or type of flammable materials carried. Detour routes for these cases should be established in a guide for truck drivers.
- Guidelines for storage near or under a bridge should be implemented prior to bridge service. This should include under-bridge parking of cars and construction equipment. These guidelines should also include safety management policies, such as specific locations, placement, and restrictions for different types of stored materials. Flammable materials should be forbidden at all times.
- For bridges in isolated locations, such as some historic bridges, routine maintenance should be coordinated to prevent the buildup of ignitable materials as well as provide routine measures for fire prevention (e.g., address vandalism and arson).

Reference

HDR. 2019. *Interstate 29 Northbound Bridge over the Perry Creek Conduit – Sioux City, Iowa*. Fire Damage Inspection report. Iowa DOT, Ames, IA. **https://www.siouxlandproud.com/news/local-news/officials-release-report-of-damages-to-northbound-i-29-bridge-after-fire/**.