Investigation of Steel-Stringer Bridges

tech transfer summary

Low-volume road bridges are evaluated to improve rating and repair procedures for superstructures and substructures.

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RESEARCH PROJECT TITLE
Investigation of Steel-Stringer Bridges: Superstructures and Substructures

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The Bridge Engineering Center (BEC) is part of the Center for Transportation Research and Education (CTRE) 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.

Objectives

The goal of this project is to provide local agencies with safe and cost effective methods for rehabilitating, strengthening, and replacing low-volume road (LVR) bridges. Researchers had several specific objectives:

1) Explore the viability of a holistic approach for the determination of bridge ratings through non-destructive load testing of superstructure elements.
2) Initiate fleet management concepts for bridge superstructure structural ratings.
3) Develop an evaluation procedure for timber substructures.
4) Develop various procedures for rehabilitating, strengthening, or replacing inadequate substructure components or entire substructures.

Background

This project is Phase II of a previous project entitled, "Alternative Solutions to Meet the Service Needs of Low Volume Bridges in Iowa" (TR-452). In Phase I, a state-of-the-practice reference was developed in the area of bridge maintenance/rehabilitation/strengthening. In this project, the two most commonly noted problem areas—problems with substructures and posted steel stringer bridges—were addressed. Volume I of this project focused on non-composite, steel-stringer, concrete deck bridge (henceforth referred to as steel/concrete bridge) superstructures; Volume II focused on timber substructures. Research and findings for superstructures and substructures will be discussed separately.

Volume I: Superstructures

Problem Statement

Nearly one-fourth of the LVR bridges in Iowa are structurally inadequate. This structural inadequacy has been determined using codified parameters that are conservative and do not account for actual lateral load distribution or other structural attributes. A formal process of identifying repeatable structural performance behaviors within a "fleet" of bridges with similar characteristics through limited load testing would allow modification of conventional ratings.

After reviewing 49 low-volume road bridges in 10 different counties, all of which had problematic timber substructures and the majority of which were steel/concrete bridges, six bridges (one each in Boone, Marshall, Carroll, and Humboldt Counties and two in Mahaska County) were selected for testing. Results of load tests on bridge superstructures are reported in the following sections.

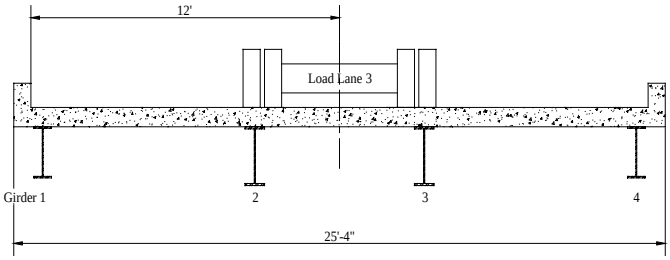
Research Description

In Volume I, six single-span, steel/concrete bridges that were representative of the fleet of this bridge type were selected for load testing. In each of these tests, the bridge was instrumented with strain and deflection transducers at critical locations and loaded with a tandem dump truck provided by the county. Data from these tests were used to rate the bridges using a diagnostic load rating approach. These ratings were then compared to codified ratings (using the Load Factor Rating [LFR] approach) calculated by three different groups: engineers at the Iowa DOT, a private consulting firm (PCF), and the research team at Iowa State University.

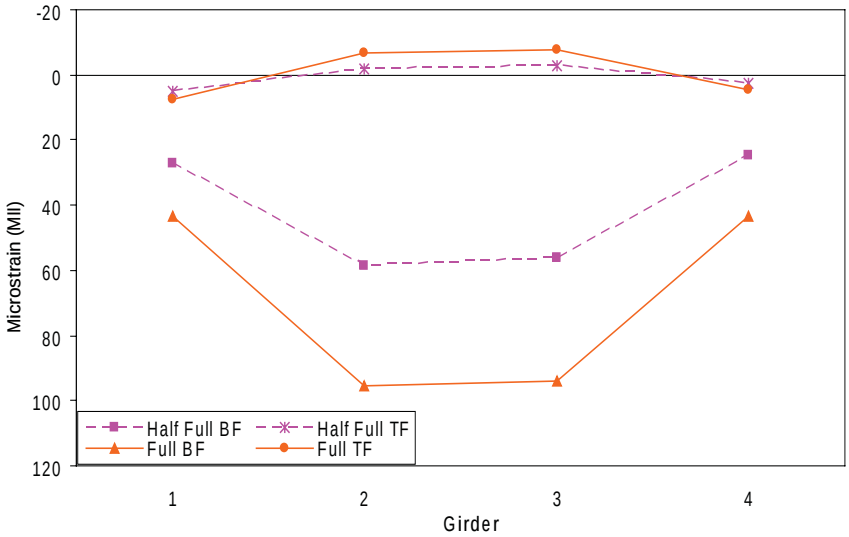
The six bridges tested include the following:

- A 36-foot single-span bridge built in 1900 with six stringers (Boone County)
- A 40-foot single-span bridge with six stringers (Marshall County)
- A 33.3-foot single-span bridge with five stringers (Mahaska County)
- A 33.3-foot single-span bridge with four stringers (Carroll County)
- A 37.67-foot single-span bridge with five stringers (Mahaska County)
- A 34.4-foot single-span bridge with four stringers (Humboldt County)

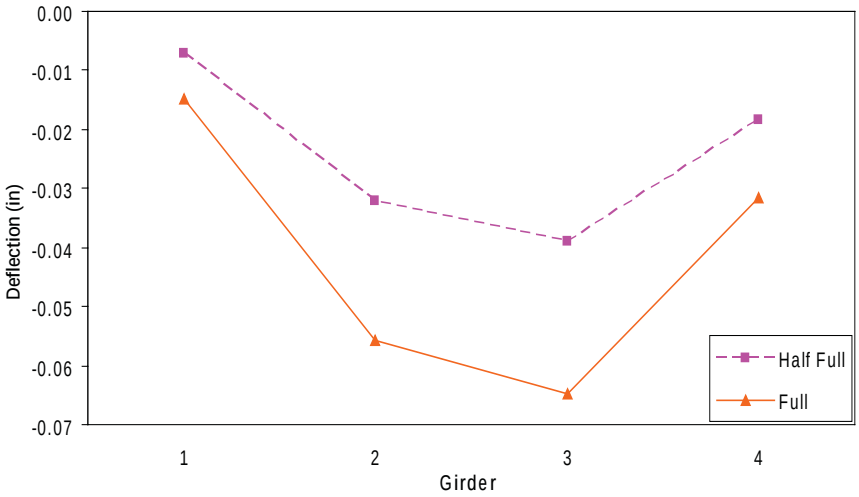
Humboldt County bridge with sections removed from three piles



a. Lane 3 Loading



b. Strain Profile



c. Deflection Profile

Strain and deflection results for 33.3-foot bridge in Carroll County, Iowa

Key Findings

The codified load ratings performed by the three different groups were very similar. The diagnostic load ratings based on load testing data for all of the bridges were significantly greater than the codified rating approach.

Some behavior characteristics could be predicted through load testing; however, the magnitude of such characteristics would require testing a more statistically significant sample size of bridges to allow for the extrapolation of predicted behavior to bridges that have not been load tested.

The following fleet characteristics were identified:

- A degree of composite action existed in all of the bridges, with the lowest level at 16% composite.
- Live load distribution in all bridges was very similar to American Association of State Highway and Transportation Officials (AASHTO) codified values.
- Bearing restraint at the abutments existed in all bridges with the load level at 10% of fixity.

Implementation Readiness

In Iowa, there are hundreds of deficient non-composite steel-stringer, concrete deck bridges. Results from this research have shown that, through load testing, more accurate and favorable load ratings can be obtained.

In general, the results indicated that it is possible to identify predictable structural rating performance characteristics in a small fleet sample and that a concept to extrapolate these characteristics to other fleet bridges is possible.

Testing of the Mahaska County bridge

Volume II: Substructures

Problem Statement

Timber piles are widely used in bridge foundation construction due to the relatively low cost of raw wood compared to steel and concrete, simple installation techniques, and their availability and ease of handling relative to other materials. A drawback, however, of timber piles is their susceptibility to damage and degradation. The purpose of this study was to investigate relatively simple procedures to detect timber pile substructures conditions and evaluate pile repair and strengthening techniques.

Research Description

An investigation of 49 low-volume bridges with poor substructure performance in 10 different counties was carried out. Even though this study only investigated steel-stringer bridges, the field reconnaissance for the substructure component of the bridge included other types of bridges, such as timber deck and truss bridges. All inspected bridges, however, had timber pile substructures. The two most common problems observed were biological and physical deterioration. Other less frequently occurring problems include UV degradation, misalignment of piles, and pile cap deterioration.

Biological deterioration resulting in reduction in pile cross section (top) and complete deterioration of a pile section causing failure of pile cap (bottom)

Maintenance of Bridge Substructures

Several substructure repair techniques are being implemented in Iowa. These techniques include (1) addition of a timber or steel pile adjacent to the defective pile when the deterioration of that pile exceeds 50%, and (2) construction of a new substructure system (i.e., replacing all existing piles) when advanced deterioration is widespread in more than one pile, threatening the integrity of the bridge. These repair techniques are considered major maintenance.

Nondestructive Evaluation

Ultrasonic Stress Wave Method

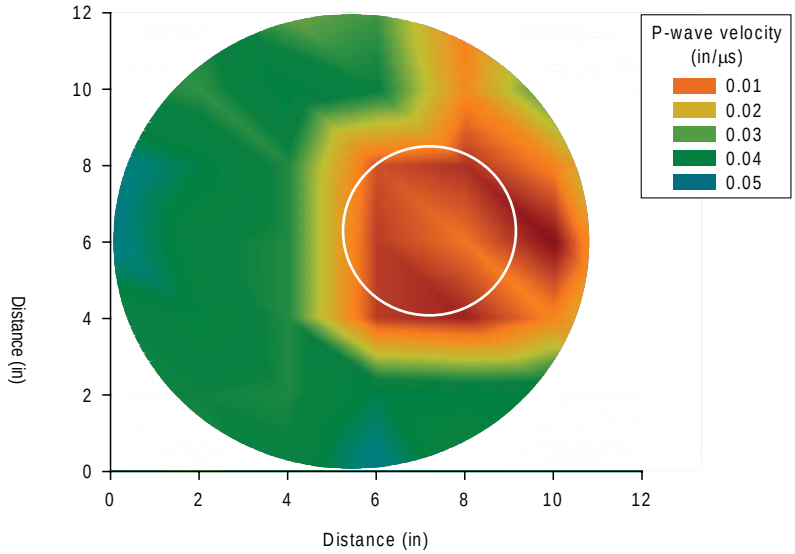
A nondestructive ultrasonic stress wave technique was used to develop cross-sectional tomography images of timber piles for the purpose of evaluating internal defects. Stress waves are generated from an impact on the side of the pile. By measuring the wave travel time through a pile in the radial direction, the wave propagation speed can be calculated, which can be used as a predictor of the internal condition of the pile. Multiple stress wave measurements at different radial orientations, together with an image reconstructing technique, were used to produce two-dimensional tomography images of internal timber pile deterioration.

Pile Integrity Method

Determining the pile length is critical in calculating the residual capacity of timber piles. Pile integrity tests were performed at one bridge to estimate the pile length or detect major cracks below the ground level. This method is based on vertically impacting the pile and measuring the time for the reflected compression wave to reach an accelerometer. The pile integrity method can estimate the length of the pile within approximately 15% of the actual length (Wightman et al. 2003).

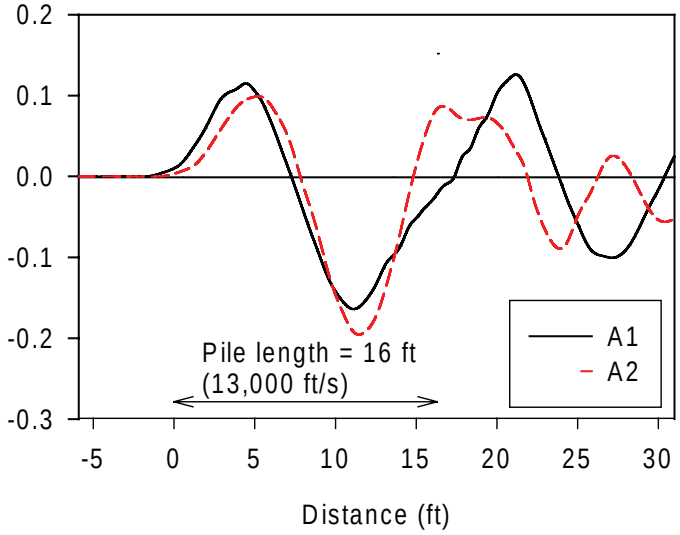
Compression failure of deteriorated pile section caused by overloading leading to bulging of timber fibers (left) and mushrooming of the pile section (right)

Steel pile driven adjacent to a defective timber pile



Two-dimensional tomography image revealing the timber pile internal condition

Pile integrity test: impacting the pile to generate a compression wave



Pile integrity test results, with pile toe estimated to be 16 feet below ground level (measured wave speed = 13,000 feet/second)

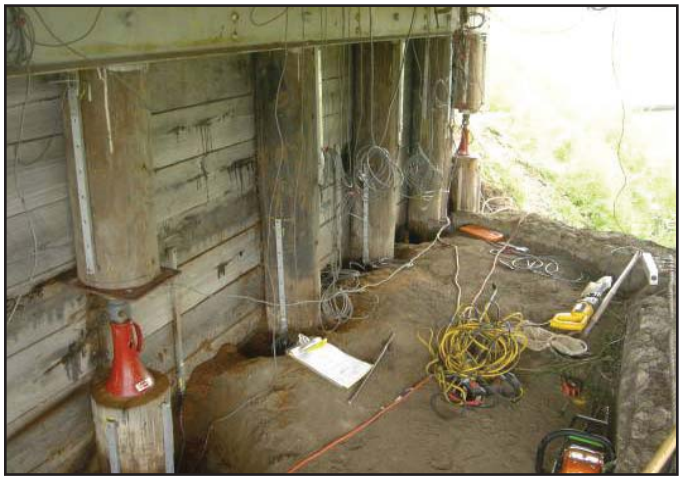
Static Load Test

Substructure static load tests were conducted at five bridges, and the strain responses of the abutment piles and backwall were measured using strain gauges with gauge lengths varying from 12 to 24 inches. Due to the non-homogeneity of wood as well as localized deteriorated zones along the pile, the exposed portion of each pile was instrumented with more than one strain gauge to capture pile behavior at both strong and weak sections.

Destructive Evaluation

Destructive evaluation was performed at one bridge where three out of the seven supporting timber piles at one abutment were consecutively removed to simulate pile deterioration. After removing each pile, the bridge was load tested to measure pile loads and strains on intact piles. The data were used to determine the stress in each pile and thus predict the variation of load distribution with different degrees of pile damage. To determine the feasibility of repairing localized deteriorated sections in timber piles, one of the removed pile sections was repaired using a splicing technique, and the percent restoration of pile capacity was measured.

Bridge abutment instrumented with strain gauges



Pile sections removed to simulate timber pile deterioration

Laboratory Pile Repair Study

A laboratory pile repair study was conducted, with the objective of evaluating the effectiveness of selected pile repair techniques in restoring axial and bending capacity of deteriorated timber pile sections. Three repair methods were selected for this study. For each method, two new timber pile sections, each four feet long, were tested to failure in axial and bending capacity.

The selected repair methods were (1) mechanical splicing, (2) replacing the damaged section with a new section with a fiber reinforced polymer (FRP) wrap, and (3) using epoxy material with FRP wrap.

Timber pile repair using mechanical splicing

Timber pile repair using fiber reinforced polymer (FRP) wrap

Recommendations and Future Research

The following recommendations and additional research are proposed to implement the findings from the timber substructure evaluation phase of this study:

- The ultrasonic stress wave techniques can be used as a rapid tool in evaluating the internal condition of in-service piles. Additional research is needed to investigate different transducer types and orientations, other image reconstruction techniques, the possibility of producing three-dimensional images of the internal pile condition, and to experiment with alternative ultrasonic stress wave devices.
- It is recommended that laboratory full-scale or half-scale abutment models be constructed. The models can be used to accurately measure pile and backwall loads and to conduct pile integrity testing against piles with known lengths. The laboratory models can also be used as a basis for developing, calibrating, and verifying a numerical model.
- On a pilot study basis, repairing and monitoring deteriorated in-service piles using the evaluated repair techniques is recommended.
- Additional field testing is needed to investigate alternative methods of determining in-service pile lengths. Methods such as parallel and cross borehole seismic tests are proposed.
- For future substructure static load tests, it is recommended to measure lateral pile movement parallel and perpendicular to the backwall to differentiate between pile strains induced by bending and axial loads.

Timber pile repair using epoxy filler with FRP shell