STUDY OF THE IMPACTS OF IMPLEMENTS OF HUSBANDRY ON BRIDGES

Pooled Fund Project
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Project Title

Study of the Impacts of Implements of Husbandry on Bridges

Problem Statement

Traditional bridge design and bridge rating are based upon codified procedures that examine a bridge's capability to resist traditional highway-type vehicles (e.g., trucks). It is known, however, that other vehicles (e.g., farm/agricultural vehicles or implements of husbandry) use these bridges. These farm vehicles have characteristics that are quite different from traditional vehicles; specifically, they tend to have different wheel spacing, different gage widths, different wheel footprints, dynamic coupling characteristics, and others. Further, these vehicles are carrying heavier loads as the agriculture industry has desired them to do so. Currently, the Iowa DOT Bridge Rating Engineer must make assumptions about how highway bridges resist these non-traditional vehicles. Thus, a research study is needed to more accurately characterize how applied loads from these implements of husbandry are resisted. Specifically, it is desired to understand how these agriculture loads are distributed through the structural elements comprising the bridge and to assess the magnitude of the dynamic loads these vehicles impose. Further, it is desired to know what methods of analyzing bridges for these loads are acceptable, so that accurate bridge ratings may be produced.

Objectives

The objective of this study is to determine how the implements of husbandry distribute their load within a bridge structural system and to provide recommendations for accurately analyzing bridges for these loading effects. To achieve this objective the distribution of live load and dynamic impact effects for different types of agricultural vehicles will be determined by load testing and evaluating two general types of bridges. The types of equipment studied will include but will not be limited to; grain wagons/grain carts, manure tank wagons, agriculture fertilizer applicators, and tractors. Once the effect of these vehicles has been determined, recommendations for the analysis of bridges for these non-traditional vehicles will be developed.

Background

Available technical literature contains little quantifiable information relating the impacts of implements of husbandry on the structural performance of bridges. However, there are a number of documents related to impacts on gravel roads and highway pavements, including: Eske, et al. (1965), Grau, et al. (1991), Chatti, et al. (1996), Fanous, et al. (2000), Oman, et al. (2001), Sebaaly, et al. (2002), and Phares, et al. (2004). In fact, only two reviewed documents contained any relevant bridge information, including the previously mentioned reference by Phares et al. (2004). The other pertinent reference is briefly discussed in the following paragraph below and focused only on timber stringer bridges. Although insightful, the information given in these two documents did not focus on quantitative information that specifically broadly related the influence of the weight of implements to bridge damage/deterioration nor provide insight into how to develop appropriate rating procedures for the husbandry vehicles. What the two documents did provide was a useful summary of the types of bridge failures that have been observed—in the laboratory in one case and in the field in the other—under "large" loads. The following two paragraphs briefly synthesize the applicable portions of the two pieces of literature.

In the work by Wood and Wipf (1999), the authors describe the procedures and results from testing four timber bridges in the Iowa State University Structural Engineering Laboratory. The four bridges were constructed from nominal 4 in. by 12 in. timber stringers removed from an existing bridge. Other bridge components, including nominal 3 in. by 12 in. deck planks, sill plates and blocking, were fabricated from new timber. Loading of the 16 ft span bridges was applied at midspan through a 30 in. by 20 in. footprint (simulating a tire from a grain cart). Based on all four test results, which are briefly described in Table 1, the authors indicate that "…there appears to be good load sharing between the stringers" and "…bridge failures could all be characterized as sudden and were due to flexural failure of the bridge stringers."

Table 1. Summary of laboratory test results from Wood and Wipf (1999)

Bridge	Number of Stringers	Failure Load (lb)	Failure Mode
1	5	42,200	Bending – Sudden failure with load redistribution
2	5	40,100[e]	Bending – Horizontal cracking of single member
3	3	27,200	Bending – Sudden failure initiated at a knot
4	3	36,300	Bending – Major flexural and horizontal cracking

[e]estimated

An article by Rholl (2004), appearing in the September 2004 issue of Minnesota Counties, summarized several aspects of maintaining Minnesota's secondary road system. Although not specifically about relating bridge damage/deterioration and the passage of implements of husbandry, the author recounts one incident in which he "…visited a bridge site where a loaded implement had punched through the deck of the bridge." Further investigation by Rholl revealed that the implement was, in fact, legal under Minnesota's Implements of Husbandry Law. Although not addressed in detail in the article, Rholl indicated that the implement user was not liable for the damage and indicated that the "…user felt it was the County's fault for not building strong enough bridges."

Neither of the above articles describes, in sufficient detail, specific metrics that can be used to relate implements of husbandry to damage to families or the entire population of bridges. They do, however, illustrate two observed failure modes: bending and punching.

Research Plan

The research is proposed to be conducted in two phases. Since the Iowa DOT has already identified bridges needing evaluation, the Iowa DOT is providing the funding sufficient for the completion of Phase I. Iowa State University (ISU) researchers associated with the Bridge Engineering Center will be performing the tasks associated with Phase I.

A proposed Phase II will provide the opportunity for other states to participate, including suggesting additional bridges/bridge types for evaluation or for the expansion of the Phase I plan to include a more comprehensive analytical component. Regardless of the specifics of Phase II, the work will be conducted with appropriate overlap with Phase I and will have the same general project scope as Phase I as described below.

Phase I

To achieve the goals of the project, work in three principal areas will be conducted: 1) load testing and evaluation of bridges, 2) development of engineering/code based comparisons, and 3) the development of analysis recommendations. It is important to note that successful completion of the Load Testing portion of the research plan described below will require the cooperation of the agriculture vehicle industry in supplying the required vehicles and drivers. On September 24, 2009 a conference call was hosted by Kevin Erb, University of Wisconsin Extension Program, to discuss the potential interest and cooperation of the agriculture industry in providing equipment for the load testing program. The conference call participants included agriculture vehicle industry members from Iowa, Pennsylvania, Indiana, Ohio, and Wisconsin, as well as a tire manufacturer from Iowa. The Iowa DOT bridge rating engineer from the Iowa DOT (Scott Neubauer) as well as several ISU Bridge Engineering Center staff also participated. There is strong interest on the part of industry in Iowa to provide the agriculture vehicles, and associated drivers, for testing at cost to the project.

<u>Load Testing</u>

During the project approximately 10 test bridges located in Iowa will be load tested and evaluated. The specific test bridges will be selected in coordination with the Iowa DOT Bridge Rating Engineer. It is anticipated from preliminary discussions that the bridges will be selected from two distinct “classes” of bridges that are known to be of concern: single-span steel stringer bridges and single-span timber stringer bridges. The following summarizes the typical test parameters and protocols that might be followed:

- Test vehicles
    - Two fertilizer applicators
    - Three manure tank/tractor combinations
    - Two grain cart/tractor combinations
    - Type 3 legal truck
- Vehicle weights
    - Empty
    - 50% full
    - X% full (An analysis will be completed on each bridge to determine the maximum vehicle weight to be used for testing. It is desired to test the vehicles fully loaded, however there may be instances where the maximum load for certain vehicles is less than full load to avoid damaging the integrity of the structure.)

- Vehicle speeds
    - Crawl
    - 5 mph
    - 10 mph
    - Higher speed
- Lateral positioning
    - 2' from face of each curb
    - Centered on bridge
    - Others as needed
- Sensor types (data collected at a minimum of 50 Hz)
    - Strain sensors (top and bottom flange) at critical cross sections
    - Deflection measuring string potentiometers
- Bridge entrance condition
    - No-bump
    - 2" artificial bump

Development of Engineering/Code Based Comparisons

Following load testing the resulting experimental data will be evaluated against typical bridge design parameters and against measured highway vehicle behaviors:

- Lateral load distribution
- Load distribution within tire footprint region
- Percent of design live load response
- Percent of measured Type 3 vehicle response
- Dynamic Amplification Factor
- Percent Composite Action

Development of Recommendations

The following general products will be the result of this work:
- Quantitative assessment of the impact of Implements of Husbandry as compared to conventional highway vehicles (both design and field measured)
- Recommendations for analyzing bridges subjected to Implements of Husbandry
- Recommendations for universal signing of bridges requiring posting

Phase II

Similar to the work to be completed in Phase I, Phase II will consist of the same the basic components. The number of bridges to be evaluated depends upon the number of states/organizations participating in the pooled fund, the level of cooperation of local implement operators, and other factors. For example, if the bridges to be tested in Phase II are all located in the State of Iowa it is estimated that the cost per additional bridge would be $10,000. If, however, the bridges selected for inclusion in Phase II are outside of Iowa, it is estimated that the per bridge cost would be approximately 20% higher. Thus, each additional bridge might cost on the order of $12,000 thereby reducing the number of bridges that could be tested for the same total budget.

Sponsorship Goals

Iowa DOT ~ Phase I	$150,000
Other states/organizations ~ Phase II	
(Minimum 2 @ $10,000 per year for 5 years)	$100,000
Total Budget ~ Phase I and Phase II	**$250,000 to $650,000**

Summary of Requirements for Project Sponsors

- Financial support
- TAC participation
- Provide bridge information files as requested by the research team
- Provide access to tested bridges
- Provide needed traffic control during testing
- Provide a tandem axle dump truck for testing

Products

The above mentioned products of the work (recommendations) will be summarized in a report format that is immediately useable by the Bridge Rating Engineer. This report will provide summaries of the test protocols followed and the results including: measured lateral live load factors, measured live load impact factors, and general performance measures. Additionally, recommendations for analyzing bridges of these types will be made. In addition to the final report, quarterly progress reports to the TAC and an executive summary will be developed.

Implementation/Technology Transfer

Engineers involved in the rating/evaluation for live load performance of bridges will immediately be able to use the resulting information. The results will be given in a format commonly used by practicing engineers. The results of this study will most likely supplement existing standards by providing information/guidance not previously available.

Benefits

This work will lead to information that will help bridge rating/evaluation engineers make better assessments of the capability of highway bridges to support implements of husbandry. As an example consider that overly conservative rating procedures could result in unnecessary and expensive bridge replacements or upgrades, while un-conservative rating procedures could compromise the safety of bridge users.

Staffing

The proposed research will be conducted by and under the supervision of Terry J. Wipf and Brent M. Phares of the Iowa State University Bridge Engineering Center. Doug Wood will serve as co-investigator on the project with the primary responsibility of oversight on instrumentation and data acquisition design and testing protocols.

Terry Wipf has had research experience related to highway structural systems since 1977. His area of research expertise has been in bridge engineering since 1983, where he has focused on field bridge testing. These tests have typically utilized conventional instrumentation technology to describe both static and dynamic structural behavior. He has supervised several research projects related to advanced sensor and monitoring technology for the performance evaluation of bridges. He also has worked with nondestructive evaluation techniques on bridges and on the design and performance evaluation of FRP bridges.

Brent Phares has been involved in conducting research and applying nondestructive evaluation technologies to the nation's infrastructure since 1995. His work has focused on the new ways of applying existing sensor systems to bridges and how to use existing sensor systems to answer critical bridge behavior questions.

Complete vitas are available upon request.

Project Administration

The Iowa DOT, through the Bridge Engineering Center at Iowa State University, will serve as the lead state and will handle administrative duties for the project. Each participating state may provide an individual to serve on the TAC that will provide direction to the project. Travel funding for these meetings will be provided by the pooled fund. The Bridge Engineering Center, under the direction of the TAC, will provide administrative management and be the lead research institution on the project for both phases.

Contacts for Further Information

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