INVESTIGATION OF CURVED GIRDER BRIDGES WITH INTEGRAL ABUTMENTS

Pooled Fund Project

Problem Statement

PROJECT TITLE

Investigation of Curved Girder Bridges with Integral Abutments

PROBLEM STATEMENT

Nationally there is concern regarding the design, fabrication, and erection of horizontally curved steel girder bridges due to unpredicted girder displacements, fit-up, and locked-in stresses. One reason for the concerns is that up to one-quarter of steel girder bridges are being designed with horizontal curvature. The concerns are significant enough that an NCHRP research problem statement has been developed and given high priority for funding.

It is also noted that an urgent need exists to reduce bridge maintenance costs by eliminating or reducing deck joints. This can be achieved by expanding the use of integral abutments to include curved girder bridges.

The purpose of the research is to investigate the use of integral abutments on curved girder bridges through a monitoring and evaluation program for in service bridges. The research will be conducted as a multiple phase study since Iowa has already identified several bridges for monitoring and evaluation that will be constructed in the near future (Phase IA).

Phase IA includes placing instrumentation on six curved girder bridges in Iowa with integral and semi-integral abutments that will be constructed in 2008. These instrumented bridges will give us a better understanding of the behavior of curved girder integral abutment bridges.

In addition to the Iowa bridges identified above, other participating states may also propose additional curved girder integral abutment bridges (outside of Iowa) to be instrumented and monitored in Phase IB. Phase IB will be an extension/expansion of Phase IA where additional bridges (if desired) can be selected by the TAC.

PROJECT OBJECTIVE AND SCOPE

The long-term objective of this effort is to establish guidelines for the use of integral abutments with curved girder bridges. The project scope will focus on the monitoring and evaluation of constructed bridges that will be documented by reports outlining the findings and recommendations for design policies.

BACKGROUND

A brief literature review was performed to determine the past and present use of integral abutments for horizontally curved bridges. Table 1 presents a list of the very limited resources identified. Most of the identified sources are technical articles and papers. However, some are correspondence and other materials such as PowerPoint presentations and plan sets.

The literature review identified significant information on the superstructures of horizontally curved bridges. These papers focused mainly on design and analysis, construction methods, and verification of experimental field data. Nothing was mentioned about the superstructure to substructure interface.

A large amount of information was found on integral abutment bridges, but mainly pertained to straight and skewed bridges. Topics covered were the increase in the bridge stresses from temperature, creep, and shrinkage, as well as soil pressure, and how the additional stresses and displacements affect the pile foundations. Steel H-piles were typically the only type of foundation discussed.

The topic of horizontally curved bridges with integral abutments was hardly mentioned, if at all, in the reviewed literature. A paper discussing a 2004 survey, (#17-2 Table 1) with 39 of the 53 states surveyed responding, found that only four states allow the use of curved girders with integral abutments and three more allow the construction of curved bridge with straight girders and integral abutments. Another survey published in 2005 states that "research on the use of integral abutments on curved bridges is scarce and the problem is not well understood yet."

Personal conversations with engineers at several universities and Departments of Transportation did not result in any studies or information related to the quantification of the structural performance of curved girder bridges with integral abutments. It is noted that the Tennessee DOT has constructed quite a few horizontally curved steel and prestressed concrete girder bridges with integral abutments, but they have not performed structural performance monitoring on the bridges.

Essentially, literature and research into horizontally curved bridges with integral abutments is scarce to non-existent. Horizontally curved bridges with integral abutments are being constructed in a few states, but no studies have been performed on these bridges. Thus, there exists no real basis for the formation of rational design policies.

Table 1. List of Literature Reviewed

	Article Name	Year	Author(s)	Bridge Type			Super-structure			Supports			Found-ation			Analysis performed? Y/N	Analysis Type			Analysis Loading							Lab testing performed? Y/N	Lab Testing Type			Lab Testing Loading			Field monitoring performed? Y/	Field Monitoring Loading				Field Instrumentation				
				Curved	Skewed	Straight	Steel I-beams	Steel Box Girders	Concrete	Integral	Semi-Integral	Pin/Roller	Steel Pile	Drilled Shaft	Spread Footing		Single Beam	Grillage	3-D FEM	Static Vehicle	Dynamic Vehicle	Thermal	Shrink/Creep	Wind	Seismic		Scale Model	Component	Full Size	Static	Dynamic	Cyclic		Static Vehicles	Dynamic Vehicles	Ambient	Long Term	Strain Gage	Press. Transducers	Accel.	Disp. Transducers	Inclinometers
1	Response of bridges curved in plan due to dead and live loads using finite element method	2003	Sasmal, Saptarshi Chakravorty, Dipankar	x																																				
2	Field behavior of an instrumented integral abutment bridge in Hawaii	2005	Ooi, Phillip S. K. Lin, Xiaobin			x			x	x			x																				Y			x	x	x			x
3	Experimental Verification of Horizontally Curved I-Girder Bridges	2000	McElwain, Brett Laman, Jeffery	x			x									Y		x		x												Y	x	x			x			x	
4	Examination of Level of Analysis Accuracy for Curved I-Girder Bridges Through Comparisons to Field Data	2006	Nevling, D. Linzell, D. Laman, J.	x			x									Y	x	x	x	x																				
5	Elastic Experimental and Analytical Studies of Curved Steel Bridge Behavior Under Self-Weight		Linzell, D. G.																																					
6	Predicted and Measured Response of an Integral Abutment Bridge	2005	Fennema, Jolene Laman, Jeffery Linzell, D. G.																																					
7	Experimental and Analytical Studies of a Horizontally Curved Steel I-Girder Bridge During Erection	2004	Linzell, D. Leon, R. T. Zureick, A. H.																																					
8	Skew and Elevated Support Effects on Curved Bridges	1974	Funkhouser, Donald Heins, Conrad																																					
9	Historical Perspective on Horizontally Curved I-Girder Bridge Design in the United States	2004	Linzell, D. Hall, D. White, D.																																					
10	Temperature - Dependent Bridge Movements	1992	Moorty, Shashi Roeder, Charles																																					
11	Tennessee Boasts Record Length Jointless Bridge (Happy Hollow Creek)		Concrete Products Staff	x					x	x	?		x		x	N										N							N								
12	Happy Hollow Creek Plans	1995	Tenn. DOT	x					x	x	?		x		x	N										N							N								
13	Tenn. DOT CD (Happy Hollow Plans and articles)		Tenn. DOT																																					
14	Tenn. DOT CD (Power Points from FHWA Conference: IAJB 2005)		Tenn. DOT																																					
15	Correspondance with Dr. Linzell	2007	Linzell, D. G.	x						x																Y	None						Y	None				None			
16	A Survey of Current Issues on the Use of Integral Abutment Bridges	2005	Hassiotis, S Roman, E. K.	x	x	x	x		x	x			x		x	N										N							N								
17	FHWA Conference: Integral Abutment and Jointless Bridges (Papers Below)	2005	See Below																																					
17-1	Integral Abutment and Jointless Bridges		Mistry, Vasant		x	x				x	x		x	x		N										N							N								
17-2	Integral Abutment and Jointless Bridges 2004 Survey Summary		Maruri, Rodolfo Petro, Samer	x	x	x	x	x		x	x					N										N							N								

RESEARCH PLAN (PROJECT DESCRIPTION)

The research is proposed to be conducted in two phases. Since the Iowa DOT has already identified a monitoring and evaluation need for soon to be constructed bridges in Iowa, the Iowa DOT is providing the funding for Phase IA. Iowa State University (ISU) researchers associated with the Bridge Engineering Center (BEC) would perform the monitoring and evaluation tasks for Phase IA. It is noteworthy that the FHWA has recently obtained approval to proceed on a project related to HPC integral abutment bridges. While not related specifically to curved girder bridges, the scope of that study, which includes a development and deployment program, would provide some valuable opportunities to contribute to the conduct of the study proposed herein.

The proposed Phase IB study would provide an opportunity for other states to participate, including providing additional bridges for monitoring and evaluation, and if appropriate, use other universities of their choice for monitoring and evaluation tasks recognizing that consistency and efficiency of research must be maintained. Phase IB would be proposed to be conducted simultaneously, and in cooperation, with Phase IA and would have the same general project scope as Phase IA as described below.

The proposed research project will investigate the behavior of curved girder bridges with integral abutments with the objective of establishing guidelines for the use of integral abutments with curved girder bridges. There are three general task groups in this project:

I. Information Collection

Integral abutment bridges have been used with greater frequency in a greater number of states. The advantages of these types of bridges are well known and will not be repeated here. At the same time, there has been interest in the use of curved girder bridges with integral abutments. The use of integral abutments in curved girder bridges has either not been tried with great frequency or is not well documented in the technical literature. As such, the first project task will be to collect information on the use of these combined structural systems. .

To accomplish this task, the following subtasks will be completed:

Task A – Technical Advisory Committee meeting
A Technical Advisory Committee (TAC) will be formed as described subsequently. The TAC will be initially charged with defining the following:

1. Current known, home-state issues with the use of:
    a. Curved girders.
    b. Integral abutments.
    c. Combinations of a and b.
2. The metrics that are likely to be indicators of curved girder integral abutment bridge performance.
3. Other information that, if available, would be useful to the research team.

Task B – Survey of available technologies

A survey of state DOTs will be conducted to determine if integral abutments have been used for horizontally curved bridges and, if so, any significant findings, conclusions, or recommendations. Any concerns regarding potential behavioral issues will be sought. If there have been any experimental investigations, information specifically related to instrumentation and monitoring will be solicited.

Task C – Review of available engineering literature
Although a brief literature search and review has already been performed, a more complete review will be conducted to determine the past and present use of integral abutments for horizontally curved bridges and any stated concerns or discovered problems. In the absence of any significant information on this combined topic, it may be necessary to examine horizontally curved bridge literature and integral abutment literature in general without regard to their relative behavior, and make engineering judgments regarding potential behavioral issues so that an appropriate project scope may be developed.

Task D – Inspect existing curved and chorded curved girder bridges
Interstate I-235 through Des Moines is currently being re-constructed. This reconstruction represents a significant effort and includes the construction of many new bridges. Although there are several bridge types being used in the reconstruction, there are several curved girder bridges with, or planned to have, integral or semi-integral abutments. In this task, two existing I-235 curved girder bridges will be inspected to determine if there is evidence of problems associated with the use of integral abutments. Additionally, other curved girder bridges that were constructed following the chorded curvature policy will be inspected (including bridges outside Iowa if any are proposed).

Task E – Analyze the proposed design for two "smaller radius" bridges (bridges with the greatest curvature)
Using analysis techniques assess the proposed designs for two bridges scheduled for construction on the reconstructed alignment (Designs 309 and 2308 – see Appendix A). The analysis of these bridges should consider the use of both fully integral and semi-integral abutments.

II. Collect and Analyze Data on the Performance of Six Bridges

This task will leverage the fact that several curved girder integral abutment bridges are scheduled to be built as part of the reconstruction of I-235. Starting in 2008, the reconstruction of the northeast mixmaster at the intersection of I-80, I-35, and I-235 will provide the opportunity to monitor a range of abutment, pier, and curvature conditions for curved steel girder bridges. The overall interchange design is being planned so that semi-integral abutments with expansion joints are used in two curved girder bridges, and integral abutments are used in two mirror image bridges. Overall there will be six, 26-foot roadway bridges with the characteristics shown in the table in Appendix A.

Task F – Develop an Instrumentation Plan

Use the previously completed analysis to develop an instrumentation plan to monitor the six steel girder bridges in the northeast mixmaster, with the intent of discovering potential problems with the use of integral abutments, as well as the differences in behavior between bridges with integral abutments and bridges with semi-integral abutments and expansion joints. In the mixmaster bridges the deck provides a very rigid plane to which the tops of the girders are attached, but the bottoms of the girders are likely to be more flexible. Depending on the restraints at pier bearings, curved bridges with different abutment conditions may have quite different behaviors.

Task G – Monitor and Analyze the Behavior of the Six Bridges for Three Annual Thermal Cycles
The above mentioned bridges will be monitored for a period of at least three annual thermal cycles. During this period, the installed sensors (strain, temperature, deflection, etc.) will be monitored for overall, global behavior. The data will be analyzed as they are collected such that modifications to the instrumentation and/or data collection scheme can be made as needed.

Task H – Develop and Validate Analytical Models for the Monitored Bridges
Using the collected data, analytical models will be created and validated. Working with the TAC, these models can then be extrapolated to other design conditions (e.g., geometry, soil conditions, etc.) that will provide information needed for Task III.

III. Develop Recommendations for Design Policy

This task basically focuses on summarizing the entire project with a focus on developing recommendations for design related policy.

Task I – Establish a Meeting with the TAC
A meeting will be reconvened so that the research team may present the results of the project to date and propose an initial direction for the development of design policy. Utilizing the conclusions from all bridge monitoring, the TAC will be asked to provide detailed input on the proposed direction.

Task J – Submit Final Report
A final report summarizing the results of the project tasks will be submitted at the completion of the study.

TECHNICAL ADVISORY COMMITTEE (TAC)

A TAC will be formed from entities participating in the project. The TAC will participate in both meetings and conference calls to help direct the study, including 1) helping formulate specific work plans; and 2) monitoring work progress and in general will provide guidance and oversight regarding the execution of the research. In addition, the TAC will be asked to participate formally in the process by aiding the research team in identifying the important behavior and design issues. As such, the TAC will consist of State DOT representatives, FHWA and other researchers who are familiar with the research topic.

It is anticipated at this time that the first TAC meeting will be held within two months of project initiation in order to facilitate expeditious execution of the research plan. Meetings or conference calls will be scheduled every quarter. Travel expenses for State DOT representatives will be budgeted within the pooled fund project. For details, please contact Terry Wipf, 515-294-8103, tjwipf@iastate.edu or Ahmad Abu-Hawash, 515-239-1393, ahmad.abu-hawash@dot.iowa.gov.

FUTURE WORK

Depending on the specific results of the work described herein, it is possible that a subsequent phase of work may be needed. Although it is difficult to anticipate exactly what additional work will be needed, it is anticipated that future work would focus on the development of state/location specific design recommendations.

RESEARCH TEAM FACILITIES AND CAPABILITIES

As noted earlier, Phase IA of this project will be conducted through the Iowa State University (ISU) Bridge Engineering Center, since the Iowa DOT has committed funding for the instrumentation and monitoring of six bridges in Iowa. ISU also be available to participate in Phase IB if appropriate. The ISU research team has significant background and experience related to integral abutment bridges (including field monitoring and development of design recommendations), as well as a strong field testing program for bridge structures. Note that Phase IB is contingent upon funding from other states as determined by the TAC, and as previously noted, other universities may collaborate at the request of the contributing state as requested.

ESTIMATED PROJECT DURATION

The total project is expected to take 60 months to complete.

BUDGET AND SPONSORSHIP

Proposed Project Funding

The total project budget is estimated at $250,000 to $625,000. A partnership for funding this research is proposed between state DOTs. With additional participation it is anticipated that further and more in-depth analysis of the project features including a greater level of extrapolation could be made.

Sponsorship Goals

Iowa DOT/Phase IA	$250,000
Other states /Phase IB	up to $375,000
(up to 10 @ $7,500 per year)	
Total Budget/Phase IA and IB	**$250,000 to $625,000**

Summary of Requirements for Project Sponsors

- Financial support
- TAC participation
- State DOTs are also asked to work with principal investigators for Phase IA as well as potential investigators for Phase IB to provide state-specific information requested by the research team(s).

DELIVERABLES

The following products will be submitted as indicated:

1. Electronic quarterly reports following lead state guidelines.
2. Quarterly reports to be published via the pooled fund website.
3. Final report and technical brief that document the results of the entire study.

PROJECT ADMINISTRATION

The Iowa DOT, through the Bridge Engineering Center at Iowa State University, will serve as the lead state and handle administrative duties for the project. Each participating state may provide an individual to serve on the technical advisory committee (TAC) that will provide direction to the project for both phases. Among other tasks described earlier in this proposal, the TAC will generally organize the specifics of the cooperative work tasks and oversee the accomplishment of these tasks. The Bridge Engineering Center, under direction of the TAC, will provide administrative management and be the lead research institution on the project for both phases.

CONTACT FOR FURTHER INFORMATION

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APPENDIX A

IOWA BRIDGES TO BE MONITORED*, PHASE IA
DES MOINES NORTH EAST MIX MASTER I-80 / I-35 / I-235 INTERCHANGE

Design #	**109**	**209**	**309**	**2208**	**2308**	**2408**
Ramp	C over EB I-80	C over WB I-80	B over EB I-80	D over EB I-80	A over WB I-80	D over WB I-80
Length (ft)	304	332	319	330	302	304
Width (ft)	26	26	26	26	26	26
Abutment Type	Integral	Semi-Integral	Integral	Integral	Semi-Integral	Integral
Pier Type	Delta	Delta	Frame	Delta	Frame	Delta
Pier Fixity	F-E	F-E	F-F	F-E	F-F	F-E
Skew	15˚	35˚	15˚	35˚	15˚	15˚
Radius (ft)	N/A	1340	950	1340	950	N/A
Spans (ft)	80-144-80	90-152-90	85-149-85	90-150-90	80-142-80	80-144-80

* All bridges are Continuous Welded Steel Plate I-Girder

APPENDIX B
IOWA STATE UNIVERSITY FACILITIES

The ISU Bridge Engineering Center was founded over 20 years ago and conducts national, state, and local research related to the design, performance, and construction of bridges and other transportation structures. Among other specialties, the Bridge Engineering Center specializes in the collection, evaluation, and use of field collected performance data to develop design standards and criteria.

The Bridge Engineering Center's main offices are located at the Center for Transportation Research and Education in the Iowa State University Research Park, roughly three miles from both the ISU campus and the Iowa DOT's headquarters in Ames, Iowa. The facility offers the following features:

- Videoconference classroom
- Large conference room accommodating 15–25 people
- Smaller conference room
- State-of-the-art computing hardware and software, including desktop publishing capabilities and a T1 connection to the university's communications backbone
- Transportation technology transfer library
- Office space for visiting and affiliate faculty

In addition to the two structural engineering laboratories located on the campus of Iowa State University, the Bridge Engineering Center maintains a significant arsenal of instrumentation and data collection equipment. The capabilities associated with this equipment include the ability to test structures for long-term and short-term behavior. The Bridge Engineering Center has, for other similar projects, developed data reduction and analysis algorithms that permit the collection and use of very large data sets. In addition to a full collection of off-the-shelf computer systems, the Bridge Engineering Center also maintains a dedicated data server with over 2 TB of storage space and the ability to process large data sets. Additionally, the Center has world-class workstations that allow for detailed analytical modeling and data reduction.